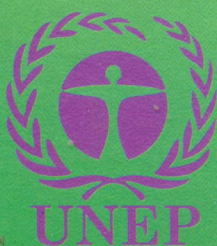


Desert and Dryland Development: Challenges and Potential in the New Millennium



International Center for Agricultural Research
in the Dry Areas (ICARDA)

Desert and Dryland Development: Challenges and Potential in the New Millennium

Proceedings

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Editor

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Table of Contents

Foreword ix
Editor's Note x

KEYNOTE ADDRESS

Reversing Desertification: The Potential for Research xi
Adel El-Beltagy

A. PLENARY SESSION

1. Statement by Executive Secretary, United Nations Convention to Combat
Desertification 3
Ambassador Hama Arba Diallo
2. Water Erosion Control: Generating Support 7
Harold E. Dregne
3. Expert Systems for Agricultural Development 10
Ahmed Rafea
4. Tolerance to Stresses in the Arid Areas 17
R. Gareth Wyn-Jones
5. Biotechnology: from Laboratory to Market Place 22
Magdy A. Madkour
6. Dryland Degradation by Wind Erosion and Potential Control 24
Geert Sterk, Rudy Rabbinge, and Leo Stroosnijder
7. A Dream Comes True 30
Adli Bishay
8. Weather Data for Crop Production and Protection 41
Ayman F. Abou-Hadid
9. Aridity, Drought, and Desertification: Roles of Science 45
M. Kassas
10. A Social Contract for Arid Zones Development: Conceptualization to Implementation 52
M.M. Mahfouz

B. CONCURRENT SESSIONS

Session 1. Soil Conservation and Degradation

11. Managing Irrigated Sandy Soils in Arid China 61
Harold E. Dregne and Chengrui Mei
12. Wind Erosion as Related to Some Soil Conservation Practices in the Northwest Coastal
Zone, Egypt 64
M.M. Wassif, S.F.T. Sharkawy, M.R. Bayoumi, A.Y. Genead, and S. Kh. Atta
13. Irrigated Soils Degradation: assessment and Monitoring 69
V. Ye. Prikhod'ko
14. Towards Sustainable Agriculture on Central and Marginal Slopes of Wadi El-Natrun Depression,
Egypt 75
W.F. Erian, F.A. Gomaa, and S.A.A. Ismail
15. Climatic and Agroecological Desertification in Jordan 78
Awni Y. Taimeh
16. Aeolian Sedimentation in Irrigated Lands of the Arid and Hyper-Arid Zones in the Sudan 90
Hassan M. Fadul, Imad-eldin A. Ali, and Shinobu Inanagad
17. Soil and Water Conservation and Dryland Farming for Sustainable Agricultural Production in Iran . 96
Esmail Sadeghi
18. Data Integration for assessing Agricultural Soil Degradation in South-Central Iran 100
A. Moameni, and J.A. Zinck
19. Crop Rotations for Sustainability of Rainfed Barley Production in Egypt's North-West
Coast 106
Naiim M.M. Moselhy

20. Arab Center for the Studies of Arid Zones and Dry Lands' Strategy for Development and Improvement of Arid and Semi-Arid Areas	112
Nuri Rohuma	
21. Approach to Sustainable Dryland Development in the Arab Region	117
Yahia Bakour	
22. Agricultural Development Strategy for Remote Desert Areas in Egypt	125
Ismail H. El Bagouri	
23. Impact of Desert Fringe Reclamation of the Nile Valley on Water and Soil Quality	131
Elsayed M. Abu El-Ella	
24. Desertification Indicators of Arid Territories in Central Asia	134
Galina A. Tolkacheva and Victor E. Chub	

Session 2. Water Management and Conservation

25. Groundwater in South Tarim Basin's Fragile Ecology	143
Ma Jinzhu, Qian Ju, and Gao Qianzhao	
26. North African Aquifer System: Shared Resource for Desert Development	148
Saad A. Alghariani	
27. Decline of Groundwater Quality in the Khanasser Valley (Syria) due to Saltwater Intrusion	156
Robert Hoogeveen and Michael Zöbisch	
28. Wadi Hydrology for Sustainable Dryland Development	164
A.M.A. Salih	
29. Agricultural Water Management in the Arabian Peninsula	173
Ian R. McCann and A. Taufic Moustafa	
30. Developing Water-Saving Techniques and Efficient Agriculture under Rainfall Harvesting in China	177
Li Xiaoyan, Gong Jiadong, and Gao Qianzhao	
31. Sustainable Development of Irrigated Agriculture in the Uzbek Part of the Hungarian Steppe	181
R.K. Ikramov	
32. Inter-Temporal Wastewater Reuse in Irrigation and Revenue Maximization: The Case of Tyre Region, South Lebanon	186
M. Ragy Darwish, Faraj El-Awar, and Mirna Sharara	
33. Runoff Modeling of Micro-Catchment Water Harvesting	192
Adriana Bruggeman and Theib Oweis	
34. Agroforestry Systems as a Sequential Drainwater Reuse Strategy for Sustainable Irrigated Agriculture	199
Fawzi Karajeh, Baryohay Davidoff, and Wayne Verrill	
35. Cotton and Wheat Response to Irrigation With Low Quality Water	204
Gilani Abdelgawad and Abdelrahman Ghaibah	
36. Monitoring Irrigation Canal and Drainwater Quality in the Egyptian Delta	210
A.A. Salam, Esmat H.A. Noufal, and H. Abdel-Azeez	
37. Crop Row-Spacing Influence on Transpiration and Soil Evaporation in Winter-Grown Wheat in Northern Syria	215
Philip L. Eberbach and Mustafa Pala	

Session 3. Range Management

38. Conservation and Pastoral Livelihoods in Jordan's Wadi Araba	225
Alan George Rowe	
39. Natural Restoration Potential of Overgrazed Slopes in Dryland Northwestern Syria	231
Michael Zöbisch, Zuhair Masri, and Amin Khatib	
40. Improvement of Rangelands in Al-Shegaya Area of Kuwait	238
S.A.S. Omar, S. Shahid, E. Al-Ali, M. Al-Bahouh, and T. Madouh	
41. Desert Forages for Sustainable Rangeland Production in the Arabian Peninsula	244
Morag E. Ferguson, A. Saleh, A. Hassan, G. Al-Hadrami, I.R. McCann, and J.M. Peacock	
42. Vetch Establishment under Supplementary Irrigation	249
H.M. Saoub and B.I. Hattar	

43. Common Vetch to Reverse Long-Term Land Degradation and Alleviate Feed Deficits in Syria	253
M. Bounejmate, S. Christiansen, J. Ryan, M. Pala, and F. Shomo	
44. Cactus to Prevent and Combat Desertification?	261
Ali Nefzaoui	
45. Feed Block Supplementation under Drought Conditions: Mashreq - Maghreb Project Experience . . .	270
Ala. D. Salman and Qassem Mamdouh	
46. Private Rangeland Intensification in Egyptian Northwest Coast	275
Scott Christiansen, F. Delaroque, S.N. Ismael, G. Gintzburger, H. Jochen Regner, H-N. Le Houérou, S. El-Naggar, N. Haddad, and N. El-Mowelhi	
47. Underground Vetch (<i>Vicia sativa</i> spp. <i>amphicarpa</i>): Potential Pasture and Forage Legume for Dry Areas	281
Ali M. Abd El Moneim and Mohan C. Saxena	
48. Kochia: Fodder Crop to Combat Desertification	286
Manuel Anaya-Garduño	

Session 4. Biodiversity Conservation

49. Genetic Diversity of Lebanese Wild Wheat Populations: RAPD and AFLP Fingerprinting	293
Kamel Chabane, Rita Kassis, and Jan Valkoun	
50. Phyto-Reclamation for Biodiversity Rehabilitation of Uzbekistan's Desert Rangelands	298
Olga Reisvikh and Victor Chub	
51. Rehabilitation of War-Damaged Areas of the National Park of Kuwait	300
Samira A.S. Omar, N.R. Bhat, Tareq Madouh, and Hanaa Abd Rizq	

Session 5. Combating Desertification

52. Sandstorms in Xinjiang, China	307
Lei Jiaqiang	
53. Assessment and Monitoring of Desertification in Northern Jordan	311
Hussein Harahsheh and Ryutaro Tateishi	
54. Sustainable Management of Deserts: Environmental Concerns in Combating Desertification	317
Zafar Adeel	
55. Assessing Techniques for Cartographical Estimation of Desertification	321
E.V. Manakhova	
56. Land Use and Sandy Desertification in the North China	324
Tao Wang and Wei Wu	
57. Taklimakan Desert and its Prospects	329
Liu Wenjiang and Yudong Song	

Session 6. Stress Physiology

58. Response of Tomato to Mycorrhizal Fungi and Salt Stress	335
Ghazi N. Al-Karaki and R. Hammad	
59. Wheat and Barley Response to Saline Conditions in South Sinai	340
N.I. Ashour and M.M. Selim	
60. Ecophysiological Indicators of Water-Use Efficiency in Hot Dry Lands	344
H.M. El-Sharkawi and K.A. Farghali	
✓61. Breeding for Salt Tolerance in Barley	347
A.M. Al-Shamma and B.A. Al-Rawi	
✓62. Selecting Barley for Drought Tolerance in Jordan's Low Rainfall Areas	351
Yahya Shakhathreh, O. Kafawin, and H. Saoub.	
63. Ethylene in Tomato Yield and Ripening	357
M.A. Atta-Aly, G.S. Riad, Z. Ei-S. Lacheene, and A.S. El-Beltagy	
✓64. Wheat Complex Resistance to Stresses	365
T.L. Tazhibaeva, A.I. Abugalieva, and Y.V. Peruanski	
65. Drought Resistance of Tunisian Olive Cultivars	368
Boujnah Dalenda and Lemeur Raoul	

Session 7. Expert Systems and Modeling

66. Expert System Technology Transfer to Agricultural Domain Experts375
Mahmoud Rafea, Ahmed Rafea, Ahmed Ezz, and Tarek El-Saka
67. Remote Sensing and Computer-Supervised Digital Classification for Monitoring Desertification in Western Sudan379
Hassan M. Fadul, B. Meissner, Imad-Eldin A. Ali and Shinobu Inanaga
68. Using Generic Agricultural Expertise Models for Technology Transfer383
Soliman Edrees, Hesham Hassan, El-Sayed El-Azhary, and Ahmed Rafea
69. Evaluation and Impact of Expert Systems on the Agricultural Sector in Egypt386
Mostafa Mahmoud, Mahmoud Rafea, and Ahmed Rafea

Session 8. Biotechnology

70. Modified Procedure for Rapid Recovery of Transgenic Wheat Plants395
A. Bahieldin, R. Qu, W. Dyer, A.S. Haider, and M.A. Madkour
71. Construction of a Genebank for an Extremely Halophilic Bacterium (*Halo bacterium halobium*) in *E. Coli*.399
M.Y. Saor, J.M.S. Jubrael, and H. Ammash
72. Construction of a PCR-Based Linkage Map in Tomato403
Dina El-Khishin, H. El-Itriby, A. Abdelsalam, and M.A. Madkour

Session 9. Sustainable Development of Oasis

73. Moisture Capture by Desert Mountains: Effects on Oasis Environment411
Wushiki Hisao
74. Oasis Ecology and Desertification Control at Taklimakan Desert's Southern Margin414
Ximing Zhang, Xiaoming Li, and Henian Zhang
75. Date Palm Insect Control for Sustainable Development of El-Bahria Oasis, Egypt418
M.A.M. Ali, M.M. Metwally, and A.E. Hussein
76. Ecological Environment Strategy and Construction in China's Hexi Corridor423
Li Fuxing
77. Artificial Oasis in Dry Lands: Shimanto Method to Reuse Treated Wastewater427
Masahiro Murakami

Session 10. Socio-economics and Anthropology

78. Resource Management: Perceptions and Strategies of Households in Bershaya Village, El-Bab District, Syria435
Aliaa R. Rafea and Malika Martini
79. Land-Use Dynamics and Farmer-Perceived Degradation Processes: Case Study from An Agro-Pastoral Syrian Village441
Trine Louring Nielsen and Michael Zöbisch
80. Vegetation Cover Protection on Southern Tunisia's Desert Ecosystem453
Azaiez Ouled Belgacem, Mohamed Chaieb, and Mohamed Neffati
81. Reducing Waterlogging and Salinization: Economics in Policies457
Dennis Wichelns
82. Fruit Tree Orchards and Well Irrigation for Family Income in Dryland Farming Systems of Northern Syria462
Andrea Pape-Christiansen, Werner Doppler, and Tom Nordblom
83. Rural Development in Dry Areas: Turkey's Gap Project468
A. Mekin Tuzun, U. Kirmizi, E. Istanbuluoglu, and F.H. Giray
84. CATOM: New Model for Integrating Women in Development in the Southeastern Anatolia Project ..475
Aygül Fazlionlu
85. Geo-Statistical Analysis and GIS in Measuring the Sustainability in El-Hammam Area, Egypt483
W.F. Erian

Session 11. Renewable Energy

86. Energy Transport Characteristics in Greenhouses Using An Earth-Tube Heat Exchanger489
A.F. El-Sahrighi, S.M. Abdellatif, A.M. Matouk, Y.M. El-Hadidi, and A.M. Kassem

87. A Solar Energy-Driven System for Crop Cultivation Using Saline Water496
Shinobu Inanaga, Tomohide Shimotashiro, Imad-Eldin A. Ali, K. Murota, and Yukihiro Sugimoto.

88. Features of Wind Conditions Over Egypt499
A.M. El-Asrag, M.A. Sayed, A. Awad, and M. Abd El-Reheem

Session 12. Application of New Technology

89. Strategies for Technology Transfer in India's Drylands505
A.S. Faroda

90. Future Trends of Technology Transfer for Egyptian Agriculture508
Azmy El-Berry and Ahmed El-Beherry

91. Strategy for Brassica Improvement for Arid Environments511
R.S. Sangwan

Session 13. Role of NGOs and Indigenous Knowledge

92. Integrating Indigenous Knowledge and Modeling for Agropastoral Systems Development517
John Fitzsimons, Fawzy H. Abdel-Kader, Ashraf Mustafa and Mohamed Bahnassy.

93. Traditional Architecture in the Egyptian Desert521
Magda Ebeid

C. POSTER SESSIONS

Soil Conservation and Degradation

94. Dry Atmospheric Fallout: Secondary Irrigated Land Salinization529
Galina A. Tolkacheva and Juliya I. Kovalevskaya

95. Organic Residues as Substitute For Chemical Fertilizers532
O.H. El-Husseiny, R.S. Abdel-Aall, and E.H. Allam

96. Land and Water Management in Yemen537
Ali Mohamed Al-Thor and Khader Balem Atroosh

97. Crop Sequence Effects on Compaction under Rainfed Conditions540
M. Abd El-Naim, R. Abou El-Enien, and A. Abd El-Shafi

98. Soil Mulching and Irrigation Methods: Soil Temperature543
M.Y. Tayel, F.M. Habib, and E.E. El-Dardiry

99. Annual Irrigation to Prevent indirect Soil Degradation546
Iouri N. Gavrilov, Jorge T. Garcia, and Oktiabrina B. Egorova

100. Deep Percolation Water Loss in Fields During Irrigation550
Iouri N. Gavrilov, Jose N. Ortiz, and Oscar L. Palacios Velez

101. Balancing Water Supply and Demand For Agriculture in Hexi Corridor, China553
Gao Qianzhao, Du Hulin, and Zu Ruiping

102. Low Quality Water Irrigation: Chemical Properties of Egyptian Soils556
A.A. Al-Sharif and H.K. Zaki

103. Irrigation Water Sources in Egypt: Water Efficiency in Reclaiming Saline Soils560
Esmat H.A. Noufal

Water Management and Conservation

104. Wastewater Reuse for Water Management in Tunisia's Arid Areas569
Rachid Boukchina and Lilia Ben Abdallah

Range Management

105. Karakul Sheep Breeding Problems in Arid Zones of Uzbekistan575
N.A. Bobokulov, N.V. Makarov, and T.H. Mukimov
106. Chemical Composition and Nutritive Value of *Ceratoides eversmaniana* (Stschegi Et Losinsk.),
Botsch Et Ikonn577
T.H. Mukimov, Sh. Shadmanov, N.A. Bobokulov, and N.V. Makarov
107. Alternatives to Improve Low-input Pastoral Systems of the Arid andes579
Didier Genin
108. Harvesting Rainfed Acacia and Atriplex in Northwest Coast, Egypt584
G.S. Mikhiehl, M.S. El-Hakeem, and T.H. Kasseh

Combating Desertification

109. Population Impact on Tunisia's Saharan Zone Environment589
Azaiez O. Belgacem, Mongi Sghaier, and Mohamed S. Zaafouri
110. The Desert Ecosystem Protective Vegetation Cover in Southern Tunisia593
Azaiez O. Belgacem, Mohamed Chaieb, and Mohamed Neffati
111. United Arab Emirates' Experience in Combating Desertification596
Mohammed Hassan Al-Shamsi

Stress Physiology

112. Apple Tree Sensitivity to Early-Season Water Stress603
Monea H. Al-Hazmi, A.N. Lakso, and S.S. Denning
113. Reduced Water Potential, Temperature and Boron on Germination of Two Hot-Desert Plants609
H.M. El-Sharkawi, K.A. Farghali, and S.A. Sayed
114. Soil Salinity Effects on Yield and Nutrient Concentrations of Some Fruit Species615
Mokhtar M. Hassan and Mahmoud M. Shendi
115. Salinity Stress on Potato as Modified By Calcium Application619
A. Abdel-Naby, M.S. El-Beltagy, A.F. Abou-Hadid, Y.I. Helmy, and S.O. El-Abd

Expert Systems and Modeling

- ✓116. Stability Analysis For Bread Wheat Genotypes in Egypt625
M.A. El-Ashry, M.S. El-Shazly, A.A. Aly and R.A. Ramadan
117. Green Cowpea Productivity in Sandy Soil with Different Organic Manures629
A.M. Abd-Alla, S.M. Adam, and A.F. Abou-Hadid
118. Response of tomato Hybrids to Organic Fertilizer under Newly Reclaimed Soils632
A.M. Abd-Alla, S.M. Adam, and A.F. Abou-Hadid
119. Wheat Genotype Adaptation to Nitrogen Deficiency under "New Lands" in Egypt635
A.M. Abdel-Ghani and A.M. Awad
120. Soil Heat Transmission at Giza Agrometeorological Station638
M.A.A. Dawod and A.A. Trabea

Renewable Energy

121. Estimating Diffuse Solar Radiation in the Arab World: Eastern Region645
Darwish Mohamed Ahmed and Taha Nagy El-Hosary

- LIST OF PARTICIPANTS649

FOREWORD

As we enter the Third Millennium, few issues have captivated the public attention more than "desertification" — the notion that the very dry areas of the globe, which support little plant, animal, or human life, are increasing in extent. While degraded dry lands and deserts have always been a feature of the world's landscape, their expansion into agricultural land, with inevitable reduction in production potential, is alarming. Degradation of the resource base is an associated outcome of this insidious and unrelenting trend.

The characteristic of dry lands is scarcity of water, or more specifically, situations where there is a deficit of precipitation relative to evaporation, and limited sources of surface water and groundwater to compensate for this deficit. Today, over one-third of the world's land area is dry, being either arid, where no cropping is possible without irrigation, or where only the most drought-tolerant species grow; or semi-arid where cropping is only possible during the "rainy" season. The extent of semi-arid areas fluctuates with climatic cycles of drought. With global warming now perceived as a reality, the problems of dry lands will become exacerbated.

Given the sizeable percentage of the world's population whose livelihoods are impinged upon by drought, the issue is what we have done and what we can do about it. Much faith has been pinned on research — learning about dry lands and how we can best manage such fragile ecosystems. In the past, dry lands were the "poor relation" of agricultural research. At the international level, this imbalance is partly redressed by centers such as the International Center for Agricultural Research in the Dry Areas (ICARDA), whose research focuses on dryland agriculture.

The International Desert Development Commission — now transformed to "The International Dry Lands Development Commission (IDDC)" — was established in 1978 to promote research and education aimed at sustainable use of dry areas of the world. A major focus has been the rehabilitation of degraded lands and mitigating future damage. The deliberations of dryland researchers and the knowledge accumulated have been documented in the proceedings of previous meetings held in Egypt, China, Mexico, and Texas, USA. This volume of proceedings is the outcome of the most recent meeting organized by the IDDC, in Cairo, Egypt, in August 1999, in collaboration with the United Nations Environment Program (UNEP) and ICARDA, and hosted by the Ministry of Agriculture and Land Reclamation, Egypt.

On behalf of the IDDC, I would like to express our gratitude to the members of the International Organizing Committee - Drs H. E. Dregne, M. Kassas, R.G. Wyn-Jones, Adli Bishay, Manual Anayo Garduno, T. Darnhofer and J. Venkateswarlu, for their help in the development of the technical program of the Conference. We thank the Chairman of the Local Organizing Committee — Dr Saad Nassar, former Director General of Agricultural Research Center, Egypt, and members — Drs Nabil El-Mowehli, Fadia Nosseir, Magdy Madkour, Adli Bishay, Ayman Abou Hadid and Nasri Haddad for their painstaking efforts in making all the local arrangements for the Conference. Dr Mohan Saxena served the IDDC as the honorary secretary for facilitating overall coordination of the Conference.

The staff of the Nile Valley and Red Sea Regional Program of ICARDA in Cairo, under the guidance of Dr Nasri Haddad, made special efforts in ensuring that the needs of the Conference were promptly and adequately met. Miss Rima El-Khatib provided major help to the editor in the preparation of the proceedings. Ms Noura Makhoul did the typesetting and Joyce Bendki did the proofreading. Dr Surendra Varma and his staff at the Communication, Documentation and Information Services of ICARDA oversaw the printing and production. The IDDC records its grateful thanks to all these persons.

This volume covers a wide range of topics of concern to scientists and decision-makers involved with dry areas: soil conservation and degradation, water management and conservation, range management, biodiversity conservation, combating desertification, stress physiology, expert systems and models, biotechnology, socio-economics, anthropology, renewable energy, applications of new technology, and indigenous knowledge. The volume is an important landmark in our efforts to exploit harsh dryland environments for the good of mankind.



Adel El-Beltagy
Chairman, IDDC &
Director General
ICARDA

Editor's Note

This volume reflects many of the presentations at the International Desert Development Conference in Cairo, Aug 21-27, 1999. Of the total 142 oral papers presented, 94 manuscripts were submitted for consideration to be published in the proceedings. Similarly, of the 60 posters presented, 32 companion manuscripts were submitted.

Given the physical difficulty of confining such a large number of papers to a single volume, considerable condensing was necessary. This involved pruning or deletion of tables and the restructuring of others. Many graphics were also omitted because of poor quality or difficulty in scanning the originals. Notwithstanding the variability in scientific content and English language, every attempt was made to preserve the author's meaning and style. Despite the variation in the format of the manuscripts, a standard format of presentation was developed.

It is my hope that the proceedings reliably reflect the deliberations of this important international meeting on addressing the problems of drought-prone lands and deserts, and will serve as a milestone in our knowledge of how to best cope with such fragile ecosystems.

John Ryan
Soil Fertility Specialist, ICARDA
Editor

Keynote Address

Reversing Desertification: The Potential for Research

Prof. Dr Adel El-Beltagy
Director General

*International Center for Agricultural Research in the Dry Areas,
Aleppo, Syria*

*Your Excellency, Dr. Youssef Wally; Your Excellency,
Dr Mahmoud Abuzeid; Dr. Serageldin, Ladies and
Gentlemen:*

On behalf of the International Commission on Dry Lands Development, and ICARDA, it is my great pleasure again to extend to you a warm welcome. Since dry lands are highly vulnerable to desertification, we see this Conference as an important step forward in addressing this problem through your valuable contributions.

INTRODUCTION

Accumulated evidence leads us to believe that the world is going through an ecological transition, that is affecting our planet and therefore our lives in many different ways. Desertification is one of the main challenges of this ecological transition. Can we control and even reverse desertification as we prepare to enter the new millennium with renewed hope for better lives for the present and future generations? I think the answer is "yes."

The Problem: Extent and Causes

Desertification continues to swallow up cultivable land. Sudan, for example, loses 5 sq. km of land per year and the world loses more than 600 million hectares of land per year to desertification. Over 100 countries and 1 in 5 of the world's population is affected. These deserts differ from the "natural" ones in that they are man-made. Their origins can be traced, and they can be controlled if the causes are recognized early enough. The annual loss worldwide through lower agricultural production is estimated to be as much as 42 billion dollars.

Because of the serious threat that it involves to the future of humanity, desertification has come to the forefront of global concerns, as reflected in a number of international conferences and conventions, the most recent being the *Convention to Combat Desertification*. The Convention defines desertification as "a process of land degradation resulting from various factors, including both climatic variation and change, and human activities." Land degradation occurs in the form of depletion or total loss of vegetative cover, and loss of its biophysical and economic productivity through exposure of the soil surface to wind erosion and water erosion, and through salinization and water-logging, leading to deterioration of the physical, chemical and

biological properties of soil. Overgrazing also leads to desertification, particularly in the case of rangelands. This is particularly serious in the dry areas.

The dry areas of the world cover an estimated one-third of the earth's surface, and have already lost over 9 million km of land. This has serious implications for the lives of millions of people who live in these areas.

The continued loss of vegetation through salinization and human activities also depletes the world's biodiversity, and it reduces the ability of the natural environment for carbon sequestration, with the consequent long-term effects of global warming and climate change. In that context, we are all painfully aware of the hole in the ozone layer over Antarctica. Predictions of increased global warming area are based on reality, with a consequent rise in sea level.

POPULATION AND POVERTY

Compounding these problems is that the expanding world population is predicted to reach at least 8 billion by 2020. Much of the population growth is projected to take place in the South, where millions of people are already under a severe grip of poverty.

More than one billion poor people inhabit the dry areas in the developing world. Over 690 million of these people are in the West Asia and North Africa (WANA) region. The picture of poverty in WANA is often distorted by averaging the poor with the rich. The oil exporters of the Arabian Peninsula represent only 5% of the region's population. The remaining 95% of the region's population has low per capita incomes. The four most economically disadvantaged countries are Eritrea, Ethiopia, Somalia and Sudan, where per capita GNP is only 88 dollars per year. Of these, some 76% have a mean per capita GNP of less than two dollars a day, and about 42% live on one dollar a day. Across WANA, women account for about half of the agricultural labor force.

There is greater absolute poverty in rural areas than in urban areas. For example, 59% of the combined populations of Afghanistan, Eritrea, Somalia, Sudan, and Yemen live below the one-dollar-a-day poverty line, and 90% of these live in rural areas. Economic disparities will continue to encourage migration from rural to urban areas and from poor to rich countries. And this will cause socio-political upheavals. Can the world survive these problems, or will it crack under the pressure? *No, it won't!* But we must continue to work hard to make the future of this planet sustainable.

ICARDA'S MANDATE REGION

I will now share with you a few examples of contributions that ICARDA is making to halt, and even reverse, desertification. I will give you these examples from the WANA region, since this is where ICARDA has focused much of its attention during the past years, although the Republics in Central Asia and the Caucasus have been recently added to our regional geographic mandate, and we call our region now as CWANA. The WANA region stretches from Morocco in the west to Pakistan in the east, and from Turkey in the north to Sudan in the south. It constitutes the single largest contiguous dryland region in the world.

In WANA, rainfall is limited and highly variable in space and time. A number of biotic and abiotic stresses, of which drought is most important, hit the crops and cause severe losses. Only 14% of the total land area is suitable for rainfed agriculture. The region has one of the highest population growth rates in the world: the total population is expected to more than double, approaching 930 million by 2020.

And the grain gap is projected to increase from 51 million tonnes in 1995 to 109 million tonnes by 2020. This is a conservative estimate that assumes no growth in per capita consumption. Assuming that grain would be priced at only \$130 per tonne, 109 million tonnes of grain would cost over 14.2 billion dollars. To visualize the import of 109 million tonnes of grain, imagine a train 16,000 km long!

Water Resources

The region has the smallest per-capita renewable water resources. Some countries are already facing an acute shortage of water, others are projected to fall into the same category in the very near future. Water is the single most important commodity which, if cheaply accessible, can fundamentally alter the potential of a low-rainfall area. Despite its scarcity in WANA, water continues to be misused. New technologies have increased the capacity to extract water to levels exceeding recharge, thereby depleting aquifers to exhaustion. Modern facilities can promote desertification. The ease of transportation has enabled herders to take water for their livestock to the sites of grazing, promoting overgrazing on the same piece of land, which ultimately leads to wind erosion and loss of biodiversity. These are some of the key issues contributing to increased desertification, global warming, famine, and starvation of millions of people.

ICARDA is ideally placed to work in arid and semi-arid environments of the world. The Center has a global mandate to improve the production of barley, lentil and faba bean, and of on-farm water-use efficiency. In the CWANA region, ICARDA's mandate is to improve the production of durum and bread wheats, chickpea, and pasture and forage crops, with emphasis on rangeland improvement and small ruminant management and nutrition, and natural resource management.

RESEARCH

The philosophy behind our research strategy is based on forming a strong link between advanced institutions on the one hand and developing national agricultural systems (NARS) on the other. The results and feedback drive this research continuum to attain solutions to the problems we face. Our research agenda can be considered as a matrix along two axes: resource management and production systems. The resource management axis recognizes that water is the most constraining resource in the drylands.

Crops and Genetic Diversity

The WANA region is well known as the home of some of the most widely cultivated crops in the world. The region contains three of the eight centers of crop origin identified by Vavilov. Barley, wheat, lentil and vetch were all domesticated in the Near East. The wild progenitors and relatives of these crops occur in the region to this day, as indicated by results of ICARDA's studies on the distribution of wild relatives of wheat. The biodiversity locked up in wild relatives of the crops that originated in the region is under serious threat from desertification.

Currently ICARDA holds over 117,000 accessions of its mandate crops and their wild relatives in its genebank. Some of these are now irreplaceable. ICARDA is also involved in in situ conservation, as it would permit adaptation of material to changing environmental conditions. The Center is coordinating a major project on in situ plant genetic diversity conservation in the region, involving Syria, Lebanon, Jordan, and the Palestine. The project is supported by the Global Environment Facility (GEF) of the United Nations Environment Program.

Fencing can provide one simple solution to protect biodiversity and arrest desertification, but only when the soil seed-bank hasn't blown away or died out. Areas must not be fenced for too long, or else plant species unpalatable to livestock will dominate the habitat. Grazing, if properly managed, is an integral part of rangeland management.

Highlights

Long-term Rotation Trials

About 30 million hectares of land is left fallow in WANA every year. If only 70% of this land could be sown to forage legumes, it would produce enough feed for 80 million sheep. Moreover, there would be an influx of 1.4 million tonnes of nitrogen from symbiotic nitrogen fixation per year.

Farming systems research has been a major component of ICARDA's research. To improve the existing farming systems, in the dry areas of WANA, long-term rotation trials were initiated both on-station and on-farm in the early eighties. These trials aimed at quantifying the effect of replacing fallow and continuous

cereal cropping with cereal/pasture and forage legume rotations. Pasture and forage legumes used in these trials included medics, chickling and vetches.

Use of medic and vetch in the cereal-based rotation over a period of 10 years showed a significant increase in total nitrogen and organic matter in the soil, when compared with cereal monocropping or cereal/fallow rotations. These changes improved soil physical properties and fertility, thereby increasing the productivity of cereals following legumes. These rotations also broke the disease and insect pest cycles which had built up in monocropping.

The results of these cereal/vetch trials were taken to farmers' fields. In on-farm trials for seven years in Syria, we compared barley/fallow and barley/barley rotations with vetch/barley rotations. Barley/vetch gave the highest yield of total feed, crude protein, and metabolizable energy. Long-term trials in Jordan have suggested that the net benefits to farmers of cereal/vetch are greater than those from cereal/fallow rotations.

Farmers are adopting this practice. In 1991 only three farmers in El-Bab village, near Aleppo, were growing about seven hectares of vetch. In 1998 the number had increased to 200 in 15 villages, with an area of about 420 hectares. This is helping reduce grazing pressure on common grazing lands, as well as contributing to reversing desertification.

Our work has also demonstrated that degradation of commonly-owned marginal land can be reversed by the application of phosphate fertilizer, reseeding with native vegetation, and deferring the grazing at flowering and seed-set of pasture legumes. Phosphate fertilizer increases the population of leguminous species three-fold in the vegetation, which provides increased live weight and milk productivity of sheep and goats.

Rehabilitation of Marginal Lands

For revegetating degraded rangeland by sowing annual legumes, it is necessary to multiply seed on farm plots. Hand-harvesting was a bottleneck in these efforts. To overcome this problem, simple, hand-operated machines, such as seen here, were developed at ICARDA.

Another rather interesting way of rehabilitating the degraded rangelands is to use sheep themselves for reseeding. Seeds of many native species pass right through the digestive system of the animals and get deposited in their droppings. ICARDA is looking at the possibility of spreading the seeds of these legumes by moving flocks of sheep where rehabilitation is needed. The sheep are allowed to graze the rehabilitated pastures, where they pick the seeds of pasture species. They are then moved to degraded marginal land where they leave their droppings to re-seed the land.

Re-seeding or encouraging self-regeneration of rangelands is an essential part of our range work. A pitting machine, adapted by ICARDA from a model developed in Australia, makes small pits in the soil that

collect rainwater and seeds, providing an ideal micro-climate for plant development.

Fodder shrubs are another option. ICARDA has found that native forage-shrub species are more promising than exotic species. In a collaborative project with Syria, over 6,000 hectares of rangeland has been rehabilitated with shrubs. Fodder shrubs provide the base vegetation cover which protects the small annual plants that grow in the protection of the shrubs. In Balochistan province of Pakistan, rehabilitation with fourwing saltbush was a major part of an ICARDA project in collaboration with the Arid Zone Research Institute, Quetta, until recently. ICARDA is coordinating a consortium on *Production and Utilization of Multi-purpose Fodder Shrubs and Trees* with other CGIAR centers, namely, ICRISAT, ILRI, and ICRAF, and the national research systems of WANA and the Sahelian countries in Africa. The objective is to improve the production and utilization of feed resources in a sustainable manner by good management of the rangelands.

The rangelands can also play a very important role in controlling global warming by capturing carbon dioxide in their vegetation. Monitoring carbon dioxide sequestration is an important component of ICARDA's research program. Bowen-Ratio equipment is being used by ICARDA in Uzbekistan to measure the amount of carbon that the rangelands can capture.

Water Resources and Management

Where rainfall is insufficient for crop growth, water-harvesting can increase available water. These techniques have been used throughout history in WANA. Indigenous cisterns, especially in Tunisia, are built on the same principles as those used by the Romans. Water-spreading, being modernized in Tunisia, is used to support field crops.

ICARDA is the convening center, within the CGIAR, for an eco-regional research program in *On-Farm Water Husbandry in West Asia and North Africa*, which links scientists from ICARDA and national programs in WANA. The research program addresses four main themes: description and analysis of indigenous systems, with particular focus on the human dimension; development of methods for site appraisal for water harvesting potential; optimizing the utilization of the harvested water; and disseminating new techniques to land users.

The idea behind supplemental irrigation is to improve and stabilize rainfed crop production, while maximizing water-use efficiency in terms of crop yield per volume of water. The same systems used for full irrigation can be adopted for supplemental irrigation. The small amount of water used in supplemental irrigation can make a large difference in crop yield when used in conjunction with rain, especially in drier years. Crop growth models can be used for optimizing supplemental irrigation practices, such as this one for wheat in Syria.

ICARDA's research has clearly demonstrated that water-use efficiency in supplemental irrigation greatly exceeds that of either full irrigation or simple rainfed farming. A cubic meter of supplemental irrigation water produced, on average, over 2 kg of wheat, while in full irrigation a cubic meter of water produced only 750 grams of wheat. In areas with very limited water resources, it is better to allocate water to maximize water-use efficiency and, consequently, farmers' profit, rather than trying to maximize yield.

Geographic Information Systems

New tools of research such as remote sensing, GIS, expert systems and biotechnology, can contribute to improving productivity in dry areas and combating desertification. Information obtained from remotely sensed satellite imagery, such as this one from ICARDA-German collaboration in central Syria, can be combined with aerial and ground surveys, to identify catchment potential for water-harvesting. Similarly, it could be used to assess and monitor trends in land degradation, such as this GIS map of erosion risk in the Jebel Abdel Aziz area, which was the result of ICARDA-Japan collaboration.

Biotechnology

Genetic engineering and other biotechnological tools offer great promise in overcoming crop-production constraints in drylands. For example, ICARDA has been working on genetic markers for drought resistance in its mandate crops. Enhancing cold tolerance in winter cereals and legumes can permit early sowing, thus preventing damage from early cold and late drought and heat. For this, ICARDA has an extensive program of incorporating cold tolerance in the breeding material, using genetic markers for cold tolerance. Improved lentil lines, developed by cold-tolerance marker selection, another can survive cold, compared with a traditional varieties. Another example is that of heat-tolerant wheat cultivars developed in Sudan in cooperation with ICARDA. This has helped in expanding the wheat area south of Khartoum where, due to high temperatures, wheat cultivation was not possible in the past.

PEOPLE, NATURAL RESOURCES AND FOOD

Ladies and Gentlemen: There is an intimate relationship between people, natural resources, and food. In

order to achieve a meaningful impact on the lives of people, these three aspects must be fully integrated into a multidisciplinary research process.

Rural incomes are directly associated with per-capita wealth of natural resources, e.g., land and water. This is true not only at the national level, but also among regions within a country, although other factors are important, such as infrastructure, distance to market, and policies and property rights. In many areas, land is left to degrade because of a lack of appropriate government policies and laws governing property rights.

Research on policy and property rights is an integral component of ICARDA's research program. A recent study in Yemen, for example, is looking into why terrace farming in Yemen has lost its importance and why terraces are left to degrade, and how this trend can be reversed. Community participation in designing rehabilitation techniques is a key component of an IDRC-supported research project on natural resource management in Yemen.

Struggle for Change

We are passing through a time in which social, political and economic realities are changing, in which a growing recognition of collective responsibility, facilitated by modern information technology, is driving the struggle for change. We also know that open-market economies will bring about major changes in the agriculture of tomorrow. The time is right for us to choose the path that would safeguard our future.

Ladies and Gentlemen: Today we have the right expertise and tools to fight desertification. We must continue to improve the awareness of the frightening consequences of its effects on people, particularly poor people, to generate support from national governments to join hands with international teams to fight this menace. Our efforts to increase productivity of the dry areas and the sustainability of its resources have the objective of enabling humanity to achieve a better life, and to pass on an improved legacy to the future generations. By working together, I am confident, we can achieve this objective.

Thank you for your attention.

A. PLENARY SESSION

Statement by Executive Secretary, United Nations Convention to Combating Desertification

Ambassador Hama Arba Diallo

Bonn, Germany

Excellency, Dr. Youssuf Wally, Deputy Prime Minister, and Minister of Agriculture and Land Reclamation of Egypt,

Dr. Ismail Serageldin, Vice-President, the World Bank, Excellencies,

Distinguished Participants,

Ladies and Gentlemen:

It is an honor and great pleasure for me to address this Sixth International Conference on the Development of Drylands on behalf of Ambassador Hama Arba Diallo, the Executive Secretary of the "United Nations Convention to Combat Desertification" (CCD). Ambassador Diallo himself was looking forward to being here with you for this important occasion, but last minute exigencies of duty came in the way. He nevertheless sends you his best wishes for a successful conference.

I would like to express my sincere thanks to Prof. Adel El-Beltagy, Director General of the International Center for Agricultural Research in the Dry Areas (ICARDA), for his kind invitation and the opportunity to address this important meeting. I wish to express my gratitude to the Government and the people of Egypt for their warm welcome and hospitality, and for hosting this Conference.

Let me also congratulate the International Drylands Development Commission and the Ministry of Agriculture and Land Reclamation of Egypt for the excellent work that has gone into the organization of this conference. This beautiful and historic city of Cairo serves as a very appropriate setting for a conference of this nature, where we can exchange views on how to handle the issues of drylands development into the next millennium.

This conference has a very clear and forward-looking theme, that is, "Desert Development: Challenges Beyond the Year 2000". Indeed, the challenges we are facing today in ensuring the sustainable use of drylands the world over are enormous, but the task itself is not *altogether insurmountable*.

Mr. Chairman,

Ladies and Gentlemen

Before addressing the subject matter of this conference, let me try to state plainly why I believe that what we are all concerned with is of paramount importance. Quite simply, it is because *the deterioration of land resources in the world's dryland areas is one of the gravest problems confronting the earth and its people.*

Desertification, probably more than any other environment-related phenomenon, demonstrates very clearly the inextricable linkage between natural resources management and social and economic as well as political factors. *We do have concrete data that illustrates that all is not well with the world's drylands, and that these habitats need our attention and concerted action today, as tomorrow may be too late.*

Over the years, various studies that have been undertaken have clearly established that desertification affects about one sixth of the world's population, 70% of all drylands, and one-quarter of the total land area of the world. The scourge of desertification has profound impacts; in addition to the widespread poverty, the principal and most obvious one is the degradation of 3.3 billion hectares of the total area covered by the world's rangelands.

This degradation is manifested in the *general decline in soil fertility and soil structure, degradation of irrigated land, and erosion of biological diversity, eventually leading to the diminution of the affected land's biological potential to sustain life*. Thus, the process of desertification is responsible for reduction in the regenerative capacity of the affected ecosystems by *directly undermining their resilience*.

It has also been demonstrated that the continued process of desertification has far-reaching consequences, as it impacts negatively on the socio-economic conditions of the affected populations. Millions of people have had to abandon their lands as desertification has made farming unsustainable, while hundreds of millions more are at risk of becoming *environmental refugees*. Desertification manifests itself as a problem of sustainable development, centered on poverty and human well-being.

Mr. Chairman,

I note with satisfaction that the agenda of this conference covers a fairly broad range of topics that encompass the realm of drylands development, including the application of new technologies for combating desertification, together with the role of indigenous knowledge and "know-how", traditional practices and coping mechanisms.

The process of rehabilitation of degraded lands is essentially a long-term development that requires the enactment of appropriate policies and supporting institutions, as well as enabling environments that ensure the participation of pastoralists, farmers and the other land-users. The most important common denominator

is partnership-building among the key concerned parties in order to place the pre-occupations of the inhabitants of dryland areas at the forefront of all the initiatives geared towards winning the fight against desertification.

The scenario obtaining in dryland areas in general, particularly in developing countries, is that the current livelihood and resource-use systems are not able to maintain or improve living standards in these marginal areas and, as pointed out earlier, there is a long-term reduction in the productivity of land, water and vegetation resources. The often-prolonged, below-average precipitation received in many of these drylands has led to a decrease in their productivity. There is enough evidence, scientific and otherwise, which amply demonstrates that the effects of a drought become more serious over a protracted period. For instance, when the precarious equilibrium of plant communities and other organisms adapted to climatic variability is upset by prolonged and persistent successive dry years, ecological recovery and regeneration, as well as growth, are jeopardized. *This may lead to ecological deterioration, and desertification.*

Mr. Chairman,

I would like to briefly touch upon the issue of promoting alternative livelihood strategies for dryland areas. The majority of inhabitants of dryland areas derive their livelihood from dryland agriculture and pastoral livestock production, and both production systems are linked together in complex ways that derive from years of traditional knowledge, practices and "know-how". The intricate linkage between these two production systems has been necessitated by the need to minimize risks in these fragile ecosystems. These systems are, however, *susceptible to the vagaries of weather and adverse climatic variations*. The production systems are also flexible and diversification can and has been introduced with positive results.

Different strategies for pastoral systems are needed from those of cropping systems, and the goal would be to augment and to increase household incomes in an environmentally sound and acceptable manner. This calls for alternative strategies to be integrated into the existing livelihood systems. The challenge here, therefore, is to identify the *appropriate alternative or supplementary production and livelihood systems that are socially and culturally acceptable*.

The key environmental spin-off from the introduction of alternative strategies of production and means of livelihood in dryland areas is that they allow rural systems to support a growing population by generating employment outside, but the basis is primary production systems. In this respect, they tend to alleviate the extractive demands on land-based resources and thereby relieve the pressure exerted on the environment.

Technology development, acquisition, and adaptation are central to drylands development. Various technologies can be employed to benefit, and to have

a positive influence on the lives of people in dryland areas. In these lands with marginal agricultural potential, this is where new technological innovations in fields such as land use, and soil and water conservation are needed most. Technologies that aim to relieve pressure on the use of wood-based resources, for instance in fuel, have been developed with significant success. Advances in agricultural research have been able to produce crop varieties adaptable to conditions in dryland areas, and the multiplication of such "success stories" need to be stepped up. Research needs to move away from dryland research centers and stations to the farmers' lands, who are the target beneficiaries, in order for them to reap the results of scientific endeavors. The experiences gained in these centers need to be harnessed for the benefit of the land-users in these dryland ecosystems.

Mr. Chairman,

I would now like to turn briefly to the issue of sustainable agriculture as an important tool for drylands development. Sustainable agricultural farming systems represent essential processes by which the biological and economic potential of dryland areas are conserved and improved. Sound dryland agricultural practices are a prerequisite for long-term maintenance of the productive potential of agricultural lands. This concept calls for *innovative methods of crop production that conserve the environment and are socially and economical acceptable*.

In order to meet the food needs of the populations of dryland areas, key activities in dryland agricultural practices should focus on the introduction of improved cropping systems and conditions for acceptable technologies, and the development of integrated management strategies by optimizing crop management technologies such as crop residue management and crop rotation, among others. The concept and practice of sustainable agricultural farming systems should be part and parcel of the available land-use options to enable inhabitants in dryland areas to overcome some of the handicaps that they encounter in their endeavors to attain food security. Improving existing agricultural systems through, among other ways, technological innovation and adoption and promoting appropriate small-scale enterprises at the local level, is a significant measure towards improving the livelihoods of the concerned communities.

One cannot fail to mention the role of *energy*, as it is closely linked to the issues under consideration. In addressing development of drylands areas, it is worthwhile to bear in mind that energy is an important factor in socio-economic development - *it constitutes the single most important input in economically productive processes*. Over the years, drylands have been under extreme pressure due to dependence on dwindling woody vegetation resources to satisfy increasing fuel-wood energy demands. This heavy reliance on forest resources has been contributing to environmental

degradation as demand continues to outstrip the supply. The need to conserve and make more efficient use of the available stock of wood-based resources is imperative, but, more importantly, the search for and provision of more sustainable alternatives is urgent in dryland areas. There is certainly added value in developing, promoting and adopting affordable renewable energy technologies that can help to make a difference in the economic development of these areas. Technology again is needed to come to the rescue of arid environments, their resources and people.

Mr. Chairman,

All the above issues that I have touched upon, and that address the development of dryland areas, have been very well articulated in the United Nations Convention to Combat Desertification (CCD), which was adopted in June 1994, and which calls for, among others, the integrated and sustainable management of natural resources as well as the development and use of technology to help in improving the livelihoods of people in dryland areas that are affected by drought and desertification.

The stated objective of the Convention is "to combat desertification and mitigate the effects of drought in countries experiencing serious drought and/or desertification, particularly in Africa, through effective action at all levels, supported by international cooperation and partnership arrangements, in the framework of an integrated approach which is consistent with Agenda 21, with a view to contributing to the achievement of sustainable development in affected areas".

Among its provisions, the Convention calls for *innovative participatory approaches* to address sustainable human development in the dryland areas. These include a new generation of bottom-up, country-driven National Action Programs in the countries affected by drought and desertification, to be supported through partnership arrangements, in addition to action programs also at the sub-regional and regional levels. The CCD also calls upon affected countries to put in place policy frameworks that address holistic drylands development that is in consonant with the preoccupations of the affected communities, through a participatory and "bottom-up" approach.

The Convention therefore offers a new window of opportunity, a distinctive, innovative, and workable framework for addressing development and environmental protection. The Convention has a unique character, a "bottom-up" approach, with the involvement of affected local populations in the affairs of implementation of anti-desertification activities, including activities geared towards mitigating the effects of drought.

One hundred and fifty-nine countries have now ratified or *acceded* to the Convention, recognizing the magnitude of problems caused by drought and desertification, and the urgency to undertake remedial measures. This large worldwide membership clearly demonstrates the universal nature and the global

constituency of the Convention. The Secretariat of the Convention, in collaboration with various partners, has been supporting activities to formulate and implement national, sub-regional, and regional action programs to combat desertification. These policy frameworks provide an environment conducive for undertaking community-driven activities to combat desertification.

The challenges for the development of dryland areas are clearly spelled out in the Convention to Combat Desertification. The key issues of *protection of soils from all types of degradation; protection of biological diversity; development and use of the appropriate technology, including biotechnology; the protection of water resources; and maintenance of stability of ecosystems*, constitute some of the basic concerns that need attention. It is clear that the availability of suitable technologies for the sustainable development of drylands is often lacking, and the added challenge in this respect is to address technological innovation.

The full impact of the degradation and loss of productivity of these drylands is difficult to quantify, but what we know is that through the combined adverse effects of climate variations, the long-term viability and stability of these ecosystems as life-support systems is severely undetermined. Desertification, or land degradation in dryland areas, is therefore not just a physical phenomenon, but also one that amplifies the difficulty of meeting the challenges of development in areas with high climatic variability.

Livelihoods in dryland areas become more vulnerable with each successive cycle of drought, and the severity of droughts determines the recovery of a given livelihood system. In most cases, communities experience progressive erosion of their bases of subsistence if droughts are prolonged and severe, as these also contribute to the degradation of natural resources. Strategies and plans that would contribute in an innovative and meaningful way to solving the problems of dryland degradation must therefore address livelihood systems. This kind of a livelihood-centered approach will undoubtedly provide us with the tools to help break the nexus between poverty and land degradation.

In conclusion, the sustainable and multiple uses of dryland resources and diversification of the means of production, with a view of making a difference in improving lives of people in these marginal areas, are concerns that are central to dryland development objectives. A mix or blend between local knowledge, "know-how" and practices with international scientific knowledge may be needed in the search for the correct solutions. But the *processes that govern the sustainability of land use in dryland areas form a complex web of interactions linking international, national and local levels*. The approach to problems in these areas should be from various fronts in order to stem the unsustainable short-term survival strategies that characterize resource use.

After considering what is at stake, we realize that the overall objective of maintaining healthy and

productive environments, generating employment and alleviating poverty, in the dryland areas can be achieved through a variety of innovative ways and means.

The challenge is with you, distinguished scientists, to present the appropriate solutions to this global problem. The dryland areas of the world need a solid foundation for local resource-based, less exploitative, production systems, in which producers share in the economic opportunities

The cornerstone of drylands development, as advocated by the CCD, is to adopt a people-centered development approach.

I am confident that with all the goodwill and efforts that you have put forth to these issues, viable solutions will come out of this Conference, *solutions that will help make a difference where it matters, and that is at the local level.*

I wish you fruitful deliberations and thank you all for your kind attention.

Water Erosion Control: Generating Support

Harold E. Dregne

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ABSTRACT

Water erosion is the most serious of the major desertification processes. Any loss of soil is essentially a permanent loss, given the generally slow rate of soil formation. Soil is the medium for growing the world's food crops. Yet, with the global increase in crop production, it is difficult to persuade the public that erosion control is a high priority. Food excesses in the USA and Great Britain in 1999 re-enforce that idea. A better reason for supporting water erosion control, in many countries, is not the on-site damage to food production, but the off-site damage caused by disastrous flooding, water pollution, siltation of reservoirs and, in China, raising the bed of the Yellow River several meters above the surrounding Plain. Off-site erosion problems are widespread and do enormous damage. We need to quantify those damages in order to make a persuasive case for erosion control.

INTRODUCTION

Desertification (land degradation) is the centerpoint of the United Nations Convention to Combat Desertification in "those countries experiencing serious drought and/or desertification", particularly in Africa. The convention generally is referred to as the "CCD"; its secretariat is headquartered in Bonn, Germany.

There are five major desertification processes: *rangeland vegetation degradation, water erosion, wind erosion, salinization of irrigated land, and soil compaction*. Of those processes, rangeland degradation is by far the most extensive, since rangelands occupy about 90% of the drylands. Rainfed cropping, where water and wind erosion constitute most of the degradation, cover about 7% of the drylands. Irrigated lands amount to about 3% of the area of arid, semi-arid, and dry subhumid climatic zones in the world (Dregne and Chou, 1992). Drought, although mentioned in the CCD title as an equal with desertification in importance, receives little or no emphasis in CCD discussions and actions.

In 1984, an analysis prepared for the United Nations Environment Programme (UNEP) concluded that desertification-control projects and programs had been poorly supported by governments, national agricultural development agencies, and international agencies such as the World Bank (unpublished report). Many aid projects were said to be desertification projects, but few actually have components that attacked the direct manifestations of desertification. Large amounts of development-aid funds went to projects to increase water supplies by wells that encouraged

extreme overgrazing in the vicinity of the wells. Research had shown earlier that vegetation (feed) was the limiting factor in the Sahelian drought, not water. Many other projects were initiated, under the rubric of desertification, that were well-intended, but had little or no effect on desertification control. As has been said frequently, countries lacked the political will to spend resources on land degradation control in the absence of a crisis such as a severe drought.

DESERTIFICATION DAMAGE

The principal adverse effect of desertification has always been considered to be the accompanying shortage of food and feed for humans and livestock. Drought is a calamity of large and immediate proportions for rural people and their livestock. It causes crises that generate global sympathy and financial support for the victims. Desertification is an insidious degradation process that gradually becomes worse and worse, but does not have the form of a short-term crisis. It is like the growth in the Antarctic ozone hole, where there is agreement that if the hole continues to become larger, the increased solar radiation reaching the earth will have harmful effects on humans. The expected damage, however, will worsen slowly, and only in future years will data show that skin cancers, for example, have increased significantly. By that time, it may or may not be too late to reverse the atmospheric condition.

With the principal desertification processes, the ability to control the problem varies with the process (Table 1). For soil compaction and most salinization problems, recovery can be rapid for all but rare, extreme situations. Soil productivity can be restored economically in 2 or 3 years. Vegetation degradation is different. With moderate vegetation loss, the speed of restoration is a direct function of the climate. It may take 30 or more years to restore the vegetative cover in the arid regions where annual rainfall averages between 100 and 250 mm (continental or monsoon type). In the semi-arid climatic zone, recovery might occur in 10 to 15 years. For severe vegetation damage, recovery could easily require 40 to 50 years - if ever - in the arid zone, and 20 to 30 years in the semi-arid zone. In many cases, any expense for recovery may not be economical in the arid and semi-arid zones.

Recovery from wind erosion damage could occur within a few months or a year, depending on the kind of damage the moving sand has done. If the wind action exposes caliche, a common indurated subsoil material in arid regions, the damage could be irreversible.

Table 1. Potential for reversing human-induced land degradation in arid and semi-arid climate zone, and restoring it to approximately its original productivity.

Desertification Process	Desertification Class		
	Moderate	Severe	Very Severe
Vegetation degradation, Rangeland ¹	medium to low	low to very low	very low
Water erosion	medium	very low	very low
Wind erosion	high	medium	low
Salinization (irrigated)	high	medium	low
Soil compaction	high	medium	low

¹Restoration depends heavily on climate.

Water erosion is special in that any surface soil loss would be irreversible if the rate of loss exceeds the rate of soil formation. In practice, a soil loss of a few centimeters in a soil that is one to two meters thick can be largely offset with good soil and crop management. If soils are deep loess (windblown particles) or deep sands, loss of large amounts of soil can have little effect on long-term soil productivity. Damage would become significant when the soil thickness is reduced to less than 1 m. For the most part, rates of soil formation are so slow (hundreds or thousands of years for 2 to 5 cm) that almost all water erosion losses exceed the soil formation rates. Gully erosion usually is an irreversible loss. Unless the gullies are filled mechanically, they can never be used for crop production.

ON-SITE/OFF-SITE DAMAGE

On-site land degradation refers to what happens to soils and plants in the field where the degradation occurs. Vegetation degradation has no significant off-site adverse effect. Overgrazing or tree-cutting affects only the supply of feed or timber or other products. It has no direct effect on neighboring land. The same is largely true of soil compaction and salinization except that soil compaction can affect rainwater runoff on to lower-lying lands, and salinization can increase water pollution by salt if leaching water flows into lower-lying surface or subsoil water. Those effects are not common.

Off-site effects can be severe and expensive in the case of water and wind erosion. Table 2 lists some of those on-site and off-site effects. A study conducted throughout the State of New Mexico, in the USA, estimated that off-site damages from wind erosion was 45 times more costly than on-site damage (Davis and Condra, 1989; Huszar and Piper, 1986). No comparable large-area study has been made for on-site and off-site

damage due to water erosion. Two nationwide estimations in the USA on on-site (Crosson and Stout, 1983) and off-site (Clark et al., 1985) costs of water erosion indicated that the costs were nearly the same.

WATER EROSION

Water erosion almost certainly is the number one land degradation problem in terms of economic damage in the long term. One study in Africa indicates that almost 85% of the land degradation is accounted for by water and wind erosion (Sombroek, 1993). Although a similar situation exists around the world, and is recognized as threatening future food supplies, adoption rates of improved soil management practices are low (Enters, 1998). Low adoption rates indicate that governments and farmers are not convinced that the problem is as severe as conservationists and others say it is.

One of the persuasive reasons that the public can reasonably believe that the threat to food supplies is not serious is the marked increases in crop production throughout the world (FAO, 1994). In that book, total food production was shown to have increased slightly on a per capita basis since 1980. Africa's food production has increased considerably, but has not kept up with population growth. It is hard to become concerned about food supplies when production is increasing steadily and countries such as those in the European Union are trying to reduce excess production. Great Britain, alone, will withdraw about 4 million hectares from crop and animal production to comply with European Union agricultural policies. 1999 is a year of large excesses of crop production in the USA and Great Britain and consequent low prices, bringing hardships to farmers due to over-production.

These production problems are economic problems occurring despite continuing land degradation.

Table 2. On-site and off-site effects of water and wind erosion.

Erosion Type	On-site Damage	Off-site Damage
Water	Nutrient removal, Reduced infiltration, Gully formation, Burying plants.	Flooding; Siltation of reservoirs, canals, stream channels; Water pollution.
Wind	Sand-blasting of plants, Nutrient removal, Burying of plants.	Deposition on railroads, highways, fence lines; Respiratory ailments of humans and livestock; Abrasion of machinery and structures; Reduced visibility; Mental stress.

Obviously, technological advances clearly offset erosion losses. Farmers do not think that their erosion problems are serious, so why should the general public be concerned? The answer is that *degradation of soil is a long-term threat both to food production and to environmental integrity*. Neither can be ignored. Soil degradation already adds considerable cost to farmers, in the form of increased costs for fertilizers and reversing soil compaction. Ultimately, on shallow and moderately deep soils, exposure of unproductive subsoils will offset the technology improvements, and yields will no longer increase. The process will be slower on deep soils.

OFF-SITE DAMAGES

Wind erosion has been confirmed as being a major contributor to air pollution, corrosion of machinery and cultural treasures such as statues and marble buildings, and abstraction of airline operations, etc. Off-site damage due to water erosion has not been documented economically to the extent wind erosion has. There are many common problems that are attributed to water erosion. Two big ones are increased flooding due to rapid runoff from eroded land and siltation of reservoirs that supply water to urban households, industries, and irrigated land.

China is an example of a very large country, which suffered badly in 1998 from runoff flowing from denuded forestland in the upper reaches of the Changjiang (Yangtze River), China's largest. An estimated 3,000 people were killed in the resultant flood. The Government has called for emergency measures to re-forest the watershed, stabilize the soils, and reduce floods. A situation exists on China's Yellow River that threatens the lives of as many as a million or more people. In the Yellow River watershed, most of which lies in the immense Loess Plateau, water erosion is tremendous. Loess is airborne mineral matter of mostly silt size, which, in China, blows out of former river flood plains in Central Asia and is deposited in central China. Loess probably is the most erodible soil material in the world.

Sediment from the Loess Plateau chokes irrigation canals, pollutes drinking water supplies, covers roads, fills storage reservoirs behind dams, and, worst of all, raises the bed of the Yellow River as it crosses the North China Plain. The latter problem (raising the height of the river bed) is what presents a hazard that dwarfs all others. The bed of the river is presently 3 to 13 m above the surrounding Plain. If a dike along the river should break in the western part of the North China Plain, a tragedy of unprecedented magnitude as the floodwater spreads across the Plain. In 1938, a break in a dike caused the deaths of 890,000 people in the resulting flood. Now that there are about 250,000,000 people living in the Plain, a flood would be unbelievably catastrophic. That threat greatly exceeds the small crop productivity loss that excessive water erosion does to the deep soils in the Loess Plateau.

The Chinese Government has been investing large sums of money for many years in the attempt to prevent eroded soil from entering the Yellow River and aggravating the potential flood problem. There has been no break in the dikes of the lower river since 1946. For the Government, on-site erosion damage is of little importance compared to the off-site damages if a dike in the lower section ever breaks.

A second kind of off-site erosion damage of importance to China is the filling of dams with silt. Both major dams on the Yellow River, one at Qingtongxia in the Ningxia Hui Autonomous Region, and another at Sanmenxia in Henan Province, have lost over 90% of their storage capacity. The same is true of smaller dams in the Loess Plateau that were built on Yellow River tributaries.

CONCLUSIONS

Urban dwellers are much more concerned about local floods and diminishing municipal water supplies than they are about crop reduction. Support for water erosion control should be based on off-site damage as well or more than on on-site damage. Sound data should be collected to assess off-site damage.

REFERENCES

- Clark, E., J. Haverkamp, and W. Chapman. 1985. Eroding soils: the off-farm impacts. The Conservation Foundation, Washington DC.
- Crosson, P., and A. Stout. 1983. Productivity effects of cropland erosion in the United States. Johns Hopkins University Press, Baltimore, MD.
- Davis, B., and G. Condra. 1989. The on-site effects of wind erosion on farms in New Mexico. *J. Soil Water Cons.* 44: 339-343.
- Dregne, H.E., and N.T. Chou. 1992. Global desertification dimensions and costs. p. 249-282 *In* H.E. Dregne (Ed.), *Degradation and Restoration of Arid Lands*, Texas Tech University Press, Lubbock.
- Enters, T. 1998. Methods for the economic assessment of the on-site and off-site impacts of soil erosion. Issues in Sustainable Land Management No. 2, Int. Board for Soil Research and Management IBSRAM, Bangkok, Thailand.
- FAO. 1994. FAO Production Yearbook, Vol. 48, 1994. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Huszar, P.C., and S.L. Piper. 1986. Estimating the off-site costs of wind erosion in New Mexico. *J. Soil Water Cons.* 41: 414-417.
- Sombroek, W. 1993. Agricultural use of the physical resources of Africa: achievements, constraints, and future needs. *In: Sustainable Food Production in Sub-Saharan Africa*, 2. Int. Inst. Tropical Agric. (IITA), Ibadan, Nigeria.

Expert Systems for Agricultural Development

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ABSTRACT

The focal theme of the paper is twofold: first, to show how expert systems work for agricultural practice, information-transfer problems; and, second, to describe our experience in developing and deploying agricultural expert systems. When examining the available information relevant to agricultural practices such as irrigation, fertilization and pest control, we found this information to be static and not necessarily responding to the growers needs. All extension documents give general recommendations because there are many factors to be taken into consideration; thus, many different recommendations should be included in the document. Most of the extension documents handle problems related to certain aspects: plant pathology, entomology, nutrition, irrigation, etc. However, in real situations, the problem may be due to more than one aspect, and may need the integration of the knowledge behind the information included in the different extension documents and books.

Information may not be readily available in any form. It is only available from human experts, extension workers, and/or experienced growers. In addition, the information transfer from specialists and scientists to extension workers and farmers represents a bottleneck for the development of agriculture on the national level. We are currently witnessing vast development in all fields of agriculture. Therefore, there is a need to transfer the information of experts in a certain domain to farmers, especially since there is a great demand for trained experts in new technologies. *Expert systems are identified as an excellent technology to transfer information from highly qualified experts to less qualified practitioners.* Examples of the expert systems developed in the Central Laboratory for Agricultural Expert Systems (CLAES) are described. Our experience in deploying the developed expert systems is also presented.

INTRODUCTION

Agricultural development is highly related to enhancing agricultural practices in order to increase production and conserve the environment. Agricultural practices can be defined as the set of agricultural operations conducted to produce a certain commodity. In order to enhance the growers' agricultural practices, reliable methods should be transferred to them in an efficient way. For example, irrigation scheduling is highly related to conserving water resources, while fertilization is

highly related to soil conservation. Rationalizing pesticide application also helps in conserving water and soil resources.

Examining the existing system for knowledge and experience transfer, we found that it mostly depends on extension documents (leaflets that contains instructions to growers) and direct contact between extension agents and growers. The problems of the conventional extension system are mainly due to the limitation of representing all interacting aspects of cultivation in printed form, and the inability of one extension agent to cover different cultivation disciplines.

The focal theme of the paper is twofold: first, to show how expert systems work for agricultural practice information transfer problems; and, second, to describe our experience in developing and deploying crop management expert systems. The paper is organized to cover these two aspects. The second section reviews some similar systems in developed and developing countries. The third section describes agricultural practice, information-transfer problems, and analyzes the suitability of expert systems to assist in solving these problems. The fourth section describes the components of crop management expert systems. The fifth section presents our experience in deploying expert systems in the field. The sixth section concludes the paper with challenges and future directions.

REVIEW OF SIMILAR EXPERT SYSTEMS

In the following two sub-sections, similar expert systems are presented in developed and developing countries.

Expert Systems in Developed Countries

The expert system applied to the problems of diagnosing soybean diseases (Michalski et al., 1983) is one of the earliest expert systems developed in agriculture. A unique feature of the system is that it uses two types of decision rules: the rules representing experts' diagnostic knowledge, and the rules obtained through inductive learning from several hundred cases of disease.

COMAX (Lemon, 1986) is a crop management expert system for cotton, which can predict crop growth and yield in response to external weather variables, soil physical parameters, soil fertility, and pest damage. The expert system is integrated with a computer model, Gossym that simulates the growth of the cotton plant. This was the first integration of an expert system with simulation model for daily use in farm management.

An expert system for integrated pest management of apple orchards (Gerevini et al., 1992), POMI, has been developed. Integrated pest management is definable as the reasoned application of agronomic methods products, as well as chemicals, to allow optimal productive factors, while respecting the farm worker, the environment, and the consumer. POMI addresses the first preliminary phase of the complex process of apple-orchard integrated control, namely the detection of the insect populations in the field and approximate the populations' dimensions. The system consists of two parts: classification of user findings, and explanation of these findings using inductive reasoning.

A picture-based expert system for weed identification (Schulthess et al., 1996) has been developed. Most current expert systems for weed identification are rule-based, using text that contains a large number of botanical terms. In this system, the hierarchical classification generic task was used and the text descriptions were replaced with pictures to minimize the use of technical terms. Hypotheses are established or ruled out on the basis of the user's choices among options presented as pictures.

Expert Systems in Developing Countries

An agroforestry expert system (UNU-AES) was designed to support land-use officials; research scientists, farmers, and other individuals interested in maximizing benefits gained from applying agroforestry management techniques in developing countries (Warkentin et al., 1990). UNU-AES is a first attempt to apply expert systems technology to agroforestry. This system addresses the option for alley-cropping, a promising agroforestry technology that has potential applicability when used under defined conditions in the tropics and sub-tropics. Alley-cropping involves the planting of crops in alleys or interspaces between repeatedly hedgerows of fast-growing, preferably leguminous, woody perennials. With the inclusion of more climatic and socio-economic data and improved advisory recommendations, UNU-AES can be expanded to provide advice on alley-cropping in more diverse geographical and ecological conditions, and eventually address other agroforestry techniques.

In India, an intelligent front-end expert system for selecting evapotranspiration estimation methods (Mohan and Arumugam, 1995) has been integrated with the methods that calculate the evapotranspiration factor. Evapotranspiration (ET) is an important parameter needed by water managers for the design, operation, and management of irrigation systems. Since there are many methods to compute ET, based on climatic data, an inexperienced engineer or hydrologist is perplexed with the selection of an appropriate method. An intelligent front-end expert system (ETES) has been developed to select suitable ET estimation methods under south Indian climatic conditions. Ten meteorological stations located in different climatic regions and 13 ET estimation methods have been considered in this ES.

Along with the recommended method, ETES also suggests suitable correction factors for converting the resulting ET values to those of methods that result in accurate estimation.

In China, there is an active group involved in developing expert systems in agriculture. Xiong (1992) presented the status of using such systems. A study on the usage of agricultural expert systems in Hebi Province of China was conducted by Guang et al. (1992). The systems developed were mainly for staple crops such as wheat, rice, and maize.

In Indonesia, expert systems were used for information transfer of soil and crop management (Yost et al., 1992). The expert system work began with a prototype for determining lime requirements for managing soil acidity. This led to the development of three expert systems: FARMSYS, ADSS, and LIMEAID. The goal of the expert system FARMSYS is to integrate information about the farmers and the farm family into a system that provides recommendations about agricultural research from a farm household's perspective. The ADSS expert system provides soil acidity management recommendations. LIMEAID is an enhanced version of ADSS.

NEED FOR EXPERT SYSTEMS IN AGRICULTURE

The need for expert systems for technical information transfer in agriculture can be identified by recognizing the problems in using the traditional system for technical information transfer, and by proving that expert systems can help to overcome the problems addressed, and which are feasible to be developed.

Information-Transfer Problems

Static Information

Examining the information stored and available in the agriculture domain revealed that this information is *static* and may *not respond* to the growers' need. All extension documentation gives general recommendations because there are many factors to be taken into consideration; thus, many different recommendations should be included in the document.

Specialties Integration

Most of the extension documents handle problems related to a certain specialty: plant pathology, entomology, nutrition, or any other specialty. In real situations, the problem may be due to more than one cause, and may need the integration of the knowledge behind the information included in the different extension documents and books.

Combining Information Source

Images may sometimes need an expert to combine other factors to reach an accurate diagnosis, and, even if a diagnosis is reached, the treatment of the diagnosed disorder should be provided through an extension document.

Updating

Changes in chemicals, their application rates, and their effects on the environment should be considered. Updating this information in documents and distributing them takes a long time. The same arguments can be made for audiotapes, which are another form of extension, but in voice instead of written words. Videotapes are more stable than other media as the information provided through the tape usually describes well-established agricultural operations. However, if the tape includes information as to what is commonly included in documents and audiotapes, this information should be updated.

Information Unavailability

Information may not be available in any form of media. It is only available from human experts, extensionists, and/or experienced growers. In addition, the information transfer from specialists and scientists to extensionists and farmers represents a "bottleneck" for the development of agriculture on the national level. The current era is witnessing a vast development in all fields of agriculture. Therefore, there is a need to transfer the information of experts in certain domains to the general public of farmers, especially that the number of experts in new technologies is less than the demand.

Suitability and Feasibility of Expert Systems

The problems already raised can, to large extent, be solved using expert systems to generate the information to the growers by using its knowledge base and reasoning mechanism acquired from human experts and other sources. The expert system generates the advice based on its knowledge base and its reasoning mechanism that are actually behind all developed extension documents, and more. Consequently, when a user enters the data of his/her plantation to the system, the appropriate advice is generated. There are no limitations on the number of generated recommendations. *Therefore, expert systems overcome the problem of static information provided in extension documents.*

The knowledge acquisition process for building an expert system facilitates the integration of knowledge and experiences of different specialties. For example, an agricultural diagnostic expert system requires the integration of specialists in nutrition, plant pathology, entomology, breeding, and production. Therefore, when a problem occurs, the system can help the user in identifying the cause of the problem in a much more efficient way than consulting a document that handles a specific problem.

Expert systems can be integrated with other information sources such as images bases and/or textual bases to make use of these sources. For example, images can be used for describing symptoms, as it is very difficult and very confusing to describe them in words. Images can also be used for confirming the diagnosis of the cause of a certain disorder. Expert sys-

tems can also be integrated with textual databases that may be the extension documents related to the specialty and/or commodity handled by an expert system. This textual database can be used for explanation purposes of basic terms and operations. It can also be used to confirm the conclusion reached in some situations.

The updating problem is also found in expert systems. However, the knowledge base can be maintained more efficiently than maintaining manual documents. The problem of updating the versions in the field can be eliminated in case that the expert systems are stored on a central computer and accessed through a computer network.

The undocumented experience and knowledge can be acquired and stored in the knowledge base of an expert system for a certain specialty and/or commodity. This experience can be available to all growers using the system. The feedback from the usage of the system can be used as a source of information when analyzed by researchers, the knowledge behind it can be identified, and the knowledge base can be updated continuously. Expert systems can also help in overcoming the problem of the relatively few numbers of experts relative to the demand from the growers. Expert systems technology can help to transfer the information of experts and experienced growers to farmers through the extension system.

CROP EXPERT SYSTEMS COMPONENTS

Analysis of agricultural operations has revealed that an expert system for crop management is a family of expert systems that work together to generate a schedule for agricultural operations. The functionality of these operations was analyzed and consequently classified into these categories: site assessment, seedling production, cultivation preparation, agriculture practice management, and disorder diagnosis and remediation. The analysis also revealed that knowledge behind advising about these operations is also dependent on a certain crop though the same categories stand for any crop. The development process starts by acquiring knowledge from domain experts, coding this knowledge, and ends by internal validation of the system by domain experts who provided the knowledge. The five expert systems developed are crop-wise expert systems. In the following sub-sections, a brief description is given for each of the crop management sub-systems.

Site Assessment

This sub-system was developed for orange (Salah et al., 1992) and lime. The function of this sub-system is to assess whether the soil, water, and weather characteristics are suitable for orange cultivation. The decisions generated from this sub-system are: the site is perfect for cultivation, a set of treatment operations has to be applied before cultivation, it is feasible to cultivate but you have to follow a set of recommendations, or the site is not suitable for cultivation. This sub-system is

very useful to be executed before any consultation because if a plantation were not suitable for cultivation, there would be no need to go to any other sub-system like diagnosis, for example.

This sub-system was developed using NEXPERT/Object (Nexpert, 1988) for orange and CLIPS (CLIPS, 1993) for lime. The orange sub-system was transferred to a knowledge representation language based on logic and object programming paradigms (KROL) developed at CLAES (Shaalán et al., 1998).

Seedling Production

This sub-system was developed for cucumber seedlings (Rafea et al., 1991; El-Desouki et al., 1991; 1992). It has six functions: seed cultivation, cultivation media preparation which includes the determination of the ratio between vermiculite and peatmos in the media, environmental growth factor control, diagnosis, treatment, and protection. This sub-system was developed using EXSYS shell (EXSYS, 1989).

Cultivation Preparation

This sub-system was developed for cucumber (Rafea et al., 1992), and another one was developed for wheat (Kamel et al., 1994). The main objective of these sub-systems is to give advice concerning the pre-cultivation activities in the production stage. For example, in the Wheat Expert System, the pre-cultivation activities include variety selection, tillage, and seed cultivation. Some of these operations are special to a specific situation, and others are routine operations. However, the description of these routine operations was found very useful for novice growers. The sub-system developed for cucumber used NEXPERT/Object shell (Nexpert, 1988) and then transferred to KROL, whereas the one for wheat was developed using routine design generic task using the programming language "Small Talk" (Kamel et al., 1994).

Agriculture Practice Management

This sub-system was developed for cucumber and orange (Salah et al., 1993). Two other sub-systems have been developed for wheat (Kamel et al., 1994), and lime. The main objective of such systems is to generate irrigation, fertilization, and preventive operation schedules. The irrigation and fertilization schedule includes the water quantity, irrigation interval, nutrient quantity, and application interval. These outputs are based on quantitative reasoning rather than heuristic reasoning. The preventive operations schedule includes preventive operations such as agricultural practice operations, and preventive chemical spraying.

The general agricultural practice operations such as pruning are described in detail with the help of a video clip to show the grower how to perform it correctly. The expert system also gives the appropriate date when an agricultural operation should be done. The expert system helps in determining the appropriate application

rate for preventive chemical spraying. It also provides precautions while performing such operations. The two sub-systems for cucumber and orange were developed using NEXPERT/Object shell (Nexpert, 1988), and have been transferred to KROL. This sub-system was also developed for wheat using "Small Talk" and for lime using CLIPS.

Disorder Diagnosis and Remediation

This sub-system was developed for cucumber (El-Desouki et al., 1993), orange, tomato and wheat. The main objective of this sub-system is to identify the cause of an observed disorder, its severity, and then propose the appropriate remediation. The user can directly consult the remediation part if the cause of the disorder is known for him. However, the remediation part, in this case, verifies the cause given by the user before giving the remediation advice. The sub-systems for cucumber, orange, and tomato were implemented using KROL. This sub-system for wheat was developed using "Visual Work". It is partially implemented for lime using CLIPS, as the diagnosis part is not included.

DEPLOYING EXPERT SYSTEMS

This section presents the activities related to the deployment of the developed expert systems. These activities start by the system evaluation, training the extension workers, usage monitoring, and the maintenance of the system.

Expert System Evaluation

Expert system evaluation is the procedure by which we can be confident that the developed expert system satisfies the needs of the end-users. We have mainly three types of users: *researchers*, *extension workers*, and *growers*. In order to ensure that the system is acceptable to the research community, external validation is conducted. To insure that the system is acceptable to the extension workers and growers, field validation is conducted.

The external experts' validation is actually like internal validation, but it is conducted with external experts, and the decisions of the external experts are not taken for granted. The external validation is done by preparing typical cases and distributing them to three external experts and to the expert system as well. A senior expert blindly evaluates the recommendations made by the human experts and the expert system. The senior experts discuss the validation results with the domain experts, who participated in providing the knowledge and in the validation process itself, to settle any disagreement. The rationale for conducting this external validation is to compensate for any defect due to any erroneous knowledge and to ensure the acceptability of the system by the professionals in the field. The erroneous knowledge may have had been provided by the selected experts, or the internal validation steps could not locate it. If the expert system performs like

the best domain expert, the system is accepted for release; otherwise, the comments taken are implemented before release.

The field validation is a continuous activity. Regular visits and meetings are conducted to the sites where the expert systems were deployed. The user comments are collected and then discussed with the domain experts to be approved for updating the knowledge base. Another type of field validation is to conduct an experiment during the cultivation season and to collect data from the field managed by the experts system and a control field. The results of this experiment are used to update the knowledge base and measure the impact of the expert system usage. The main objective of the field validation is to measure the impact of using expert system on giving the farmers good service at the extension offices, as part of the mission of the Ministry of Agriculture, and hence national production will increase and the environment will be conserved. This will lead indirectly to paying off the development cost of the expert systems.

Extension Workers' Training and System Distribution

Once the expert system is approved to be disseminated after the external validation is conducted, the training activity starts. The training activity includes the trainee selection, conducting the training sessions, and trainee evaluation. At the end of training, the trainees get the expert system diskettes with them.

The trainees were selected according to the following criteria: age, computer literacy, and eagerness for learning. Unfortunately, the computer literacy was dropped from the criteria, as most of the extension workers are computer-illiterate. Therefore, we had to add one week training on computer literacy. The eagerness for learning is measured through interviewing several candidates and selecting two from each site.

Training material was prepared and distributed on the first day of training. One week was dedicated for training on the usage of the expert system. Lectures and "hands-on" training sessions were held. On the last day, the trainees are usually trained on installing the system by using the distributed diskettes. They have also been trained on reporting any bugs in the system and/or any comments on the expert systems recommendations. It is worth noting that the one-day training course is repeated when a new version is produced.

The computers are installed in the extension offices where the farmers usually come to ask extension workers about advice and recommendations.

Monitoring Expert Systems Usage

The extension workers in the village, district, and/or governorate used the system to support them in making their decisions in giving the appropriate advice to the growers. A survey has been conducted to measure the adoption of the expert system by the extension workers

who have been trained (Nawar et al., 1997). The adoption of the system has been measured using three main factors: *frequency of operating the system, training others on the system, and extension workers views related to the system adoption.*

The results showed that 57% of the trained extension workers use the system at least once daily and 16% use it several times daily. Therefore, we can say that 73% of the extension workers use the system on a regular basis. It was also found that 68% of the trained extension workers had trained others to operate the system. The reasons hindering the adoption of the system, as indicated by the extension workers, were lack of publicity (27%), expert system-related reasons (26%), clients' related reasons (21%), and financial and administration reasons (10%). Only 8% responded that there is no need for the system, while another 8% responded that there is no problem hindering the adoption of the system.

Another important aspect, which we could not include in the above-mentioned survey, was the usage of the explanation facility in the system. The reason was that the deployed system did not include this facility at the survey time. However, personal contacts and feedback from the users indicated that this facility gives them confidence in the system.

Maintenance

There are mainly two objectives of system maintenance. The first is to discover bugs and problems that may arise during the actual, at site, running of the system. The second is to make sure that the system is up-to-date and possessing the most accurate and the most recent knowledge concerning the domain of application.

Users' remarks and complaints experienced, while at the actual site running of the expert system, and results of field validation, are collected in a "*Field Evaluation Report*". These are the main sources that support the decision of what to be done to refine and maintain the expert system. Changes are discussed and classified to minor and major changes according to the modification implementation time. Minor changes are usually implementation corrections and are to be performed immediately by the developer and transferred to the sites, if they were urgent. Major changes are documented, studied, and discussed with domain experts if they concern the knowledge base. Approved items of these changes are enrolled in the plan of next version and should be documented and attached to the user manual.

The second objective is achieved by the arrangement for half-yearly meetings with domain experts, where domain knowledge is reviewed, and the latest updates to the field are discussed, and the required knowledge are acquired and augmented into the knowledge base.

CHALLENGES AND DIRECTIONS

Although the expert systems development has contributed to the solution of the agricultural practices, information-transfer problems, new problems arise, and should be solved due to the usage of the expert systems. These problems can be classified into two main categories: development problems, and deployment problems.

The development problems include the management of the development life-cycle activities of any knowledge-base system. However, the problem that will continue through the whole lifetime of an expert system is the continuous maintenance and porting the systems from one platform to another. The continuous knowledge base and software maintenance needs extensive documentation and management, as there is a great demand for the knowledge and software engineers who may leave for any reasons. Porting systems from one platform to another platform is another maintenance problem. For example, when we started developing expert systems in late eighties, the operating system on PC machines was DOS, but now the common platform is Windows 98. Therefore, we had to port all expert systems developed on DOS to the new environment. Tools and methodologies should be developed to achieve the maintenance and porting procedures efficiently.

The deployment problems are specific to the agricultural environment. New activities are included in the research stations, and extension services that are relevant to the introduction of the expert systems as a new tool for information dissemination. The researchers should conduct field validation experiments for the deployed expert systems, analyze the results, and provide feed back comments to the developers. Extension service activities are training on the expert systems developed, equipping the extension offices with computers, following up the usage of the expert systems, and feeding back any comments to the developers. Although these are new activities, because of the usage of the expert system, some of them are currently done on manual systems. For example, the validation experiments of extension package for a specific crop are routinely conducted in experimental research stations.

In order to respond to these challenges, a specialized laboratory has been institutionalized within the Agriculture Research Center to be responsible for providing the extension services and growers with computerized packages (expert systems) to be used in addition to the manual package provided by the research centers. This specialized laboratory is called Central Laboratory for Agricultural Expert Systems (CLAES), which is divided into three research departments namely: *Knowledge Engineering Methodologies and Expert Systems Building Tools* (KEBT), *Agricultural Expert Systems Development* (AESD), and *Training, Evaluating, and Updating Expert Systems* (TEUES).

The main directions of the KEBT department are to continuously enhance the methodology to respond to

the development and deployment needs, and to build tools to facilitate the development and maintenance of the systems. Another direction is to enhance the tool such that researchers could use it to build their own expert systems. Enhancing the explanation methodology and implementation is also considered.

Another important issue, which is currently being investigated, is the automation of the knowledge-base translation. Although our expert systems are bilingual, great efforts are exerted to maintain the two language versions (Arabic/English). The need of two versions is due to the interaction with international community and, in the meantime, the extension workers are more comfortable when the expert systems inputs and outputs are in Arabic.

The main direction of the AESD department is to build expert systems for main crops in Egypt and for animal health care. Priorities of expert systems to be developed are settled with the administration in the Ministry of Agriculture. Sharing and re-use of the previously acquired knowledge is a research direction, which this department is investigating in order to expedite the expert system development.

The main directions of the TEUES department are to invent methods and tools for training extension workers on the expert systems and any updates, conducting verification, and validation, participating in field validation, and updating the deployed expert system.

REFERENCES

- CLIPS, 1993. CLIPS v. 6.0 Lyndon B. Johnson Space Center. Information System Directorate, Software Technology Branch, NASA, Houston, TX.
- El-Desouki, A., A. Rafea, M. Youssef, and H. Safwat. 1991. An expert system for seedling production management. *Proc. "First National Expert Systems and Development Workshop"* (ESADW-91), MOALR, Cairo, Egypt.
- El-Desouki, A., A. Rafea, and M. Youssef. 1992. Verification and Validation in Knowledge-based Systems. *Proc. First International Conference on Expert Systems and Development* (ICESD-92), MOALR, Cairo, Egypt.
- El-Desouki, A., S. Edrees, and S. El-Azhari. 1993. CUPTEX: An integrated expert system for crop management of cucumber. *Proc. "Second National Expert Systems and Development Workshop"* (ESADW-93), MOALR, Cairo, Egypt.
- EXSYS, 1989. EXSYS professional: advanced expert system development software. *Tech. Manual*, EXSYS Inc., NM, USA.
- Gerevini, A., A. Perini, F. Ricci, D. Forti, C. Ioratti, and I. Mattedi. 1992. POMI: An expert system for integrated pest management of apple orchards. *AI Applications*, 6(3): 51-62.
- Kamel, A., K. Schroeder, J. Sticklen, A. Rafea, A. Salah, U. Schulthess, R. Ward, and J. Ritchie. 1994. Integrated wheat crop management system based on

- generic task knowledge-based systems and CERES numerical simulation. *AI Applications* 9(1): 17-27.
- Lemmon, H. 1986. COMAX: An expert system for cotton crop management. *Science* 233: 29-33.
- Michalski, R., J. Davis, V. Visht, and J. Sinclair. 1983. A computer-based advisory system for diagnosing soybean diseases in Illinois. *Plant Disease* 67: 459-463.
- Mohan, S., and N. Arumugam. 1995. An intelligent front-end for selecting evapotranspiration estimation methods. *Computers and Electronics in Agric.* 12(4): 295-309.
- Nawar, M., M. Mahmoud, and I. Rashwan. 1997. Social impacts of using expert systems in field practice. *Tech. Report*, Publ. by CLAES TR/CLAES/7/97.2
- NEXPERT, 1988. Neuron data, NEXPERT object fundamentals, PC Version 1.1, *Tech. Manual*, Neuron Data Inc., Calif., USA
- Rafea, A., and A. El-Beltagy. 1987. Expert systems as an appropriate technology to speed up agriculture desert development in Egypt. *Proc. "Second International Desert Development Conference"*, Harwood Academic Publ., 47-57
- Rafea, A., M. Warkentin, and S. Ruth. 1991. An expert system for cucumber production in plastic tunnels. *Proc. "World Congress on Expert Systems"*, Florida, USA
- Rafea, A., A. El-Desouki, S. Nada, and M. Youssef. 1992. An expert system for cucumber production management under plastic tunnels. *Proc. "First International Conference on Expert Systems and Development" (ICESD-92)*, MOALR, Cairo, Egypt.
- Rafea, A., S. El-Azhari, I. Ibrahim, S. Edrees, and M. Mahmoud. 1995. Experience with the development and deployment of expert systems in agriculture. *Proc. "IAAI-95 Conference"*, Montreal, Canada.
- Ritchie, J., D. Godwin, and S. Otter-Nacke (Ed.). 1985. CERES wheat, a simulation model for wheat growth and development. College Station, Texas A&M Univ. Press, TX.
- Salah, A., A. Rafea, and E. Mohamed. 1992. An expert system for citrus cultivation feasibility. *Proc. "First International Conference on Expert Systems and Development" (ICESD-92)*, MOALR, Cairo, Egypt.
- Salah, A., H. Hassan, K. Tawfik, I. Ibrahim, and H. Farhat. 1993. CITEX: An expert system for citrus crop management. *Proc. "Second National Expert Systems and Development Workshop" (ESADW-93)*, MOALR, Cairo, Egypt.
- Schulthess, U., et al. 1996. NEPER-Weed: A picture-based expert system for weed identification. *Agron. J.* 88: 423-427.
- Shalan, K., M. Rafea, and A. Rafea. 1998. KROL: A knowledge representation object language on top of prolog. *Expert Systems with Applications: An Inter. J.*, 14(4).
- Warkentin, M., P. Nair, P. Ruth, and K. Sprague. 1990. A knowledge-based expert system for planning and design of agroforestry systems. *Agroforestry Systems* 11(1): 71-83.

Tolerance to Stresses in the Arid Areas

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ABSTRACT

"Life is organized water", a quotation from the Nobel Laureate Albert Saint-Gyorgyi, and "We are made from water every living thing", (The Holy Koran, Sura 21:31), summarize a universal truth at the political, civic, agricultural and biological/cellular levels. Primary production is directly related to the proportion of available water that can be transpired through the leaves of plants. In relation to the human development of drylands, one set of fundamental issues is the efficiency with which mankind can manipulate the entrapment and effective concentrations of available water. The conversion of that water into transpirable water by the desired crop, while minimizing evaporative loss, determines the water-use efficiency of biomass production and finally the proportion of that biomass that can be sustainably utilized to support various human needs.

This presentation will concentrate on two aspects of this complex water use continuum. It will discuss ways in which simple manipulations can improve seedling establishment and the early development of a good rooting system and enhanced growth, resulting in significant yield gains in many situations. Secondly, I will briefly discuss the use of various molecular biological techniques to both identify and manipulate desirable traits and finally allude to the relative merits of agronomic- and breeding-derived inputs in increasing stress tolerance and utilizable yield under water-limited conditions.

INTRODUCTION

It is clearly not possible in this short contribution to do justice to the breadth and complexity of the myriad of issues implied in the title. My aim is to provide a framework for further discussion and to make some useful generalizations, hopefully without lapsing into banality, oversimplification, or too much re-hashing of well-known material.

The arid and semi-arid lands of this planet are characterized by extremes of climate and soil conditions that limit plant growth and all too often are associated with human deprivation and environmental degradation. In plant sciences, we conventionally refer to such areas as 'stressed' environments, but it is as well to remember that native species are well adapted to such conditions and complete less successfully if exposed to apparently less 'stressful' conditions (see, for example, Jones and Jones, 1989; Wyn-Jones and Pritchard, 1989). Dryland plants have evolved a wide range of subtle and beautiful mechanisms to successfully exploit these conditions.

With this important caveat, we can recognize some of the "stresses" commonly experienced by plants in such dryland conditions as drought, high and low temperatures, salinity, sodicity and water-logging, and nutrient deficiencies. Such areas are characterized by large annual variability in rainfall, seasonal uncertainty, often large diurnal fluctuations in temperature and, especially in salt-affected soils, great soil heterogeneity. Furthermore, the "stresses" do not occur individually, but in various combinations which are characteristic of specific locations.

Indeed, it is misleading to speak of 'drought stress' or 'tolerance' as a single phenomenon. It is a complex variable phenomenon reflecting local climatic and edaphic conditions and human needs within particular settlement patterns. Despite all these interlinked issues, the dominant concern in drylands is the availability of water, and this will be the focus of this paper.

As noted, the distinguished Nobel Laureate Albert Saint-Gyorgyi, stated that 'Life is organized water'. He spoke from the perspective of an animal biochemist, but this insight reflects a profound truth at many levels. In addition to the particular physical properties such as low melting point and boiling point due to the quasi-crystalline structure of hydrogen-bonded liquid water, it is also the unique three dimensional folded structures of macromolecules bordered by 'hydrated structures' of liquid water that confer the unique physical properties that permits life on this planet. Water (H_2O) is not just the solvent for biology, but is intimately involved in the structure and sometimes the activity of catalytic proteins of lipoprotein membranes and of DNA (see Wyn-Jones and Pollard, 1983).

The 'molecular organization' of water is also vital to cellular integrity, to whole plant vegetative growth (and of animals), to field crop performance and yield, to sustainable village life, and to the social functioning of great cities. Nowhere is this fundamental truth more dramatically illustrated than here the Nile Valley.

While the proportion of planetary water that is available to biology and to humanity is very small (well under 1%), it is important to note that it is not the equilibrium distribution that is necessarily limiting. Bio-geospheric water fluxes are enormous, and the situation is highly dynamic. Water plays out its many biological and socio-economic roles in a very steep thermodynamic gradient, leading usually and inexorably to rapid evaporation from any wet surface.

An indication of the steepness of this gradient is that, while fresh water has a water potential of approximately -0.01 MPa, (and seawater -2.5 MPa), this is equivalent to air at 98.2% RH. In contrast, air at

50%RH has a water potential of -95 MPa (Nobel, 1974). It is within this context that we can now appreciate that changes in leaf water potentials, ranging from circa -0.8MPa in well-water conditions to -3 to -4 MPa in saline or drought conditions, have little effect on the steepness of the gradient. This gradient massively favors water loss on all but the wettest day [>98%RH].

The fluxes of water are dependent on the negative gradient of water potential, but are regulated by the resistances in the pathway, e.g., stomatal or cuticular resistances, or soil surface, subsurface and root hydraulic conductances. Although quite large changes in the leaf water potential have a minimal effect on the driving force, changes in these resistances are critical to the actual flow rates (see Nobel, 1974; Loomis, 1983).

Some years ago, Passioura (1977) suggested a simple identity which, in a way rather similar to Saint Gyorgyi's dictum, expressed a fundamental concept which is true at many levels:

$$\text{Yield (Y)} = \text{Transpiration (T)} \times \text{Water-Use Efficiency (WUE)} \times \text{Harvest Index (HI)}$$

This identity, which is capable of being interpreted at levels ranging from a single leaf through to the field, or village scale, or to even a regional irrigation scheme, emphasizes the major characteristics of the system.

Yield, be it biomass, grain yield or a complex mixture of outputs reflecting multiple human aspirations, including conservation biology, depends on transpiration. *No transpiration means no vegetative growth and no biomass.* Thus, it is critical to maximize transpiration (T) while minimizing the proportion of water simply evaporated (Es) or otherwise lost from the system by surface or subsoil flows. However, the water-use efficiency (WUE) can itself be modified or manipulated at many levels depending on such contrasting factors as leaf morphology, cellular photosynthetic biochemistry (C-3, C-4 or CAM plants), field agronomy, irrigation management, even social practices in villages, and international water politics.

$$\text{WUE} = \frac{\text{Yield per unit area}}{\text{Water used to produce yield}}$$

Within the context of the conference, it is worth noting that in fieldwork at ICARDA and in Australia (Cooper et al., 1987), the % of water 'lost' by evaporation as opposed to 'used' by transpiration varies from 35% to 75%. Broadly, the harsher the conditions and

Table 1. Agronomic manipulations.

Reduced Evaporation

- Mulching,
- Early development of leaf area, (transplanting and pre-wetting),
- Plant population and structure,
- Fertilization,
- Use of varieties with early vigour.

the poorer the plant cover, the greater the 'evaporative waste'.

Thus, at the heart of "water-use efficiency" in dry-land conditions is the need to *minimize evaporative water loss*, or leakage from the system, *while maximizing the amount of transpirable water*, while, of course, also ensuring that the transpiration profile is compatible with the 'yield(s)' required.

Therefore, to increase the tolerance to the stress of arid area we have recourse to two complementary approaches. The first is through *agronomy* and, of course, in irrigation systems, through overall efficient water management, and the second is through *breeding*. This latter encompasses conventional yield-based breeding, although recognizing the special challenges cause by the large seasonal and annual climatic variability, by trait or marker-assisted breeding and by chromosome or genetic engineering.

Considering first agronomic manipulation, it may be noted in Table 1 (adapted from Cooper et al., 1987) that these can be classified roughly into methods for reducing evaporation either by producing an artificial surface insulation (increasing the resistance in the thermodynamic gradient) or increasing the rate of leaf area growth to minimize the evaporative loss. The second set of interventions seeks to increase the amount of water available for transpiration at critical times in the plant life cycle.

Each of these interventions is discussed in a large literature and deserves detailed analysis. However, it will only be possible in this short paper to allude briefly to two promising, but somewhat unusual initiatives being pursued by CAZS. In Zimbabwe, preliminary on-farm trials on the production of sorghum seedlings, in small village nursery for subsequent transplanting when the rain arrives, is proving beneficial. This method, which can be likened to rice transplanting, allows the crop to take maximum advantage of the rains whose arrival is uncertain and effectively increases the early vigour (rate of leaf development) and earliness of the subsequent crop with consequential advantages in terms of yield, yield security, and management options (Young, unpublished data).

While the potential value of seed priming (pre-wetting) has been known for years in many regions, it has not been widely adopted. Using a "participatory farmer-orientated approach", work by the CAZS in the KRIB-HCO project in India has shown how the social and technical barriers can be overcome.

Increased Transpiration

- Irrigation,
- Rain water harvesting,
- Cultivation to reduce runoff/ increase infiltration, Fallow?,
- Use of varieties with extensive/ root systems.

In the case of chickpea growing on residual soil moisture, the effect can be dramatic (Table 2) (Musa et al., 1999) and there is every likelihood that, by pre-wetting seeds in gypsum slurry or CaCl₂ solution, a significant benefit would accrue in salt-affected areas.

photosynthate (usually as simple sugars) to allow osmotic adjustment under drought conditions. In contrast, in saline conditions, gross osmotic adjustment by Na and Cl accumulation is a general phenomenon and makes a lesser energy demand (Gorham et al., 1985). However, in the latter circumstances, it does not

Table 2. Summary of data from 30 locations on effect of "seed priming" on chickpea performance in the High Barind Tract of Bangladesh, 1998/'99 season.

Variable	Mean Primed	Mean Non-Primed	Increase with Priming ---%---	Probability (Paired T-Test, 2-Tailed)	Significance ¹
Emergence, plants m ⁻²	36.7	30.2	21	1.51E-08	***
Early growth, plant height (cm)	10.5	8.6	22	1.47E-12	***
Plant height at harvest (cm)	36.4	33	10	1.17E-07	***
Diseased plants, no. m ⁻²	1.1	2.0	-45	2.87E-05	***
Pod borer damage, damaged pods, m-2	3.6	4.1	-13	0.366	ns
Unfilled pods plant, m ⁻¹	3.4	4.4	-21	0.1287	ns
Plants at harvest, m ⁻²	30.6	25.0	22	2.56E-07	***
Pods, no. m ⁻²	1493	1074	39	4.09E-05	***
1000-grain mass (g)	117.7	111.3	6	0.0734	ns
Grain yield (t ha ⁻¹)	1.63	1.11	47	1.96E-05	***
Residue yield (t ha ⁻¹)	2.0	1.53	31	2.94	***

¹*** = Significant difference at *f*<0.001; ns = difference not significant.

Complimentary to the adoption of the most advantageous agronomic practice is breeding for enhanced drought tolerance. Table 3 lists some of the more promising traits capable of genetic manipulation and of potential benefit. It should not be expected that these traits are cumulative, nor that each will be relevant to each type of drought. Their possible value must be assessed in the light of local conditions, e.g., soil depth and texture, rainfall pattern and temperature regime (compare Leuschner and Manthe, 1996; Squires and Tow, 1991). Of these, there is no doubt that fitting the life cycle of the crop to the rainfall or water availability pattern is the most important (Bolanos and Edmeades, 1996; Cooper et al., 1987; Loomis, 1983).

necessarily confer salt tolerance, and the high leaf salt loads can themselves be toxic.

Gross osmotic adjustment necessarily involves solute in accumulation in the vacuole; however, there is compelling evidence that high salt concentrations in the cytoplasm/symplasm are damaging. In tolerant plants, this is avoided by the accumulation of compatible solutes, predominantly in cytoplasmic/symplasmic compartment (Wyn-Jones et al., 1977; Wyn-Jones and Gorham, 1983). These solutes also appear not only be to a factor in salt tolerance, but also confer some additional heat or cold tolerances in a number of instances. It is in, my view, important that these related, but distinct phenomena should be clearly distinguished.

Table 3. Genetic manipulations to increase drought tolerance.

• Phenology; duration, early vigour, synchrony • Rooting pattern and depth • Osmotic adjustment; cell wall traits/ solutes • Compatible solutes; betaine/ proline/inositol • Desiccation tolerance	• Photosynthetic/ stomatal control • Osmotin/ dehydrins • Leaf morphology / (induced) waxiness • Stomatal numbers and orientation
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Again, as with the agronomic interventions, each of the traits deserves a detailed analysis, which lies outside the scope of this brief review. I would, however, wish to emphasize a few points. There is good evidence that in certain species, e.g., wheat (Morgan, 1995), sorghum (Ludlow and Biggins, 1987), gross osmotic adjustment can occur and is modestly valuable under moderate drought. This requires the diversion of

Similarly, the ability of some plants, notable resurrection plants (e.g., Gaff et al., 1997) to lose water and dehydrate, while retaining the capacity at the cellular level to re-hydrate and renew vegetative growth, is another distinct phenomenon. In virtually all plants, embryonic tissue is capable of such dehydration and rehydration (c.f. Alamillo et al., 1994), but such a capability in vegetative tissues is rare, e.g., members of

the *Eragrostisaceae*. However, 'resurrection characteristics' could be very useful in situations of intermittent, unpredictable rainfall. At the molecular level, some of these events may be interrelated, but they should not be confused.

We need, in general, a much more careful analysis on the potential advantages conferred by these and other traits in a different agricultural systems, also on the interplay one with another in the context of the growing plant and the reproductive cycle (e.g., Blum and Belhassen, 1996). It is likely that the use of restricted fragment length polymorphism (RFLP) markers will prove useful both in identifying genetic traits related to tolerances (be they directly attributable to a given physiological traits or not) and to breeding strategies for these traits. A good example of this approach is breeding for root characteristics such as rooting patterns, thickness, and penetration. These are known from various studies to be implicated in tolerance in particular conditions, but conventional directed

breeding for these characters is obviously very difficult. In Table 4 and Fig. 1, an example of the use of RFLPs to map rooting traits in this is presented (Price and Tomos, 1997; Price et al., 1999).

In summary, while we are faced with a great array of possible agronomic and genetic manipulations, it is wise to remember that we are working within the physical constraints of the steep thermodynamic gradient. Since we are dependent on transpiration, however efficiently modified, we must not lose sight, in our rush to genetic modification of crop, that great benefits are to be gained by small increases in transpiration and decreases in evaporation. By contrast, small changes in leaf water potential are less likely to give large returns.

Returning to the insight of "Life is organized water", we must emphasize that "water-use efficiency" must be addressed at all levels from the cell to the city if 'dryland development' is to become a reality in a water-limited world.

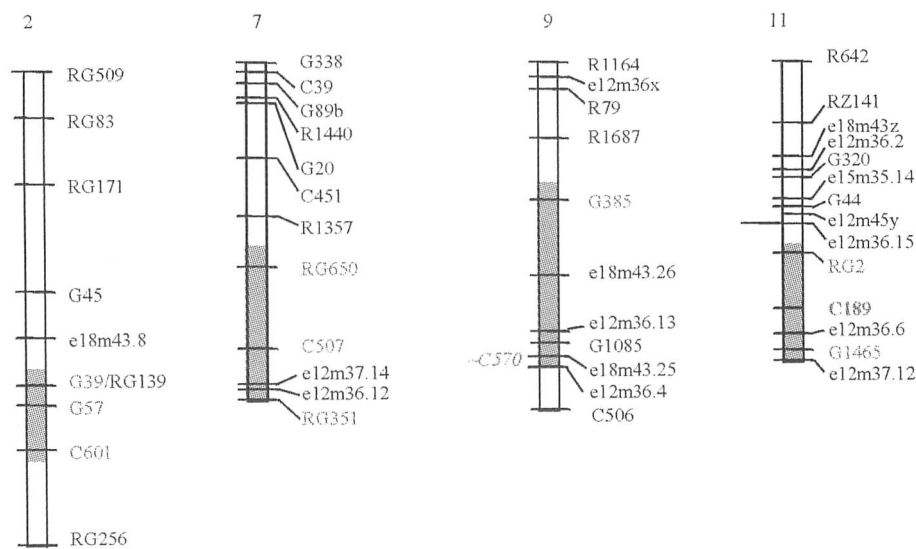


Fig. 1. Marker-assisted selection for root traits.

Note: The current backcrossing program aims to improve the roots of Kalinga III (poor roots) by introducing four roots growth quantative trait locs (QTLs) from Azucena (long, thick roots) through selection of Azucena alleles at restriction fragment length polymorphism (RFLP) markers (chromosome sections highlighted).

Table 4. Quantative trait loci (QTLs) being selected in marker-assisted selection.

Chromosome	QTL effect for root	Nearest Marker	Mapping populations in which QTLs identified
2	Length Thickness Penetration	G39	Co39 × Moroberekan, Azucena × IR64 Bala × Azucena
7	Length Mass	RG650	Azucena × IR64
9	Length Mass	G385	Azucena × IR64
11	Length	C1465	Co39 × Moroberekan Bala × Azucena

REFERENCES

- Alamillo, J.M., et al. 1994. Molecular analysis of desiccation tolerance in barley embryos and in the resurrection plant *Craterostigma plantagineum*. *Agronomic* 14: 161-167
- Bolanos, J., and G.O. Edmeades. 1996. The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. *Field Crops Res.* 48: 65-80
- Blum, A., and E. Belhassen. 1996. Drought tolerance in higher plants, genetical, physiological and molecular biological analysis. *Plant Growth Regulation* 20: 135-148
- Cooper, P.J.M., P.J. Gregory, D. Tully, and H.C. Harris. 1987. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. *Expl. Agric.* 23: 115-158.
- Gaff, D.F., D. Bartels, and J.L. Gaff. 1997. Changes in gene expression during drying in a desiccation tolerant grass *Sporobolus staptianus* and a desiccation sensitive grass *Sporobolus pyranidalis*. *Aust. J. Plant Physiol.* 24: 617-622
- Gorham, J., R.G. Wyn-Jones, and E. McDonnell. 1985. Some mechanisms of salt tolerance in crop plants. *Plant and Soil* 89: 15-40.
- Jones, H.G., and M.B. Jones. 1989. Introduction: some terminology and common mechanisms p. 1-10. In: H.G. Jones, T.J. Flowers, and M.B. Jones (Ed.) *Plants under stress*. SEB Seminar, Series 39. Camb. Univ. Press, Cambridge, UK.
- Leuscher, K., and C.S. Mantha. (Ed.). 1994. Drought-tolerant crops for Southern Africa, p. 1-358. ICRISAT, Patancheru, India.
- Loomis, R.S. 1983. Crop manipulation for efficient water use: An overview. In: *Limitation to Efficient Water Use in Crop Products*. ASA/CSSA/SSSA Madison, USA.
- Ludlow, M.M., and J. Biggins, 1987. Contribution of osmotic adjustment to the maintenance of photosynthesis during water stress. *Progress in Photosynthetic Res.* 4: 161-16
- Ludlow, M.M., J.M. Santamaria, and S. Fukai. 1990. Contribution of osmotic adjustment to grain yield in *Sorghum bicolor* (L.). Moench under water-limited conditions. II. Water stress after anthesis. *Aust. J. Agric. Res.* 41: 67-78
- Morgan, J.M., 1995. Growth and yield of wheat lines with differing osmo-regulative capacity at high soil water deficit in seasons of varying evaporative demand. *Field Crops Res.* 40: 143-152
- Musa, A.M., C. Johansen, J. Kumar, and D. Harris. 1999. Response of chickpea to seed priming in the high Barind tract of Bangladesh. *Int. Chickpea & Pigeonpea Newsletter* 6: 20-22.
- Nobel, P.S., 1974. *Introduction to biophysics and plant physiology*, W.H. Freeman. San Francisco.
- Passioura, J.B., 1977. Grain, yield, harvest index and water use of wheat. *J. Aust. Instit. Agric. Sci.* 43: 117-120
- Price, A.H., and A.D. Tomos. 1997. Genetic dissection of root growth in rice (*Oryza sativa* L.) II: Mapping quantitative trait loci using molecular markers. *Theor. Appl. Genetics* 95: 143-152
- Price, A.H., K.A. Steele, B.J. Moore, P.B. Barraclough, and L.J. Clark. 1999. A combined RFLP, and AFLP linkage map of upland rice (*Oryza sativa* L.) used to identify QTLs for root penetration ability. *Theor. Appl. Genetics*.
- Squires, V., and P. Tow, (Ed.) 1991. *Dryland Farming: A Systems Approach*. Sydney University Press, Melbourne, 306 p.
- Wyn-Jones, R.G., and J. Gorham. 1983. Osmoregulations. p. 35-58. In: *Encyclopedia of Plant Physiology*. Physiological Plant Ecology, Vol. 12 C.O.L. Lange, P.S. Nobel, C.B. Osmond, and H. Ziegler (Ed.), Springer Verlag, Heidelberg.
- Wyn-Jones, R.G., and J. Pritchard. 1989. Stresses, membranes and cell walls. p. 95-114. In: H.G. Jones, T.J. Flowers, and M.B. Jones (Ed.) *Plants under Stress*. SEB Seminar Series 39. Camb. Univ. Press, Cambridge, UK.
- Wyn-Jones, R.G., and A. Pollard. 1983. Proteins, enzymes and inorganic ions. p. 528-562. In: A. Lanehli, and R.L. Bielski (Ed.) *Encyclopedia of Plant Physiology*, Vol. 15. Inorganic Plant Nutrition. Springer Verlag, Heidelberg.
- Wyn-Jones, R.G., R. Storey, R.A. Leigh, N. Ahmad, and A. Pollard. 1977. A hypothesis on cytoplasmic osmo-regulation. p. 121-136. In: E. More and O. Ciferi (Ed.). *Regulation of Cell Membrane Activity in Plants*. North Holland, Amsterdam.

Biotechnology: from Laboratory to Market Place

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EXTENDED ABSTRACT

In biotechnology, the private sector has access to technology, has invested considerable sums in the research and development of the technology, and has the necessary ancillary expertise to bring a product to the marketplace. The competitive edge of a private company depends upon the proprietary nature of its research and development and the protection offered by intellectual property laws.

A private company might engage in development of a product in conjunction with a developing country because it addresses a technical problem critical to its own product development; it presents an opportunity to enhance its public relations, and it provides a window to an important market, technology or germplasm of interest.

Developing-country institutions may be interested in working with private companies to gain access to important technology, develop managerial and business expertise, build intellectual capacity, or form a partnership with an entity that has an existing capability of bringing a product to market.

The Egyptian agricultural sector is in the process of major change. The Government of Egypt is moving towards privatization. Transfer of technology to the private sector has occurred in the case of *in vitro* micro-propagation of virus-free potato technology. This shows the capacity and interest of the private sector to adopt new technology; this aspect of technology transfer is expected to grow dramatically in the current phase as the research program of the Agricultural Genetic Engineering Research Institute (AGERI) becomes more product-oriented.

The relationship between AGERI, an Egyptian public sector institution, and Pioneer, a US private company, was forged through a relationship that involved common business interests. The importance of co-development of technology, as opposed to technology transfer, is especially pertinent in the case of Pioneer's relationship with AGERI. In this collaboration, a public-sector institution was able to bring a significant contribution to the table. AGERI has isolated a number of strains of *Bacillus thuringiensis* that had pesticidal activity of interest to a private-sector company. AGERI has also a state-of-the-art biosafety facility and a cadre of trained scientists. Finally, AGERI could provide access to the local Egyptian market and the broader Middle East market, both of which were sufficiently developed to be attractive. In turn, Pioneer came to the table with technology as well as with marketing, regulatory and legal expertise of value to AGERI.

In this context, AGERI has initiated collaboration with Pioneer through a USAID research and development grant to achieve the following objectives:

1. Research and training for four AGERI scientists to be trained at Pioneer/Iowa in methodologies relating to agricultural biotechnology.
2. Potential for product development and in this context Pioneer was granted access to evaluate certain novel Bt proteins and genes patented by AGERI.

Four parties have signed this agreement, namely, Pioneer-USA, AGERI-Egypt, ABSP/MSU-USA, and USAID-Cairo/Washington D.C. Both collaborators, Pioneer and AGERI, have their inputs to training collaboration. Pioneer's inputs are:

- Insect bioassay protocols and field evaluation/scoring of natural and transgenic, insect-resistant maize.
- Bt-receptor binding methodologies.
- Maize transformation technology with Bt-genes to establish comparable research on Egyptian maize lines.
- Methods for molecular/protein characterization of transgenic maize to develop a program to introgress Bt-genes into maize lines appropriate for Egyptian agricultural environments.

AGERI's inputs to training collaboration are:

- Proprietary Bt. strains, genes and toxins, including a unique Bt strain
- Support from the USAID funding program.

All joint discoveries resulting from the work are to be shared and patent rights will be sought according to terms of the USAID agreement. Pioneer will retain sole ownership of its proprietary Bt-gene(s) and proprietary germplasm, and AGERI will retain sole ownership of its proprietary Bt-gene(s).

Under separate agreement(s), AGERI shall grant Materials Transfer Agreement for Pioneer to evaluate the Bt toxin protein. AGERI shall also grant the option to Pioneer for possible commercial development using the proprietary Bt-gene to develop insect-resistant transgenic maize and to other novel Bt proteins and genes from AGERI identified as a result of this training.

A second model of moving research into commercial application is elaborated through the successful interaction between scientists at AGERI and the University of Wyoming who have been involved in collaborative research studies for the past six years on *Bacillus thuringiensis* (Bt). The research efforts led to

the development of a biological pesticide based on a highly potent strain of Bt isolated in the Nile Delta. This strain is extremely effective against a broad range of insects represented by the orders *Lepidoptera* (moths), *Coleoptera* (beetles), and *Diptera* (mosquitoes) as well. An additional significant feature of this strain is its capacity to kill nematodes.

AGERI has successfully managed to manufacture its first bio-pesticide AGERIN, based on the insecticidal bacterium *Bacillus thuringiensis*. AGERIN is capable of protecting a broad range of important agricultural commodities, and of controlling a number of biomedically significant pests, and has the potential for sales on a worldwide scale.

In order to fulfill its commitment to bring research results into application and large-scale commercial distribution to the targeted end-users, namely the farmers, AGERI established a commercial business entity under the name "BIOGRO". This company would be responsible for the commercialization of research results conducted in AGERI and will be in a position to sell products of AGERI. This is essential to guarantee that sales revenue will be pumped back to the institute to support the constitution of its activities.

It is envisaged that BIOGRO would link with The Genetic Engineering Services Unit (GESU), which was established earlier at AGERI to work out any commer-

cial agreements to benefit both the institute and BIOGRO. It will also allow for a free flow of information and products related to genetic engineering being produced by the institute for commercialization purposes.

AGERI attaches a high priority to collaborating with the private sector, which will be fully informed of research and development in the field of genetic engineering and biotechnology in Egypt through the circulation of newsletters and reports, inviting representatives of the private sector to workshops and seminars, also through the participation of the private sector in the design of product research and development, and the representation of the private sector in the governing board of AGERI.

As one of the leading institutions in the field of agricultural genetic engineering in the regions of West Asia, North Africa, and the Middle East, AGERI is planning to share their "know-how" and experience with other countries within the framework of Technical Cooperation among Developing Countries (TCDC). This will be achieved through the organization of specialized workshops, seminars, and internships. Moreover, the institute can provide professional consultation in the field of molecular biology and agricultural genetic engineering.

Dryland Degradation by Wind Erosion and Potential Control

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ABSTRACT

Global population growth is expected to put an increasing pressure on agricultural production in the world's drylands, which cover approximately 41% of the continental area. Drylands are characterized by low and variable rainfall, chemically poor soils, low-productive agricultural systems, and large-scale soil degradation. Wind erosion is the main soil degradation process on drylands. It causes sedimentation at undesired places, crop damage by sand blasting and burial, deterioration of soil structure, and a loss of soil fertility. In many arid and semi-arid drylands, adequate wind erosion control is currently not achieved due to low crop biomass production and management constraints. A potential solution is to make use of the natural dryland vegetation of scattered trees and shrubs. This aspect has not received much scientific attention, but an agricultural development project in Niger, West Africa, has proven that management of natural vegetation can provide sufficient wind erosion control.

INTRODUCTION

Worldwide population growth has resulted in an increasing demand for food, fiber, fodder, and firewood. From the beginning of agriculture until approximately 1950, increased agricultural production resulted almost entirely from an expanded cropland base. Since 1950, however, the yield per unit of land area for major crops has increased dramatically (Stewart and Robinson, 1997). The main reasons for the higher production are mechanization, large-scale fertilizer application, control of pests and diseases, expansion of the irrigated area, and development of high-yielding crop varieties.

The improved agricultural practices are particularly applied on land with favorable topography, soils, and climate. On marginal land, increases in production per unit land area have been significantly lower, and sometimes even negative. For instance, increased food production in semi-arid West Africa during the past decades has mainly come from expansion of the cropland area into more marginal land. At the same time, the fallow periods have become too short to allow natural restoration of soil productivity. As a consequence, yields per unit land area have declined (Klaij and Hoogmoed, 1989). Apparently, West African farmers

have not adopted the production-stimulating practices that have been so successful in other regions.

There are few areas left with favorable environments for further development of high-productivity agriculture; especially the expansion of irrigated land is expected to be small in the near future. Hence, future increases in agricultural production will more and more rely on rainfed crop production on marginal land. This is especially true for the world's drylands, which cover many of the developing countries where population growth rates are the highest in the world (Rozanov, 1994). Drylands are defined by UNEP (1991) as those lands that have a precipitation over potential evapotranspiration ratio of less than 0.65. They can be sub-divided into hyper-arid, arid, semi-arid, and dry sub-humid lands. Drylands cover approximately 41% of the continental land area. Two-thirds of the drylands are in Africa and Asia (Table 1).

The arid, semi-arid, and dry sub-humid drylands are inhabited and exploited for agricultural production. General characteristics of these drylands are insufficient precipitation, low soil fertility, and a rapid loss of arable land to soil degradation (Stewart and Robinson, 1997). Dregne et al. (1991) estimated that 154 million ha (2.5%) of the world's drylands is irrigated cropland, 458 million ha (7.4%) is rainfed cropland, and 4546 million ha (74%) is used as rangeland. It was also estimated that 70% of all agriculturally used dryland is subject to some degree of degradation. Irrigated land is affected by waterlogging, salinization, and alkalization. Rainfed cropland is degraded by wind erosion, water erosion, soil nutrient depletion, and physical deterioration. Rangelands are affected by degradation of vegetation and, to a lesser extent, by wind and water erosion (Dregne et al., 1991).

According to the Global Assessment of Soil Degradation (GLASOD) map (Oldeman, 1994); wind erosion is the most important soil degradation process on drylands, closely followed by water erosion (Table 2). Chemical degradation is the third soil degradation process that mainly affects the irrigated area. Of least importance in drylands is physical soil degradation. Dryland degradation by wind erosion occurs mainly in the non-irrigated arid and semi-arid agricultural lands. The aim of this paper is to give an overview of wind erosion processes in those areas, and to evaluate the potentials for wind erosion control.

Table 1. Distribution of the world's drylands.

Dryland Type	Africa	Asia	Australia	Europe	North America	South America	World Total
	Million ha						
Hyper-arid	672	277	0	0	3	26	978
Arid	504	626	303	11	82	45	1,571
Semi-arid	514	693	309	105	419	265	2,305
Dry sub-humid	269	353	51	184	232	207	1,296
Total	1,959	1,949	663	300	736	543	6,150
% World total	32	32	11	5	12	8	100
% Total global land area	13.1	13.0	4.4	2.0	4.9	3.6	41.0

Source: UNEP (1991).

Table 2. Global and continental extent of water and wind erosion.

Continent	Water			Wind		
	Total	Dryland Zone	Humid Zone	Total	Dryland Zone	Humid Zone
	Million ha					
Africa	227	122	105	186	186	1
Asia	441	165	276	222	206	16
Australia	83	70	13	16	16	0
Europe	114	48	66	42	39	3
N. America	106	38	68	40	38	1
S. America	123	35	88	42	28	14
World	1094	478	615	548	513	36

Source: Oldeman (1994).

WIND EROSION PROCESSES

Wind erosion can become a problem whenever the soil is dry, loose and finely granulated, the surface is bare or nearly bare, the wind velocity regularly exceeds the threshold for initiation of soil particle movement, and the susceptible area is sufficiently large (Fryrear and Skidmore, 1985; Lyles, 1988). By definition, wind erosion is the removal of soil material, whereas sedimentation is the deposition of wind-blown material. Between erosion and sedimentation, the material is transported by three different transport processes: *saltation*, *creep*, and *suspension* (Fig. 1).

Saltating particles jump and bounce over the surface, reaching a maximum height of approximately 1 m, but the main particle mass moves just above the soil surface. Saltation transports soil particles with sizes roughly between 50 and 500 µm. When saltating particles fall to the soil surface, they not only eject other saltation-size particles but also induce creep, rolling and sliding of larger particles (>500 µm), and suspension, and raising and transport of dust particles (<100 µm). The overlap in diameters for suspension and saltation indicates that certain particles may be moved by different transport modes, depending on particle density and wind speed.

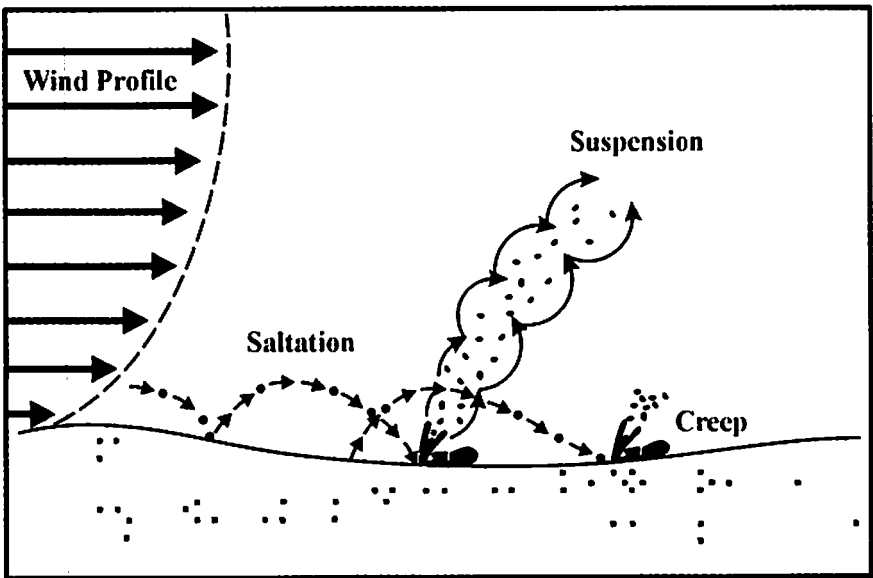


Fig. 1. Three processes of wind-blown particle transport.

The three transport processes move particles over a wide range of distances. During a storm, creep can move particles over distances from a few centimeters to several meters, saltating particles travel from a few meters to a few hundred meters, and suspension transport ranges from several tens of meters to thousands of kilometers (Stern, 1998).

Wind-blown particle transport is characterized by a large temporal and spatial variability. At a certain location, the number of storms differs from year to year, and during a particular year, storms are different in duration, wind speed, and wind direction. This results in a wide range of particle mass fluxes. Moreover, soil erodibility is determined by several variables like soil texture, surface roughness, and topography. These variables usually show spatial variability, resulting in spatial variability in soil erodibility and thus in particle mass fluxes as well. This spatial and temporal variability makes quantification of wind erosion a difficult task (Stern and Stein, 1997).

Measurement techniques of wind-blown particle transport can roughly be divided into direct and indirect techniques, and are scale-dependent (Stern, 1998). Indirect techniques, such as repeatedly measuring soil surface elevation (e.g., Wilson and Cooke, 1980), do not quantify soil particle transport itself, but determine the erosion or sedimentation rate from changes in soil surface elevation. This technique gives point observations with a temporal resolution varying from days to several decades. Other indirect techniques that work at larger spatial scales and at similar or larger temporal scales are the use of remote sensing, for instance for tracing sand and dust movement in the Saharan desert (e.g., Mainguet, 1984), and the description of wind erosion features in geomorphological studies. Direct measurement techniques sample fluxes of wind-blown particles at a fixed position. Erosion and sedimentation in a certain area can only be determined from the spatial distribution of a number of these transport observations by calculating a sediment balance, which is the mass balance between input and output of soil particles (Mainguet, 1996).

Wind erosion may cause three types of agricultural damage: *sedimentation at undesired places*, *crop damage*, and *soil degradation*. Sedimentation of wind-blown material may cause dune formation within or at some distance from the source area, may fill drainage ditches, irrigation canals, and can cause blockage of roads. Crop damage is caused when seedlings suffer from abrasion and burial in sand during storms. Abrasion, or sand blasting, damages plants by the scouring effect of saltating sand particles. Young plants buried during storms suffer afterwards from the weight of the sand, reduced sunlight interception, and high soil temperatures during daytime. The damage ranges from reduced growth and development to total destruction of crops (Michels et al., 1995).

Soil degradation is caused by the loss of topsoil, which has an impact on the physical and chemical

properties of the soil. The selective removal of fine particles, characteristic for wind erosion, results in a deterioration of soil structure. The texture of an actively eroding soil becomes progressively coarser, which negatively affects structure stability and water-holding capacity. The chemical soil properties are affected because most plant-available nutrients are located in the top few centimeters of the soil and wind erosion preferentially removes the organic matter and clay which hold these nutrients (Lal, 1988).

Creep, saltation, and suspension transport have different impacts on soil productivity. Creep particles are large and do not contain nutrients. Hence, creep transport does not affect soil fertility. Saltation particles contain nutrients at a low concentration, while suspension material is relatively rich in nutrients (Stern et al., 1996). Saltation transports material over limited distances, from unprotected sources towards protected sinks. For instance, a site with a dense vegetation cover traps saltation material coming from surrounding source areas, like arable fields. So, the fertility status of the vegetated site is improved at the expense of decreasing soil productivity in unprotected, upwind areas. This process can also occur on a smaller scale. Individual obstacles in a field, like a tree or a shrub traps wind-blown material from nearby sources. The resulting micro-dune formed by wind deposits are known to farmers as having the best productivity after the shrubs have been cut down (Stern and Haigis, 1998).

Suspended dust raised from a field may be carried over long distances, resulting in a loss of fine particles and nutrients, and thus enhancing regional soil degradation. Several observations of dust from West Africa crossing the Atlantic were reported in the literature (e.g., Westphal et al., 1988). Prospero and Carlson (1972) estimated that between 25 and 37 million tons of wind-blown dust cross the Atlantic annually, with even greater amounts presumably deposited in the ocean (Lal, 1988).

WIND EROSION CONTROL

The negative impact of wind erosion on dryland cropping systems can be prevented by applying soil conservation measures. Wind erosion is most effectively controlled by reducing the wind velocity at the soil surface or by creating sufficient resistance of the soil surface to wind forces. The available methods that have been extensively tested involve roughening of the soil surface, maintaining soil cover, or using wind barriers (Tibke, 1988). For maximum effectiveness, the optimum wind erosion control system uses a combination of all control methods. While one method may provide better control under one set of soil-crop-weather conditions, a different method may be required during drought periods (Fryrear, 1993).

Soil roughening can be achieved by appropriate tillage operations that leave a sufficient quantity of non-erodible soil aggregates at the surface. Loose,

erodible particles may be moved by a strong wind, but will be quickly trapped in the lee of the stable aggregates. Thus, soil movement will stop and erosion is controlled. The same can be achieved by creating ridges at the surface which are perpendicular to the prevailing erosive wind direction.

Generally, the sandier a soil the more fragile the aggregates, and the less effective soil roughening will be. If tillage is used to control wind erosion the soil must be tilled again whenever the previous non-erodible aggregates or ridges are destroyed by rain or weathering (Fryrear, 1993).

Several measures exist to maintain sufficient soil cover for wind erosion control. Leaving post-harvest crop residue as flat mulch on the soil surface is an easy applicable and widely applied technique. However, leaving the same quantity of residue standing at the soil surface is much more effective in reducing wind erosion (Siddoway et al., 1965). The soil cover required depends on soil texture; a sandy soil is more erodible and therefore requires a better soil cover than loam and clay soils. A slightly different technique for maintaining soil cover is a cover crop. Cover crops are usually planted when protective residues are inadequate and wind speeds outside the cropping season are high (Tibke, 1988).

Wind barriers consist of trees or crops planted in a strip perpendicular to the prevailing erosive wind direction. They effectively reduce wind velocity downwind of the barrier. The reduction in wind velocity depends on the porosity and the height of the barrier. For most design purposes, the protected zone is assumed to be ten times the height of the barrier. The actual protected zone depends on the velocity of the approaching wind and the erodibility of the soil. The higher the wind velocity and the more erodible the soil, the smaller the protected zone (Fryrear, 1993).

Many of the wind erosion control methods described here are successfully applied in the US. But the adoption by dryland farmers from developing countries has been much less for several reasons that are related to the small scale and the low productivity of their farming systems. Roughening of the surface by tillage is not always possible as not all small-scale farmers possess tillage implements and a tractor or animal traction. In addition, in areas where the wind erosion problem is most severe, soils are usually sandy and thus the effect of tillage will be limited.

Mulching with post-harvest crop residues, either standing or flat, is without doubt the most widely applied soil conservation measure in drylands. However, this method is limited by the mulch quantity available for soil conservation purposes. In general, biomass production in arid and semi-arid regions is low, and the residue is needed for other purposes, like fuel, fodder and construction. Cover crops are often not practical because they compete for nutrients and soil moisture, which is also true for living wind barriers of trees or crops.

Other problems with establishing effective wind barriers are the often irregular fields, the variable wind directions during storms, and management constraints. In short, adequate wind erosion control in many arid and semi-arid drylands is currently not achieved due to low biomass production and management constraints. Therefore, an urgent need exists to explore other potential wind erosion control methods.

NATURAL VEGETATION

One aspect that has largely been neglected in wind erosion research is the soil protection created by natural vegetation of scattered trees and shrubs, which is characteristic for many arid and semi-arid drylands. Farmers from seven villages in Niger, West Africa, mentioned the potential role of the natural vegetation in wind erosion control (Sterk and Haigis, 1998). Unfortunately, much of it has been destroyed for construction material, firewood, expansion of the cropped area, and by overgrazing. In addition, the increasing need for food production has caused a decline of the area of well-vegetated bush fallow, which traditionally is applied to restore soil productivity after several years of crop production.

In an agricultural development project in south-central Niger, natural woody vegetation was regenerated and incorporated into the farming systems. The developed strategy was successful in reducing wind erosion, but was largely based on time-consuming "trial and error" research which lasted more than 10 years (Rinaudo, 1996). Therefore, research is needed to evaluate the potential wind erosion control by natural vegetation of scattered trees and shrubs, and to develop management strategies.

In general, vegetation shelters the soil from the erosive force of the wind by covering a proportion of the surface, it reduces the shear force near the ground by extracting momentum from the wind above the surface, and traps soil particles in transport, thereby acting as a catchment for sediment deposition (Fig. 2). Successful exploitation of soil protection properties of natural vegetation in drylands requires a thorough understanding of the effects of vegetation on wind speed and soil erosion. So far, quantitative knowledge is limited on the impact of scattered vegetation on near-surface wind speeds at spatial scales ranging from the flow around an individual obstacle to the flow over a more or less homogeneous but sparsely vegetated area (Kainkwa and Stigter, 1994).

Currently, the main source of information is scientific papers describing wind tunnel experiments with low densities of flow-disturbing obstacles (roughness elements). These studies are not easily translated to natural conditions for the following reasons: (i) the roughness elements are usually of a more simple geometric nature as compared with vegetation, and (ii) the flow conditions in wind tunnels are homogeneous and less turbulent than in the field.

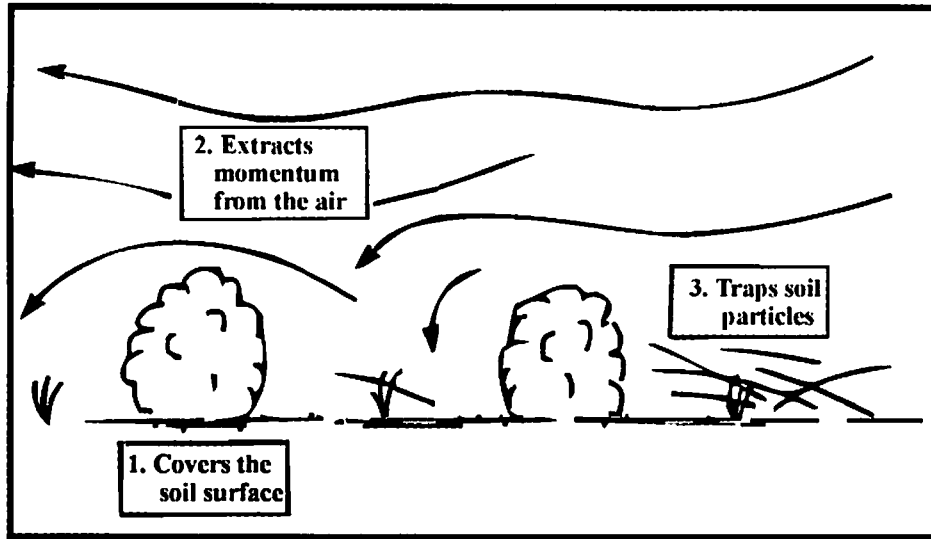


Fig. 2. The stabilizing role of vegetation (Wolfe and Nickling, 1993).

Finally, it is unknown how much vegetation cover is needed for adequate soil protection (Wolfe and Nickling, 1996). The latter is very much dependent on the spatial scale that is considered. At the scale of a certain arable field without any vegetation other than a crop, wind erosion may cause severe losses of soil particles, organic matter, and nutrients. But a field with a dense vegetation cover, e.g., when under bush fallow, protects the soil against erosion and can trap sediments that are eroded from unprotected fields. This means that when a scale larger than the field scale is considered, there may be enough protection to keep the mass balance between wind-eroded and wind-deposited materials close to zero at that scale.

CONCLUSIONS

Agricultural development in the world's drylands is severely constrained by soil degradation. Wind erosion is the main degradation process in drylands, closely followed by water erosion. Adequate wind erosion control is currently not achieved in many drylands because crop biomass production is too low for sufficient quantities of mulch, management constraints, or the measures introduce competition for water and nutrients with crops. A potential solution for better wind erosion control in drylands is by making use of the protective properties of scattered trees and shrubs. An agricultural development project in the Sahel has proven that it is possible to protect the soil from damaging winds by management of natural vegetation. But, basic knowledge of the effects of this vegetation on wind speed and sediment transport is lacking. Therefore, research of the protective properties is needed to develop vegetation management strategies that can provide adequate wind erosion control in drylands.

REFERENCES

Dregne, H.E., M. Kassas, and B. Rosanov. 1991. A new assessment of the world status of desertifica-

- tion. *Desertification Control Bull.* 20: 6-18.
- Fryrear, D.W. 1993. Parameters of wind erosion. p. 347-348, 351 *In* McGraw-Hill *Yearbook of Science and Technology*. McGraw-Hill, New York.
- Fryrear, D.W., and E.L. Skidmore. 1985. Methods for controlling wind erosion. p. 443-457. *In* R.F. Follet and B.A. Stewart (Ed.) *Soil erosion and crop productivity*. ASA - CSSA - SSSA, Madison, WI.
- Kainkwa, R.M.R., and C.J. Stigter. 1994. Wind reduction downwind from a savanna woodland edge. *Netherlands J. Agric. Sci.* 42: 145-157.
- Klaij, M.C., and W.B. Hoogmoed. 1989. Crop response to tillage practices in a Sahelian soil. p. 265-275 *In*: Soil, crop, and water management in the Sudano-Sahelian zone. *Proc. Int. Workshop*, Niamey, Niger. 11-16 Jan. 1987. ICRISAT, Patancheru, India.
- Lal, R. 1988. Soil degradation and the future of agriculture in sub-Saharan Africa. *J. Soil Water Conserv.* 43: 444-451.
- Lyles, L. 1988. Basic wind erosion processes. *Agric. Ecosystems Environ.* 22/23: 91-101.
- Mainguet, M. 1984. Space observations of Saharan aeolian dynamics. p. 59-77 *In* F. El-Baz (Ed.) *Deserts and arid lands*. Martinus Nijhoff, The Hague, The Netherlands.
- Mainguet, M. 1996. The Saharo-Sahelian global wind action system: One facet of wind erosion analyzed at a synoptic scale. p. 7-22. *In* B. Buerkert et al. (Ed.) *Wind Erosion in West Africa: The Problem and its Control*. *Proc. Int. Symposium*, 5-7 Dec. 1994, Stuttgart, Margraf Verlag, Weikersheim, Germany.
- Michels, K., M.V.K. Sivakumar, and B.E. Allison. 1995. Wind erosion control using crop residue II. Effects on millet establishment and yields. *Field Crops Res.* 40: 111-118.
- Oldeman, L.R. 1994. Global extent of soil degradation. p. 99-118. *In* D.J. Greenland and I. Szabolcs (Ed.) *Soil resilience and sustainable land use*. CAB International, Wallingford, UK.

- Prospero, J., and T. Carlson. 1972. Vertical and aerial distribution of Saharan dust over the western equatorial North Atlantic Ocean. *J. Geophys. Res.* 77: 5225-5265.
- Rinaudo, T. 1996. Tailoring wind erosion control methods to farmers' specific needs. p. 161-171. In B. Buerkert et al. (Ed.) *Wind Erosion in West Africa: The Problem and its Control. Proc. Int. Symp.*, 5-7 Dec. 1994, Stuttgart, Germany. Margraf Verlag, Weikersheim, Germany.
- Rozanov, B.G. 1994. Constraints in managing soils for sustainable land use in drylands. p. 145-153. In D.J. Greenland and I. Szabolcs (Ed.) *Soil resilience and sustainable land use*. CAB International, Wallingford, UK.
- Siddoway, F.H., W.S. Chepil, and D.V. Armbrust. 1965. Effect of kind, amount, and placement of residue on wind erosion control. *Trans. ASAE* 8: 327-331.
- Sterk, G. 1998. Quantification of aeolian sediment balances from soil particle transport measurements. p. 155-171. In M.V.K. Sivakumar et al. (Ed.) *Wind erosion in Africa and West Asia: Problems and control strategies. Proc. of the Expert Group Meeting*, 22-25 April 1997, Cairo, Egypt. ICARDA, Aleppo, Syria.
- Sterk, G., and J. Haigis. 1998. Farmers' knowledge of wind erosion processes and control methods in Niger. *Land Degradation Develop.* 9: 107-114.
- Sterk, G., L. Herrmann, and A. Bationo. 1996. Wind-blown nutrient transport and soil productivity changes in southwest Niger. *Land Degradation Develop.* 7: 325-335.
- Sterk, G., and P.A.C. Raats. 1996. Comparison of models describing the vertical distribution of wind-eroded sediment. *Soil Sci. Soc. Am. J.* 60: 1914-1919.
- Sterk, G. and A. Stein. 1997. Mapping wind-blown mass transport by modeling variability in space and time. *Soil Sci. Soc. Am. J.* 61: 232-239.
- Stewart, B.A., and C.A. Robinson. 1997. Are agroecosystems sustainable in semiarid regions? *Adv. Agron.* 60: 191-228.
- Tibke, G. 1988. Basic principles of wind erosion control. *Agric. Ecosystems Environ.* 22/23: 103-122.
- UNEP, 1991. Status of desertification and implementation of the United Nations plan of action to combat desertification. UNEP, Nairobi, Kenya.
- Westphal, D.L., O.B. Toon, and T.N. Carlson. 1988. A case study of mobilization and transport of Saharan dust. *J. Atmos. Sci.* 45: 2145-2175.
- Wilson, S.J., and R.U. Cooke. 1980. Wind erosion. p. 217-251. In M.J. Kirkby and R.P.C. Morgan (Ed.) *Soil erosion*. Wiley, Chichester, UK.
- Wolfe, S.A., and W.G. Nickling. 1996. Shear stress partitioning in sparsely vegetated desert canopies. *Earth Surface Processes and Landforms* 21: 607-619.

A Dream Comes True

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ABSTRACT

In my inaugural address at the first International Desert Development Conference held in September 1978, i.e., 21 years ago, I stated that I have a dream! The dream amounted to establishing a Desert Development Center (DDC) at the American University in Cairo (AUC) based on the integrated approach which requires coordinated efforts in many disciplines related to the natural resources, and technological and community aspects appropriate for the specific desert area. The philosophy of DDC was based on treating a desert as a desert (no silt or manure from other areas is added) and achieving a balance of indigenous methods with the modern technology. The center also stipulates that the desert research and development programs should be: a) *technologically feasible*, b) *economically viable*, c) *socially acceptable*, d) *environmentally sustainable*, and e) *replicable*.

The paper summarizes the achievements of DDC over the last 21 years in the areas of desert agriculture, desert technology, desert architecture, renewable energy, and desert communities. Training of owners of desert farms who have common problems and common aspirations culminated in the establishment of a Non - Governmental Organization (NGO) called "Friends of Environment and Development Association (FEDA)". Also, training of large numbers of university graduates who have been allocated small plots of land by the government was initiated in 1993, and is still active.

Since 1990, the DDC adopted the concept of *sustainable desert development* in which a balance should be reached between economic and social development, resource management, and environmental protection. With the achievement of the integrated and sustainable desert development pilot projects at the DDC sites, the dream of 1978 is finally realized. It is hoped that this experience would be replicated at the gigantic new projects recently initiated by the Government of Egypt at Toshka and East Owinat.

INTRODUCTION

The first International Desert Development Conference on "Application of Science and Technology for Desert Development" organized by the American University in Cairo (AUC), was held on 9-15 September 1978. In his inaugural address, the Chairman of the Conference, Dr. Adli Bishay, stated that he has a dream; namely, to initiate a desert development program at AUC. As a result

of the recommendations of the conference, the "Desert Development Demonstration and Training Project" was officially initiated in January, 1979, by the President of the AUC, after the approval of its Board of Trustees.

The concept of this new AUC activity was based on the establishment of a demonstration project in a newly reclaimed desert area, with various approaches and alternatives to development of integrated desert communities. The ultimate goal was to establish different patterns of desert development as alternatives of what could be done in larger scale programs for development of other desert areas by the Egyptian Government or the private sector. The project linked application of existing knowledge, research, and educational aspects to serve as a training ground for students and visiting scientists from Egypt and other countries.

The demonstration and training project was primarily concerned with arid-lands technologies appropriate for Egypt's climate, physical, human, and capital resources, its environmental concern and its socio-economic and traditional patterns.

The program emphasis was on arid land agriculture where water supply is the limiting factor. Optimum land and water resources management was a major goal. Also, the uses of underground water as a source for irrigation and problems of salinization of such sources were emphasized.

The program was also directed at the establishment of small-scale agriculturally based industries. The program also included the production of solar, wind and biomass energy for rural communities, and the most appropriate designs of energy efficient low-cost housing for hot, arid environments. Raw material resources were studied, particularly to determine the suitability of indigenous materials for construction and other development activities.

Desert communities, based on alternative patterns of development, particularly those concerning agricultural and water use practices, were established in an integrated rural development context. Social science research was conducted in synergy with technical research to identify and ensure a productive, viable lifestyle during the development of these communities.

In order to aid the University in implementing this project, the Government of Egypt, through the Ministry of Land Reclamation, has allocated 500 feddans in the "Al Intelag" area of South Tahrir province. This area became the center for testing, training and applying research and alternative approaches for desert development. In order to encourage immediate implementation of this project, the Ministry of Development and New Communities granted the University \$50,000 towards

the construction of the project's first building facility at Sadat City, on an area of 25 feddans, for demonstration of passive solar architecture, solar and wind energy applications, as well as modern technologies in the area of desert agriculture and research.

In all the areas of activity conducted at the two above-mentioned sites, the primary concern of AUC and cooperating agencies was to ensure that an interdisciplinary approach is affected in real terms. This means that every activity was conducted under the immediate supervision, monitoring, study and evaluation of a group of persons representing all disciplines involved in the activity (Physical and Social Sciences, Agriculture, Engineering, Management, Economics, etc.). It was the expressed commitment of AUC and the group of local and foreign experts and interested persons involved in this project to see that the interdisciplinary group works efficiently and cooperatively in connection with each activity and with a view of the overall program.

In the field of agriculture, AUC, which does not have a Faculty of Agriculture, has established cooperation with national universities and research institutions as well as international institutions, with the goal of providing research, training and demonstration of arid land agriculture in an interdisciplinary program not available in any local institution.

In recognition of its accomplishments, expansion and potential, the AUC Desert Development Demonstration and Training Project was elevated in 1985 to the level of an independent unit within the University and renamed the "Desert Development Center (DDC)". The Center conducts applied research based on its theme of an integrated approach and emphasizes demonstration and training in desert development.

This paper will discuss the philosophy, goals, and objectives, as well as major activities of DDC over the last 20 years. The successful performance of the Center over this period and its potential for continuing its successful applied research and training activities for the years to come is a confirmation of its sustainability. In other words, *the 1978 dream has been realized.*

DESERT DEVELOPMENT CENTER PHILOSOPHY

The Center's philosophy is simple: a) Treat a desert as a desert; b) Achieve a balance of indigenous methods with modern technology; c) R&D programs should be: Technologically feasible, Economically viable, Socially acceptable, Environmentally sustainable, and Replicable; and d) Adopt on "Integrated Approach".

DESERT DEVELOPMENT CENTER'S GOALS AND OBJECTIVES

The Desert Development Center of AUC undertakes applied research into alternative, economically viable, integrated approaches to arid land agriculture and

community development. This desert development systems approach covers: a) biological aspects, including appropriate drought-resistant varieties, cropping systems, livestock, and desert soil development; b) technological aspects, including agricultural technology, irrigation, water management, agri-industry, renewable energy technologies, materials technology and passive solar architecture; and c) community aspects, including infrastructure, socio-economics, management, aesthetics and desert housing.

While the DDC has been working with farmers settled in desert lands reclaimed over the last 30 years, the Center's ultimate goal is to demonstrate alternative patterns, which others can replicate for the establishment of viable desert communities in Egypt. Such communities should offer a quality of life attractive enough to encourage migration of families from the overcrowded cities and villages to desert areas.

In order to achieve these goals, the DDC has been searching for technologies appropriate for desert agriculture where water and nutrients are scarce and energy is expensive. To achieve this objective, it is necessary to:

- Monitor, assess, and demonstrate alternative desert farming systems for improvement of productivity of desert soils based on variable technical and socio-economic concepts. Examples are: a) crop rotation/tillage practices/sheep/multi-purpose trees, b) horticulture/fodder/livestock system, and c) fodder/livestock/biogas system. One element common to all these systems is proper water and soil management. Different irrigation systems have been evaluated. The optimum irrigation frequency and total amount of water required by different crops at different times have also been determined.
- Experiment with, demonstrate, and evaluate appropriate non-conventional techniques. This covers: a) controlled environment agricultural techniques; b) soilless agriculture, e.g., nutrient film technique (NFT); and c) the tissue culture technique for propagation of desert and salt-tolerant plants.
- Test, select, and/or adapt appropriate: a) fruit rootstock/variety combinations (e.g., citrus, avocado and apples), b) vegetable crops with high economic return, c) salt tolerant crops for food and fodder, d) indigenous fodder species with potential for domestication and incorporation in some farming systems, e) medicinal and aromatic plants for domestic applications and for export, and f) certain exotic plants with potential for industrial applications, e.g., jojoba, guayule.
- Initiate pilot agri-business projects such as: a) dairy processing, b) seedling production (e.g., Casuarina, Eucalyptus, Acacia), c) seed produc-

tion (e.g., alfalfa), d) oil and resin extraction, and e) appropriate handling/storage/processing/packing techniques for crops, dairy products and other commodities produced under desert environments.

In order to harness renewable energy resources abundant in the desert and developing technologies appropriate for desert environments, it is necessary to:

- Conduct applied research and field-testing on solar photovoltaic, solar thermal, biogas, and wind energy systems, as well as on passive solar architecture.
- Monitor, assess, and demonstrate the above-mentioned renewable energy sources and combine two or more of these technologies into a hybrid system. The latter is chosen on the basis of site information and the optimum energy demand pattern obtained from the database created by the Center. Such a selection leads to minimization of energy storage requirements and its related problems.
- Develop appropriate control and load management techniques suitable for renewable systems and expected site activities.

In order to identify and demonstrate desert community development strategies which: a) are feasible and sustainable under local conditions and resources, b) are socially acceptable, c) protect the natural environment, and d) enhance the quality of human life, the DDC draws upon four sources of information:

- The experience of neighboring farmers in South Tahrir and Sadat City (derived from socio-economic surveys and informal interviews).
- Data collected from alternative designs for a) demonstration family-farming units at both sites, and b) agri-business pilot project based on the fodder/livestock/biogas system (100 feddans in South Tahrir).
- DDC experimental sites (Sadat City and South Tahrir), where applied research is conducted in order to improve soil productivity, and to develop alternative conventional and non-conventional desert farming systems as well as different applications of renewable energy technologies. The interaction among the above-mentioned sources are imperative and should give us the necessary guidelines for planning new desert communities.

Disseminating the results of the above activities through demonstration sites, consulting, training and on-site experience for farmers, students, technicians, scientists, businessmen, and policy makers.

The training aspect of DDC's work is becoming increasingly important as time goes by. In early 1993, approval was given for a grant of \$4 million for DDC to be established as a permanent training center for desert development practices, with facilities for up to

100 students per term. This grant has been recently renewed for further training of University graduates who have been allocated 5-6 feddans each in one of the reclaimed desert areas.

CENTER ACHIEVEMENTS

The achievements of the Desert Development Center over the last 20 years can be summarized as follows:

Desert Agriculture

The DDC approach to the problem of practicing agriculture in the desert, where water and nutrients are scarce and energy is expensive, stipulates that "a desert should be treated as a desert" and no silt or manure should be transported to a desert site from other areas. Technologies, practices, crop varieties, and rotations appropriate for desert agriculture are expected to be quite different from those adopted in the Nile Delta and Valley.

Due to the environmental conditions commonly prevailing in the desert, windbreaks and shelterbelts are necessary and should be one of the first activities in initiating a desert farm. Some of the trees and shrubs, which can be grown in desert areas, may be used as fodder or fuel purposes, and some varieties are salt-tolerant.

The task of developing desert soils includes identifying soil resources, assessing soil development under different agronomic methods, identifying major factors limiting soil productivity, studies to improve soil management, and developing training and dissemination methods.

The scarcity of water in desert areas necessitates proper water management as well as energy and water conservation. The latter can be done using special irrigation techniques such as drip, bi-wall, bubbler, and low-pressure sprinkler systems. Under no condition should flood irrigation (the predominant irrigation system used in the Nile Delta and Valley) be allowed in desert agriculture.

Field and fodder crops, plant varieties, agronomic practices and rotations appropriate for desert environments have been tested and demonstrated in specific desert farming systems. Some fruits and vegetables and selected rootstock /variety combinations and cultural practices have been introduced at the two DDC sites. Selection of drought-resistant and salt-tolerant plants was also the focus of experiments. Plant protection measures against weeds, nematodes, and other potential plant diseases and pests were tested under desert conditions.

While growing of fodder crops in the limited area of the Nile Delta and Valley may be debatable because of the critical shortage of food crops needed by Egypt's continually expanding population, it is our belief that fodder /animal /biogas system is most appropriate for desert development. Most of the fodder crops, in addition to animal manure, improve the desert soil's

productivity. Barki sheep and two types of hybrid cattle are important components of one of DDC farming systems that has been demonstrated and evaluated for its economic viability.

The following is a summary of the different activities of the desert agriculture program:

Desert Farming Systems Research

The concept of desert development systems adopted by DDC gives equal stress to the biological, technological and community aspects of desert development. If more emphasis is given to agricultural aspects, the term "desert farming systems" is used.

Desert farming systems research (DFSR) adopts an integrated approach and typically uses interdisciplinary teams whose composition varies according to the task. Field teams conduct on-site and on-farm research, and are aided by: 1) disciplinary specialists in physical, biological, and social sciences who may operate out of the AUC headquarters or experiment stations, 2) extension specialists, and 3) others concerned with agricultural production.

Desert farming systems demonstrated at the South Tahrir site included: 1) forestry/fodder crops/sheep (sponsored by IDRC), 2) fodder/livestock/biogas (sponsored by USAID/FRCU), and 3) fodder/sheep/horticulture (sponsored by NEF).

Afforestation and Desertification Control

The forestry program has two principle objectives; namely, establishment of windbreak in order to protect farms and farm buildings, and introduction, testing and evaluation of multi-purpose trees and shrubs under desert conditions. The activities included works on: 1) Protective tree plantations [shelterbelts of *Casuarina* (*C. glauca* and *C. cunninghamiana*) and *Acacia saligna*; 2) Fodder/fuel/shrubs silvopastoral desert farming system, involving the introduction of fodder/fuel shrub *Acacia saligna*. This leguminous shrub showed good potential as a fodder, especially when mixed with alfalfa; 3) Salt-tolerant tree species (*Tamarix* and *Casuarina glauca* trees grew successfully in saline soils at Sadat City and Fayoum); and 4) Biomass evaluation (*Acacia saligna* foliage alone or mixed with other fodder indicated that acacia could be used to maintain animals, especially sheep).

A study of root biomass of four tree species as affected by irrigation systems showed that the vigor and extension of the root systems decreased in the following order: *A. saligna*, *Eucalyptus camaldulensis*, *Casuarina glauca*, and *C. cunninghamiana*.

Soil Development

The soil at the DDC Sadat City site is generally characterized by its calcareous nature; its sandy texture is combined with a highly compacted surface layer and high gravel content (desert pavement); extremely high salinity, very low organic content; and low supplying power of most nutrients.

The soil at the South Tahrir site is generally very coarse in nature with no clay fraction; it has low water-holding capacity and a narrow available-water range, an extremely low level of organic matter, poor supply of nutrients; and initial salinity in the low or medium range. The soil was classified into two types; gravely calcareous (10-16% CaCO_3), and non-calcareous soils (1-3% CaCO_3).

The following activities were conducted:

1. Assessment of soil development under various agronomic practices and crop rotations.
2. Identification of major factors limiting soil productivity, e.g., nutrient and micronutrient contents of the soil at the root zone; salinity levels; hard compacted gravely surface layer.
3. Studies to improve soil management and enhance soil development, e.g., a long-term fertilizer experiment; application of organic manure produced on the DDC farm.

Water Management and Irrigation Systems

Water management is the comprehensive control of water delivery, conveyance, distribution, and application, all coordinated to increase production and improve farming techniques. Good water management practices aim at ensuring maximum uptake by plants and minimum loss of water delivered to the field. Accurate hydrological and meteorological data, estimates of water requirements of desert crops, effective methods of irrigation, techniques for increasing soil moisture retention and decreasing water losses, are all included in the development of optimum irrigation management, designs, and practices.

Meteorological data have been collected and analyzed at the Sadat City site since 1981. An HP 85 Data Logger and Computer was installed at the DDC Headquarters Building and used to collect, store and analyze meteorological data, including insolation, wind speed and direction, and temperature. A neutron probe was procured for studying soil moisture retention and providing data necessary at the two sites (courtesy of John Goelet and Wye College).

The South Tahrir site depends mainly on Nile water delivered through a small feeder canal connected to the Nasr Canal. However, two wells which use diesel engines, were drilled by the DDC for emergencies when there are electricity cuts or water shortages. A system of semi-portable sprinkler irrigation was originally used for irrigation. Later, the DDC installed a system of drip and bi-wall irrigation for watering citrus and forest trees as well as vegetables. Furthermore, side-roll sprinkler systems have gradually replaced the semi-portable systems for irrigating field and fodder crops at the South Tahrir site.

The Sadat City site depends on underground water for irrigation. The water is at about 45 meters below the surface, and is of good quality (total soluble salts around 320 ppm. for Sadat City as compared to 430

ppm for South Tahrir canal water). The water at Sadat City was pumped from a well by two solar pumps - one DC Robin & Meyer deep well pump, and one AC Grundfos submersible pump. The latter is now solely responsible for pumping water due to its ease of operation and maintenance. In addition, another solar DC pump was used as a booster pump for the drip and bi-wall irrigation system at Sadat City. A second well has been drilled in the Sadat City site, with two Grundfos AC pumps, one powered by a hybrid wind/photovoltaic system, and the other connected to the mains.

A system using thin-walled corrugated plastic pipe of sufficient diameter to allow for low head operation (the bubbler irrigation system) was designed by Rawlins at Riverside, California, and implemented in 1981 at the Sadat City site for watering the windbreaks of *Casuarinas* trees planted around the site.

A water management experiment was initiated in 1983 on 12 feddans at South Tahrir to test the effects of irrigation frequency, keeping the total amount of water delivered to the crops constant. The soil moisture pattern as well as soil bulk density, soil moisture characteristics curve, and infiltration characteristics and soil water-holding capacities were monitored during the growing season.

Water requirement studies were based on two approaches. The first is a program for soil moisture determinations under different crops; the second approach uses a lysimeter system for determining crop water requirements. This involved the determination of evapotranspiration and water use by different crops (field crops, forage crops, vegetables, or medicinal plants) cultivated in the area. The water-use efficiency values for wheat, sorghum, and peanuts were based on the performance of these crops cultivated in the lysimeter during 1987 and 1988.

Crops and Crop Rotations

The major objectives of applied research in this field are: 1) monitor and test the appropriate crop varieties and agronomic practices as well as various long-term rotations within suitable desert farming systems, 2) evaluate the effect of crop rotations on crop yield and soil improvements, and 3) identify the most appropriate crop rotations under desert conditions. In all tests and rotations, the DDC approach, which stipulates that "a desert should be treated as a desert", is adopted, and no silt or manure is transported to the site from other sites.

Five different crop rotations have been tested in an area of 80 feddans at the South Tahrir site since 1981-'82. These are: 1) alfalfa, 2) legume/ legume/ legume, 3) cereal/ legume/ cereal/ legume, 4) legume/ cereal/ legume/ cereal, and 5) cereal/ legume/ legume/ cereal. Different crop yields were obtained under the various rotations. Results over about 3 years favored Rotations 1, 3, 4, and 5. These were continued on an area of 40 feddans over an additional 2 years for further evaluation based on productivity, quality, and economic viability. Furthermore, different tillage practices, including

zero and minimum tillage, have been introduced and implemented on an additional area of 20 feddans using the same crop rotation. When planting alfalfa, inoculation and nodulation by *Rhizobium* were very successful.

Crop rotation studies have shown that CUF 101 alfalfa (*Medicago sativa*), a perennial legume, plays a very important role in improving productivity of the desert sandy soils. It also tolerates water stress, relative to other crops. Alternative legume/cereal rotations are also beneficial, and represent an attractive pattern for most crops and for improving soil productivity.

In addition to alfalfa, the following crops, with various varieties, were tested for their potential under desert conditions: Egyptian clover, triticale, safflower, sunflower, wheat, lentils, faba beans, cowpeas, peas, barley, lupin, grain sorghum, corn, fodder sorghum - sudan hybrid, millet, and sweet sorghum.

Mixing alfalfa with Egyptian clover proved to be a good agronomic practice in terms of production and biological weed control. This is due to the competition of clover against weeds for the essential growth requirements.

Trials on fodder beets showed high productivity in the saline, calcareous soil of the Sadat City site, and less success in the sandy area of South Tahrir. However, in the calcareous patches of the same South Tahrir field, the growth, and yield of fodder beet was satisfactory.

A long-term fertilizer experiment was initiated in winter 1983-84 to determine the optimum fertilizer requirements of the major crops under desert conditions. Three different rotations were designed with two levels of superphosphate (150, 300 kg) and three levels of potassium sulphate (100, 200, 300 kg) applied to each rotation in each season. Response to micronutrient applications based on soil testing was remarkable in improving the yield of various crops. Also, all crops responded positively to the addition of potassium as compared to the control (without potassium).

Horticulture

A nursery was established in 1980 at the South Tahrir site as part of a project supported by NEF for "Improving Productivity of Fruit and Vegetable Crops in the Desert of Egypt". Fruit and vegetable production is well established in the old lands, but it is evident that under desert conditions other varieties, rootstocks, and cultural practices will need to be introduced to make successful production possible.

The initial NEF-sponsored activity was based on testing a large number of citrus rootstock/cultivar combinations and selecting the most successful under sandy desert conditions. While waiting for the citrus trees to mature, other testing and selection experiments were conducted on avocado, olives, some deciduous fruit such as apple, pear, peach and guava, and vegetable crops with export potential such as asparagus and broccoli.

The basic idea is to compare the traditional citrus rootstock of the old lands (sour orange) with other rootstock more suitable for sandy desert soils. This is particularly important since the sour orange rootstock is easily affected by the "Quick Decline" disease which has wiped out citrus culture in different parts of the world. Most of the newly introduced citrus rootstocks are resistant or tolerant to this disease.

In addition, different citrus species and varieties (including grapefruit, orange, mandarin, lemon, lime and tangelo) were grafted onto different types of rootstock, and a selection process of the most suitable combinations (rootstock + species or variety) was undertaken. The citrus variety-rootstock trial planting was completed during the 1984/1985-winter season. The trial orchard (9 feddans) consists of 68 variety-rootstock combinations. The trial is divided into five groups: mandarin (5 varieties), orange (2), grapefruit (4), lemon (5), and lime (1).

After more than a decade of selection trials, the DDC fruit tree nursery at South Tahrir can now offer farmers a choice of superior citrus plant material for activities in the desert. This activity has been so attractive that agreements have been reached with four NGOs to transfer the knowledge and plant material to four desert locations in Upper Egypt (Minya, Sohag, Farafra and Beni Suef). The agreements cover technology transfer, initiation of nurseries, and training of farmers and graduates.

Plant Protection

The pest control philosophy adopted by the DDC is based on following insect-control programs which accept and use ecological factors and compatibility. The concept is one of optimizing control rather than maximizing it, i.e., pest management.

The presence of pesticide residues in food, feed and organisms occupying every part of the ecosystem has caused widespread concern among scientists and thoughtful citizens alike. The ecological balance sought in pest-management programs necessitates the encouragement of beneficial insects that are often natural enemies of the pest species. These are often unfortunately removed by contact with broad-spectrum insecticides regularly applied to the fields, and are also destroyed by starvation when their prey is totally eliminated by chemical control. Therefore, an important concept of pest management is the necessity for leaving a permanent presence below the economic threshold in an area where control measures are conducted. *The concept is to suppress a pest but not annihilate it.*

The advantages of biological control and the deleterious effects of chemical control methods became more obvious over the years of testing on DDC sites. Accordingly, all chemical control methods were phased out in 1991 and all control is now by biological methods or by manual and mechanical methods.

Livestock Production

Shortage of feedstock for livestock is a well-recognized problem in Egypt. In the Delta and Valley, berseem (Egyptian clover) is the most important fodder crop in winter and spring, while in summer and autumn fodder crops are scarce and there is a critical shortage of animal feeds. Feeding animals in the latter two seasons is based on poor quality roughages (mainly rice straw and wheat straw) in addition to inadequate quantities of concentrates (cotton seed cake, rice bran and wheat bran).

With increased demand for fodder crops, the market price of these crops gives the farmer an incentive to grow more berseem in the Delta and Valley at the expense of food crops. Efforts are now being made to encourage growing of fodder crops for animal production in newly reclaimed desert areas.

The objective of the animal production activity at DDC is to solve the shortage problem by:

1. Producing fodder crops throughout the year.
2. Raising cattle and sheep under grazing for meat and milk production.
3. Providing animals with well-balanced rations in irrigated desert farming.

It has been found that Brown Swiss is the most suitable breed for crossing with indigenous cattle. (The critical temperature after which milk production steeply declines is 21-27°C in Jersey and Holstein, while it is 29-32°C in Brown Swiss and higher again in the case of local cattle). Brown Swiss is a dairy breed, but its value for beef production is also excellent compared to other dairy breeds. Crossbreeding with local cows improved overall meat and milk production.

Animal production at DDC farms is based on an irrigated farming system. Grazing is used for feeding animals. Barki sheep, native to Egypt's Western Desert, were introduced at South Tahrir to improve their productivity using better management. Sheep graze after cattle, making grazing more efficient.

Desert Technology

Technological practices compatible with desert environments cover a variety of activities, including 1) zero and minimum tillage (conservation tillage), 2) nutrient film technique, 3) plant tissue culture, 4) controlled environment greenhouse and nursery, 5) dairy processing, and 6) materials for housing.

Zero and Minimum Tillage

Conservation tillage is defined as any tillage system that uses special techniques to reduce soil erosion or conserve soil moisture and structure in order to improve land use and reduce labor and energy consumption. Zero and minimum tillage are common types of conservation tillage. Minimum tillage depends on the specific crop and soil conditions. It may range from only one less field operation than normal to no tillage

at all. The latter is the same for all crops since it describes the procedure in which planting is done directly into an essentially unprepared seedbed. A special planter is needed for this type of no-tillage procedure, and a John Deere 7000 conservation 4 row planter was bought for this purpose.

Three tillage treatments (conventional, minimum, and no-tillage) were applied to three different rotation experiments. Crop response (yield and quality) and development of soil characteristics (physical and chemical) were monitored in 1986-'88. Results indicated no significant differences in crop yields that could be attributed to the level of tillage. While soil compaction increased in zero-tilled plots, soil bulk density and permeability to water did not vary significantly among tillage treatments. It should be pointed out, however, that chemical weed control was, by necessity, used in zero-tilled plots, while manual or mechanical weed control was applied in the conventional and minimum-tilled plots. The residual effect of some herbicides could be a factor affecting the yield of some crops in the case of zero-tillage applications.

Soilless Agriculture

The concept of the nutrient film technique, or NFT, is simple: a nutrient solution is circulated in a shallow stream over the roots of growing plants. The solution, which contains all of the nutrients necessary for plant growth, is regularly monitored and fresh nutrients are added when depletion occurs. This solution is allowed to flow down channels (or gullies) into a catchment's tank. The solution is then pumped up from the catchment's tank to a header tank which feeds the inputs to each channel. *This is a closed system.* Use of water and nutrients is regulated to that which is needed for plant growth with very little loss. In a desert environment, where the scarcity of water and nutrients are major constraints, and where soil development is a major difficulty, NFT appears to constitute the basis of an economically attractive desert cropping system, since it is based on a soilless approach.

The gullies were later replaced by plastic tubes where seedlings were inserted in suitable holes. It has also been observed that aeration of the roots improves as the slope of the tubes increased. It was therefore decided to erect the tubes with a much higher slope by suspending them in an inclined vertical position. The plants were inserted in special holes and held in a position by a piece of spongy plastic. The branches grew sideways on wires in alternate directions to allow space for each. The roots inside the tubes grow well in a moist and well-aerated medium, forming a common mat, which acts as a strong support for the plants.

Plant Tissue Culture

A Tissue and Cell Culture Laboratory at Sadat City was established as a result of a grant made by former Board member John Goelet. Micropropagation involves the

production of plants from very small parts, tissue, or cells grown aseptically in tubes or other containers where the environment and nutrients can be rigidly controlled. The methods used have been known collectively as "tissue culture", a term that is sometimes used synonymously with "micropropagation". Successful protocols have been established at the DDC Tissue Culture laboratory for some multi-purpose forest trees which are suitable for desert agriculture, such as *Casuarina*, *eucalyptus*, and *acacia*. An apple root-stock/variety and a banana variety have also been successfully micropropagated, and research on date palm is in progress.

Controlled Environment Greenhouse and Nursery

In 1986, a contract for conducting cooperative research and development was signed by the Ministry of Development and New Communities and the Government of Finland, with the DDC as the implementing agency, for an environmentally controlled greenhouse - nursery for the Sadat City site.

In order to achieve the aims of this project, construction of one 600-m² greenhouse and one shade house of 425 m² at Sadat City, as well as two other shade units at South Tahrir, was implemented in cooperation with ENSO-GUTZEIT, a Finnish company under contract with the Finnish Government.

First-year production (1986-'87) was about 70,000 seedlings of *Casuarina*, *eucalyptus*, and *acacia*. Production rose to 150,000 in 1987/88 and 500,000 in 1988/89, mostly of *Casuarina equisetifolia* for planting as shelterbelts on Montaza beach, Alexandria, and salt-tolerant *C. glauca* for afforestation at a fish farm outside Alexandria. Nearly one-third of this quantity was designated for sale to neighboring farmers, especially those who are starting new desert farms.

The same greenhouse and shade facilities have also been used for citrus grafting, as well as for germination of vegetable seeds for soilless agriculture. Cuttings of some aromatic plants have also been rooted in the greenhouse. Two other greenhouses were for production of out-of-season vegetable crops. Species, varieties, organic matter sources for soil preparation, and some cultural practices were studied as part of the research program.

Dairy Processing Demonstration Plant

Following the University Linkages Project's theme of fodder/livestock/biogas, the DDC embarked on a pilot project for dairy processing at the South Tahrir site. The objective of the dairy-processing laboratory was to transform fresh milk into a more durable product, i.e., white cheese.

Materials for Desert Housing

The design and construction of appropriate desert housing is an objective of the DDC. *Attractiveness*

combined with self-sufficiency is a goal. Such design and construction requires a multi-disciplinary team approach involving engineers, material scientists, architects, sociologists, planners and prospective inhabitants. Climatic conditions, culture, and local traditions are important inputs to the design of desert housing, drawing, insofar as is possible, upon traditional Islamic and Coptic styles and adapting them to modern application such as solar energy.

To complement the goals of the Center, building construction must maximize the use of locally available materials. Therefore, a survey of raw materials in the desert sites and nearby locations was conducted, and some construction materials were tested in light of thermal and mechanical specifications and economic constraints. A major objective was the identification of suitable bricks and blocks as a substitute for bricks made from Nile silt. Production of silt bricks has been stopped by Government Decree, as no new silt has been deposited in the Delta since construction of the High Dam.

The building of the DDC Desert Headquarters at Sadat City was made possible through a grant from the Ministry of Development and New Communities. The building was constructed in 1980 from adobe bricks (not fired) made onsite. The material for making the adobe bricks came from the Sadat City site and from the nearby Wadi Natroun area. The bricks for the walls were mostly of Sadat City sandy soil; however, the bricks for the domes have a high percentage of Wadi Natroun clay combined with straw. Since the building uses old traditional Islamic and Coptic domes and vaults, it was necessary to bring the mastermason and his assistants from Upper Egypt. The mastermason was originally trained by internationally known Egyptian architect Hassan Fathi. Furnishing the Headquarters building was based on the use of indigenous materials and designs appropriate for desert environment.

Since 1980, additional buildings have been constructed at South Tahrir and Sadat City DDC sites for the use of research assistants, animals, and for housing equipment. The first "detached" house, using bricks made of desert clay, was built on Model Farm # 1. Two "semi-detached" houses were then constructed from limestone blocks on Farms # 2 and # 3 at South Tahrir.

A major animal shed for cattle and two buildings for rabbits, were constructed at South Tahrir site; in addition, one building for control equipment of the hybrid solar/wind system and another for housing a steam extraction facility for aromatic and medicinal plants were built at Sadat City site. All of these buildings are based on passive solar architectural design, dome and vault roofing and courtyards. The energy needs of these houses are provided by renewable sources (solar, wind, biogas), wherever feasible.

Renewable Energy

Because of its location and dry climate, Egypt has a high incidence of solar radiation that can be used as an

energy source. The total number of sunshine hours reaches about 3600 hrs/year. It varies between 7 and 9.5 hours daily in winter, while it reaches more than 12 hours daily in summer. The global solar radiation varies between 3.2 and 5 kw.hr/m².day in winter and 2.6 to 8.6 kw.hr/m².day in summer, depending on site location.

With the abundance of solar energy in the desert locations, its use naturally receives considerable attention in schemes aimed at providing energy needs for life in the desert. However, the overall plan for satisfying energy demands need not be limited to solar energy and should consider other sources of renewable energy such as wind or biomass. Wind is mostly available in coastal areas with average annual speeds over 4 m/sec, particularly in the Red Sea area where it reaches 6-8.5 m/sec. Inland desert areas may have wind speeds varying between 2.5 and 4 m/sec., depending on site.

Wind Energy

Based on the analysis of the wind data recorded at the DDC Sadat City site, and the technical and commercial data for wind turbines, a selection of a 7-m wind turbine was made and installed at the Sadat City site. The selected wind system was a Bergey BWC - Excel-R/48.

Photovoltaic Energy Systems

Four photovoltaic ARCO solar systems operate at the Sadat City and South Tahrir sites. Two were installed in the summer of 1981; namely, a 10kw_p system, which through an inverter provides the 220V, 50Hz necessary to power the Headquarters building and an AC submersible pump, and a 3kw_p DC system devoted to powering a deep-well pump and an irrigation pump. In addition, a 700w_p system powers the re-circulating DC pump used in the stand-alone NFT facility; and a 1.2w_p system mounted on the roof of an animal shed as part of Model House # 1 at the South Tahrir site supplies its power needs. A fifth system of 5.8kw_p has been installed as part of the solar-wind hybrid system, which is designed to supply the power for the irrigation systems of the 15-feddan plots at Sadat City.

Biogas Technology

In addition to evaluating naturally available sources of energy such as solar and wind, the use of animal residues has been investigated as part of the energy use program. Through biogas technology, part of the energy is required to produce biomass, e.g., food and feed crops, fruits, etc., could be recycled again in the overall ecosystem. Biogas technology, which is the anaerobic fermentation of animal manure and crop residues, can provide the desert agriculture system with clean fuel; biogas, and a valuable organic manure, biogas manure.

The fodder/livestock/biogas system has been implemented at the South Tahrir site, where animal husbandry activities are going on and the agribusiness pilot

unit has been developed. The biogas energy may be used for operating the animal shed (supplying hot water for cleaning milking cows), generating electricity, and/or supplying the local inhabitants with fuel for cooking and lighting.

In order to make the best use of the manure and urine wastes collected from the animal shed of Model Farm # 1, a biogas system, based on a family-size unit, was designed and constructed in cooperation with experts from the National Research Center. The main components of the unit are the mixing room of the feed material, the digester, the gasholder, and the composter (effluent treatment part).

A 12-m³ volume Borda-type digester was built. The digester is fed directly from the animal shed. The effluent slurry after digestion is absorbed by agricultural wastes in order to produce organic compost. The composter is made up of two adjacent reservoirs about 50 cm. high, 1.2 m wide, and 8 m long. The composter is connected directly to the digester effluent room. Handling of compost is similar to dry manure handling. The gas produced is used in Model House # 1 for cooking.

Bioclimatic Architecture for Desert Housing

For new communities and desert settlements, the DDC plays an effective role in promoting the adoption of bioclimatic architecture for desert housing.

Accordingly, climatic conditions and physical comfort of the desert settler are taken into consideration through the design of the building form based on appropriate traditional and modern passive solar architecture concepts as well as suitable locally available material.

In Egypt, dome and vault architecture is a traditional style of roofing. Its method of construction is simple. Building materials are locally available almost everywhere since either adobe bricks (made of clay or desert shale), or vitrified shale bricks can be used.

Climatically, domes are extremely suitable: their shape naturally reflects 50% of the incident solar radiation and the outer surface of the dome is cooled much more quickly than of the normal flat roof. This cooling effect is due to the increase in the currents and air velocity around the dome caused by the positive air pressure created at the front of the dome, and the negative pressure at the lee side. The materials used to build the dome have a lower coefficient of conductivity than concrete (0.5 w/mk for shale bricks and 1.8 w/mk for concrete).

Internally, domes have excellent aeration properties. Hot air is allowed to rise and collect under the dome from which it can escape through the vents and small windows at the top. In addition, internal air movement is better inside the house. It should be stressed that in addition to the above-mentioned passive solar characteristics, the house is provided with electricity through a PV solar system. A solar water heater is used to heat water in bathrooms, a biogas system to provide gas for the kitchen, and a mechanical windmill to pump potable water for use by the house residents.

The Sadat City Headquarters Building

The Sadat City Headquarters Building has been designed and built to incorporate many passive solar architectural features based on the traditional Islamic and Coptic designs and techniques: domes, vaults, courtyards, etc. The building was constructed from adobe bricks made on site from a mixture of calcareous sandy soil of Sadat City and desert clay from the neighboring Natroun Valley. A 10-kwp photovoltaic Arco Solar system is used to provide the building and its laboratories with its electric power needs. Three solar water heaters are used to provide hot water to the kitchen and bathrooms in the building. Potable water is provided by a submersible Grundfos pump powered by a 3-kwp solar system.

DESERT COMMUNITIES AND SOCIO-ECONOMIC STUDIES

The Desert Community Unit, as a research unit of the DDC, was initiated in September 1983 through a grant from the Ford Foundation. A long range-objective of this unit is to investigate, identify, and demonstrate strategies for the development of desert communities which are feasible within the framework of local resources and social norms, and which do not sacrifice adequate health and environmental standards. This includes identifying and designing incentives which attract people to live and work in the desert. The Unit also concentrates on studying the economic viability and social acceptability of different activities conducted at the AUC demonstration sites and in the surrounding communities. This Unit is specifically concerned with "people" to whom the new technologies, facilities, systems, and policies must be suited if these new communities are to succeed.

Socio-Economic Surveys

The DDC is committed to not only introducing or developing technologies for desert development, but also to ensure that these technologies are compatible with the socio-economic conditions of the settler groups who are the intended beneficiaries. In an effort to gain an understanding of the key socio-economic factors in South Tahrir, the DDC has conducted surveys of two major groups of farmers who have settled in the area: graduates and smallholders. The graduates have earned university or technical degrees in agriculture and are farming areas of approximately 20 feddans. The smallholders have received little formal education and generally have farm plots of 3 to 5 feddans.

Since the graduates and the smallholders as groups have widely differing backgrounds and experiences, the constraints and opportunities that they face may be entirely different. Therefore, separate surveys were designed for each group. The two surveys (graduates and smallholders) were then followed by a study of institutions and settler partnership in South Tahrir and three problem-oriented studies. In response to the major

marketing and water/energy problems facing farmers in the South Tahrir region, the DDC conducted the following studies:

1. Agricultural Marketing

In order to gain a fuller understanding of the functioning of the marketing system, and to investigate ways in which the system might be improved, the Desert Community Unit carried out a study of marketing patterns in the area. The existence of reliable marketing outlets is critical for integrated desert development, because without them even a highly efficient system of production cannot be supported.

2. Water-Energy Problems

A survey was made in summer 1988 to determine the contribution of agricultural inputs to the production of some major crops with emphasis on water and energy inputs. A water account study was also initiated. The purpose of the study was to assess the water supply available at the farm level, evaluate the irrigation systems, and estimate the temporal demands of different cropping patterns for irrigation water.

3. Investors and Workers in the Western Desert of Egypt: An Exploratory Survey

This study represents the combined efforts of an interdisciplinary team comprising an economist, a social anthropologist, and a statistician to investigate and interpret the experiences and perceptions of investors and workers in selected areas of the Western Desert (Marsa Matrouh, Wadi El Natroun, Sadat City, and South Tahrir).

The field work underlying this study took place during July - August, 1990. Data were collected to cover five main topics: living in the desert, investing in the desert, working in the desert, constraints to desert development, and the future of desert development.

4. Economic Analysis of On-Site Activities

This category of studies is concerned with economic monitoring and evaluation of research experiments and demonstrations performed on DDC sites. Specifically, the model farms and agribusiness units, the long-term fertilizer and rotation experiments, and the nutrient film technique experiment were examined.

5. On-Farm Demonstration

The on-farm demonstration activity, initiated in summer 1985, was based on a collaborative effort where a team of DDC scientists, rural sociologists and economists, worked with several individual farmers on the farmers' land to demonstrate appropriate practices for desert agriculture and help to solve some of the problems identified in the socioeconomic surveys. Members of the DDC Desert Community Unit (rural sociologists and economists) played a major role in this activity.

TRAINING

A major objective of the DDC is the training of different levels of individuals in various fields of specialization within the area of desert technology and development. The individuals include laborers, farmers, technicians, students, agronomists, engineers, scientists, economists, and social scientists. The fields of specialization include water management and appropriate irrigation systems, soil treatment, testing and soil improvement techniques, arid land plants, appropriate crops and crop rotations, animal husbandry, meat and dairy processing, and other desert technologies as well as farm management, economics of land reclamation and desert settlements, including socio-economic aspects and passive solar architecture for desert housing.

Since energy has been clearly identified as a major constraint in desert development, it is necessary to train different levels of personnel in the technology and applications of energy. The training involves: a) use of technologies of low-energy consumption, e.g., drip, bi-wall, or bubbler irrigation systems, and b) applications of renewable energy technologies (solar, wind, biomass and appropriate hybrids) for desert development, taking into consideration technical, economic, and social aspects of these technologies.

Short month-long training programs and seminars have been developed by DDC covering basic concepts of desert agriculture and technology, renewable energy and socio-economic aspects of farming systems. While some introductory lectures (different levels) may be necessary to acquaint the trainees with basic concepts, a major component of these programs are based on "hands-on" experience and on-site demonstrations at the model facilities set up around the DDC Sadat City and South Tahrir sites. Courses usually include at least four full-day field trips to Sadat City and South Tahrir.

When an On-Farm Demonstration Program proves to be technically feasible, economically viable, and socially acceptable, an outreach program is carried out by DDC to diffuse the new findings to the farmer population at large. Thus, agricultural bulletins for specific crops of interest to a particular group of farmers were prepared by the DDC interdisciplinary team and distributed among the concerned farmers in the area.

A departure in DDC's training program began in January 1993 with the first intensive week-long course in desert farm management. Attended by nearly 30 participants, it was sponsored by Caritas, a Catholic aid organization, and represented the first co-operation between the two organizations. The course was a condensed form of the usual month-long course organized by the DDC. It concentrated on showing farmers how to evaluate land and crops, and how to market their products, especially for export. Strong emphasis was put on the practical aspects of farm management.

In April 1993, the DDC's training program was given a huge boost after approval of a LE 13.2 m (\$4 million) grant from the US Department of Agriculture through the Egyptian Ministry of Agriculture. Over a

period of 4 years, the grant enabled the DDC to train 1370 graduate farmers in desert farming techniques and management. Construction of facilities was undertaken in the first year. Facilities built include accommodation for 100 students, lecture halls, dining rooms and recreational areas. Recently, this grant was renewed for another 3 years. All experience gained by the DDC in applied research and training was used in planning courses and facility construction. Thus, the principles of treating the desert as a desert using no Nile silt, of blending old and new practices, and of ensuring that all systems are technically, economically, and environmentally sound were adhered to.

SUSTAINABLE DESERT DEVELOPMENT

The Bruntland Commission defined sustainable development as the path of human progress, which meets the needs and aspirations of the present generations without compromising the ability of future generations to meet their needs. In other words, each generation must meet today's needs without incurring debts it cannot repay, and without compromising the lives of future generations.

Sustainable development, or environmentally sound development, indicates that environment and development are closely linked and are mutually supportive. In other words, there will be no sustained development or meaningful growth without a clear commitment at the same time to preserve the environment and promote the rational use of resources.

Sustainable development argues that "real" improvement cannot occur unless the strategies being formulated and implemented are ecologically sustainable over a long term, are consistent with social values and institutions, and encourage public participation in the development process. As the primary objective is to provide lasting and secure livelihoods that minimize resource depletion, environmental degradation, cultural disruption, and social instability, this process can be viewed as an interaction among three systems: *the biological and resources system, the technological system,*

and the socioeconomic system. The general objective is to maximize all these systems through a dynamic and adaptive process of trade-offs. This is the basis of DDC's integrated approach.

In 1990, a task force sponsored by the United Nations Development Programme (UNDP) and coordinated by the DDC Director, was assigned to propose strategies for sustainable development for Egypt. Furthermore, the International Desert Development Commission (IDDC), chaired by DDC Director, organized its fourth International Conference based on the theme "Sustainable Desert Development for Our Common Future". The conference was held in Mexico City, 25-30 July 1993.

In order to achieve sustainable development (and self-reliance), a balance should be reached between economic and social development, resource management, and environmental protection. This is a dynamic system which would require appropriate management (especially under micro/macro crisis conditions), necessary finances, and research and development with emphasis on optimization between the ecological and economic dimensions of development. Public participation (social and political) and necessary infrastructure and support services are of utmost importance in implementing the different strategies proposed for achieving sustainable development. These strategies were grouped into four sets: a) *public policy and legislation*; b) *information management, monitoring and public awareness*; c) *technical support (research and development, training)*; and d) institutional and international cooperation.

The Desert Development Center of The American University in Cairo, over the span of the last 20 years has emphasized that in order to achieve sustainable desert development i.e., desert development for our future generations, we have to *work within the boundaries of water scarcity and energy limitations.* These were stressed in its research, demonstration, and training programs.

Weather Data for Crop Production and Protection

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ABSTRACT

Distribution uniformity of irrigation water and fertilizers, pests and diseases prediction, and planting dates are major problems under different climatic regions in Egypt.

The old land is characterized by uneven field surfaces, short furrows and small basins, deep percolation, water and fertilizer losses, soil profile heterogeneity, and other soil characteristics that affect water and fertilizer distribution. Early planting is one of the options for summer-cultivated crops in order to get the maximum economical yield at harvesting. Early prediction for diseases and insects is important to help the farmers avoiding heavy spraying of pesticides and take necessary actions to avoid dangerous diseases.

Proper management nowadays depends on *accurate irrigation scheduling that reduces the cost of irrigation and minimizes problems related to the misuse of water*. Early pest and disease forecast and warning allow suitable time for taking necessary actions to avoid chemical sprays. Proper calculation of sowing dates ensures uniform plantation in several crops and reduces the cost of sowing seeds. The above-mentioned agro-management practices require "real-time" weather data system covering the country. The Agricultural Technology Utilization and Transfer Project (ATUT) has established the Irrigation Requirement Information System (IRIS) in collaboration with the Central Laboratory for Agricultural Climate (CLAC). The system covers more than 30 agro-meteorological stations. Dissemination of information is one of the CLAC efforts that occur through different mass media facilities.

Computer modeling is used to calculate water and fertilizer requirements, disease and insect prediction, and planting dates. On the other hand, planting dates for different vegetable crops are determined according to the agro-meteorological data, especially soil temperature at different depths. Research is being conducted to know the prices, and soil temperature for each cultivar of different vegetable species. This is important for selecting the proper cultivation time and area - in case of newly reclaimed lands - in order to achieve the best germination and escape the major diseases and/or pests.

INTRODUCTION

Water resource management and water availability are among the most important political, social, and economical issues of the 21st Century (Harsh et al., 1989; Krug, 1989; Medany et al., 1997). In Egypt, the misuse

of limited water resources creates serious yield reduction in the traditional agro-management systems. On the other hand, control of insects is the outcome of dynamic processes that can be conceptualized as a system depending on weather conditions, the pest and its natural enemies and the host plant as interrelated components.

If mathematical models designed to simulate integrated pest management (IPM) events are to be realistic, they must include insect phenology and behavior, host-plant growth rate, attractiveness, period of vulnerability and response to injury; and the impact of weather conditions on all of these components (Berger, 1977; Fry, 1982; Jones et al., 1984; Royer and Russo, 1989).

Planting at a suitable date prevents plant damage caused either by insects or diseases; in addition to better planning, it improves growth, and yield both on the level of growers and on the country in general. Studies concerning improving or changing technologies to maximize crop production and transfer of knowledge gained from such studies involve large amounts of information from different areas (Bilbro, 1975; Lichev, 1965; Makram et al., 1995; Nelson, 1968).

Engineering practices and system management are required before recommendations are made for selecting the proper irrigation system, IPM, and planting dates. From an agronomic standpoint, all irrigation methods that maximize crop production are equally important. However, particular soil types, crop species, and climatological status may affect efficiency of irrigation water. Poor IPM, unsuitable planting dates, and a weak delivery system will finally lead to yield reduction.

There are several studies in Egypt on developing and modifying utilization of climatic data in crop management. CLAC is investing in these studies to serve agricultural development. It is known that Egypt is divided into several climatic regions. In combination with the availability of water, soil types, and demographic factors, those regions can be modified to three major agroclimatic zones as follows:

1. *The Nile Delta and Old Valley*: characterized by clay soil, available fresh water, and mild climate with heavy population.
2. *The New Lands*: this term generally refers to new land reclamation projects surrounding the Delta and the Old Valley with similar climate but with sandy soil and lower population density.
3. *North Coast*: a range of land of 50 km strip parallel to the Mediterranean Sea. The climate is quite mild with relatively higher rainfall than the Egyptian standard, (180-200 mm/yr.) and sandy soil.

WEATHER DATA SYSTEM OBJECTIVES

The main objectives of the CLAC weather data system are to develop management techniques for water and fertilizer, integrated pests and diseases, and planting date for selected crops in both old and new lands. This is to be achieved through introduction of the proper design of modified or improved irrigation system of uniform water distribution, highly insects and diseases, prediction systems and accurate planting date of vegetable crops to maximize the yield. Finally, it provides information on the chilling requirement of deciduous fruit trees to allow the growers starting timely management practices with the fulfillment of chilling hours. Long-term objectives includes information related to:

- 1. Greenhouse heating, ventilation, and cooling systems.
- 2. Animal and poultry farm information, including expected heat waves, possible flux of diseases and water consumption in relation to animal farm management.

- 3. Aquaculture information systems that provide temperature, humidity, radiation, and other factors affecting fish production.
- 4. Policymaking information system related to the best possible use of land and water resources for agricultural production.

Data Collection and Processing

Fig. 1 illustrates the interaction between CLAC as a research and development unit and research institutions, on-going training activities, universities and on-going research projects to produce services for growers, investors, extensionists, scientists, and policy-makers. The services may be provided in the form of recommendations and technological packages.

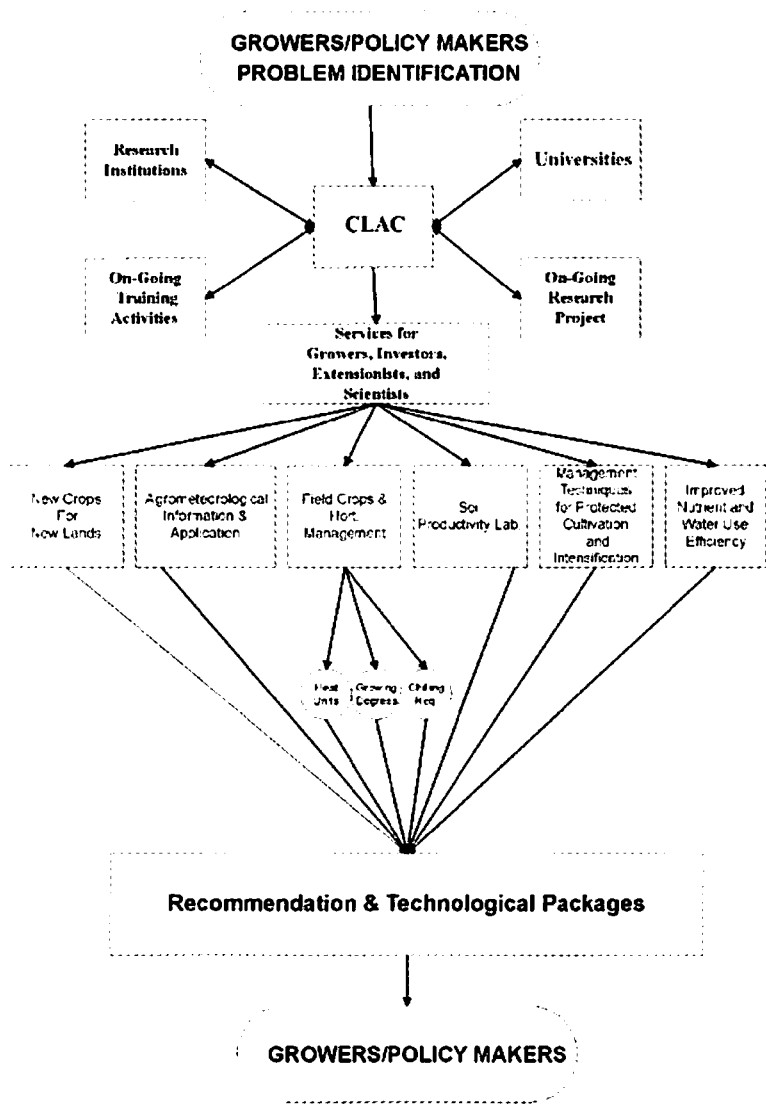


Fig. 1. The interaction between CLAC and other organizations to produce recommendations and technological packages for growers.

Historical data are retrieved from the Egyptian Meteorological Authority (EMA), as well as daily data of some locations; real-time data are logged by the Agro-meteorological Stations belonging to CLAC; manual stations of the Ministry of Agriculture provide daily data for several other locations. These are the main three data sources and main input for the daily weather data. Besides, some information on the regional levels are retrieved from the INTERNET and satellite images.

Historical data are used as an alternative source in case of any shortage in the real-time data. Data collected from different sources have different formats and cannot be utilized as they come. In any case, all data

are subjected to a series of data processing to produce uniform data file shown in Fig. 2. For example, relative humidity could be calculated from air temperature and dew-point temperatures, or from wet- and dry-bulb temperatures using specific equations.

Hourly and synoptic 3-hr interval data are being processed to produce daily averages for some applications. On the other hand, synoptic data are processed to calculate hourly data for other applications. Automatically received data are handled through specific software to produce the same uniform outputs to be used for different applications.

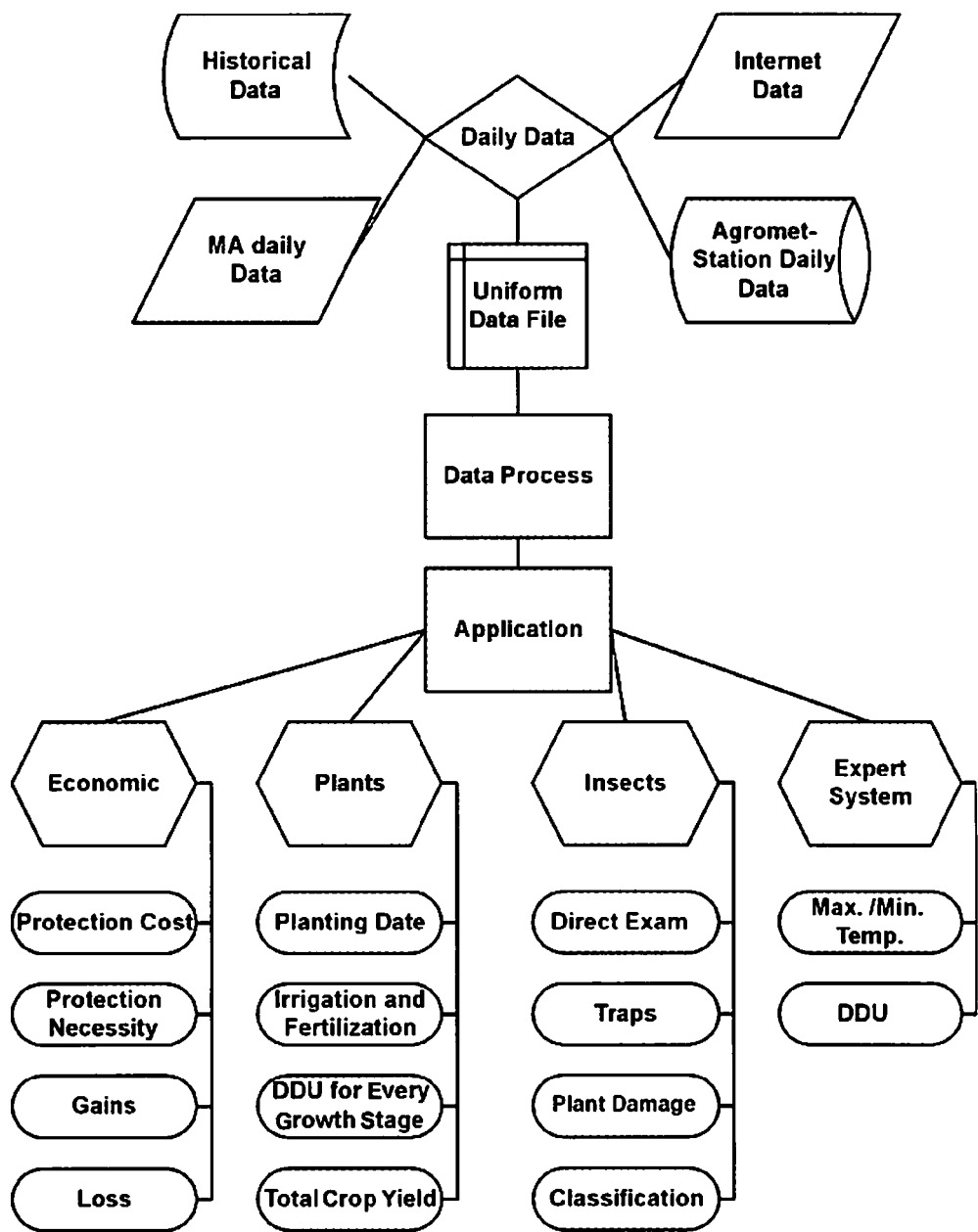


Fig. 2. Data collection, processing and applications.

Application

As illustrated in Fig. 2, the uniform data are utilized by four main activities that perform the necessary data-processing according to each application. Applications include the logical flow of the integrated pest management, and the utilization of daily data for the calculation of irrigation scheduling.

The uniform data file is used to calculate daily potential evapotranspiration (ET), chilling requirements for fruit trees, growth rates, and yield from the daily weather data using computer models. The main model used to estimate crop water requirements is based on Penman-Montieth equations. Plant growth is directly related to the climatic conditions that affects canopy area index and leaf area index. Estimating plant growth according to prevailing weather conditions dramatically improves the quality of estimated crop-water requirements. There are several growth models that are currently utilized in this aspect.

Growing-degree-days (GDD) is estimated from the hourly temperature and two thresholds (upper and lower), and GDD is used for the prediction of the development rate of any biological organism, providing the upper and lower threshold temperatures. It is currently used for some economical insects. Growing-Degree-Day Units (GDU) are calculated using the equation:

$$(T-B)*(T/1.440)= DD$$

Where:

T $\equiv$ Temperature at time (t); B $\equiv$ Base temperature;
 T_i $\equiv$ Time interval in minutes between temperature readings.

Daily GDU data is calculated at CLAC and send to the Plant Protection Research Institute (PPRI), and, by knowing lower and upper thresholds of each insect; we can build a good prediction for development of the pest and for planting dates.

Distribution

Information is produced and disseminated to the growers via several channels. It is faxed to ten local broadcasting stations to be included in the daily news programs. Daily distribution to the direct customer as specifically needed is also possible by fax upon request. CLAC produces a newsletter at 10-day

intervals, including meteorological information and agricultural applications in the form of extension recommendations. It is distributed to a mailing list, including all universities, research organizations, agricultural offices in the Ministry of Agriculture and Governorates, and also to growers on their demand. CLAC is now preparing a web page that includes current activities and available data and information.

REFERENCES

- Bilbro, J.D. 1975. Relationship of air temperature to first bloom dates of cotton. *Texas Agric. Exp. Sta. Misc. Publ.* No. 1186.
- Fry, W.E. 1982. *Principles of Plant Disease*. Academic Press, New York.
- Harsh, S.B., J.W. Lloyd, and L.R. Borton. 1989. Models as an aid to decision-making. *Acta Hort.* 248: 27-48.
- Jones, A.L., P.D. Fisher, and J. Seem. 1984. Development and commercialization of an in - field microcomputer delivery system for weather - driven predictive models. *Plant Dis.* 68: 458-463.
- Krug, H. 1989. Growth models as an aid for planning vegetable production in greenhouses. *Acta Hort.* 260: 391-400.
- Lichev, S. 1965. Effect of the weather condition on the emergence and development of cotton. (Bulg.) *Rast. Nauki* (1964), 1, No. 10: 93-101. (Cited after *Field Crop Abs.* VI. 18 No. 4).
- Makram, E.A., K.A. Ziadah, and W.M. El-Shazly. 1995. The proper soil temperature for sowing cotton early. *J. Agric. Sci. Mansoura Univ.* 20(7): 3191.
- Medany, M.A., M.M. Wadid, and A.F. Abou Hadid. 1997. New extension system for modern irrigation management in Egypt.
- Nelson, L.E. 1968. Effect of root temperature variation on growth and transpiration of cotton (*Grossypium hirsutum* L) seedlings. *Agron. J.*, 59(5): 391-396. (Bibl. 14, Mississippi Agric. Exp. Stn. State College.
- Royer, M.H., and J.M. Russo. 1989. Plant disease prediction using a meso-scale weather forecasting technique. *Plant Dis.* 73: 618-624.

Aridity, Drought, and Desertification: Roles of Science

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ABSTRACT

Productive lands provide their associated societies (humans, livestock, and fauna) with food, fodder, fuel, and other needs. There are limits to the quantity of biomass materials that may be harvested sustainably, which, if exceeded (over-exploitation), bio-productivity declines and land shows signs of degradation. In humid regions, the limits may be within a wide range: bio-productivity is active and is capable of replacing the harvested biomass at rates that redress the damage. In drylands, limits are narrow, bio-productivity is low, and the capacity of the ecosystem to recuperate and to redress damage is low. This restricted resilience is often described as fragility.

The purpose of this paper is to review the features of habitats and their vulnerability to stress, describe environmental hazards that menace life-support systems in the worldwide drylands, and to outline the roles that science and technology can play in enabling the habitats (ecosystems) and their people (societies) to cope with these environmental hazards. Science and technology operate within systems that need to be institutionalized in the arid regions of world.

ECOSYSTEM FRAGILITY

Fragility of ecosystem often relates to inherent attributes that make it vulnerable to irreparable damage if stressed (Kassas, 1998).

Drylands

Dryland ecosystems represent one class of fragility that relate to the following natural features:

1. Water resources limited (low rainfall) and year-to-year variable (recurrent incidents of drought), and rainfall confined to a season.
2. Plant cover thin (does not afford effective protection against erosion), bio-productivity low (carrying capacity limited).
3. Plant growth with notable seasonal variation, soil devoid of protective plant cover during the dry season.
4. Skeletal soil (surface deposits show little development), with low content of organic carbon (litter actively oxidized at surface and not incorporated in A horizon).
5. Physico-geochemical processes may form surface crusts (in stabilized deposits), sub-surface carbonate/sulphate-rich layers, or hardpans.
6. Bio-geochemical processes within the ecosystem

retain nutrients within aboveground biomass and not in the soil; removal of plant growth deprives the ecosystem of its stock of nutrients.

7. Recurrent drought (one or a few years with below-average rainfall) and desiccation (prolonged drought of several successive years: UNSO, 1992) represent acute ecological stress.
8. Many species of plants and animals are at the limits of their temperature ranges; spells of higher temperature or incidents of cold temperature (frost) may cause widespread damage to these organisms.
9. Locust raids recur and may have destructive impacts on dryland vegetation.

Highlands

Highlands with their slopes, precipices, and ravines represent fragile ecosystems worldwide. This relates to the intensity of runoff processes and the active erosive powers associated with it. In humid territories (annual rainfall more than 1000 mm), growth of tree formations (natural or planted) can reduce this erosive power. Deforestation causes widespread erosion. In dryland areas, vegetation cover of highlands is often thin and may only partly impede the erosive powers of runoff. Coastal mountain ranges may receive additional orographic precipitation, and plant cover is less austere (mountain oases, see Troll, 1935; Kassas, 1956). Extensive soil conservation structures (contour terraces, bunds, etc.), and plantations (grass stripes, tree lines, etc.) are necessary to sustain productive plant growth. These are labor-intensive works and their maintenance requires sustained management. Neglect of these elaborate structures results in land degradation, i.e., desertification (Kates et al., 1977).

Drainage Systems (Wadis)

Landforms in dryland territories (rolling plains, plateaus, hills and other physiographic units of dryland-erosion cycle (Cotton, 1974) control water redistribution: runoff water collects in sites with levels lower than the surrounding territories. It has been suggested (Monod, 1954) that arid lands may be classified into: (i) runoff deserts (extremely arid) where perennial plant growth is confined to runoff collecting sites, and (ii) rainfall deserts where perennial plant growth, though richer in runoff favored sites, is widespread. These topographic peculiarities have been utilized by dryland inhabitants: areas of the Near East countries bear relicts of elaborate systems of runoff farming, especially during the Greco-Roman times (Evenari et al., 1971; Kassas, 1972). This has been elaborated in recent times into water-harvesting farming.

Extensive drainage systems (*wadis*, *khors*, etc.) that collect and contain runoff water are features of dryland landscapes. Each system is fed by an often-extensive catchment area; *wadis* may be transformed into ephemeral water flows (torrents) after incidents of cloudbursts. These torrents are often mighty and destructive (one of the natural hazards of arid lands). History of land use in drylands include examples of constructions (dams) that were meant to store parts of these water flows, e.g., Saad Maareb in Yemen, Sad El-Kafara (Wadi Garawi) in Egypt.

Recent projects of building reservoirs in drylands to tap these spates of water flow have met limited success, reservoirs soon silted and their capacity was reduced. Here, vulnerability relates to the accidental nature of rainfall (cloudbursts) and the efficiency of the naked terrain in collecting runoff water and transforming it into rivers that are short-lived and destructive. Ecological management that harnesses the natural alluvial-depositional processes may render the system less vulnerable (Kassas and Imam, 1954). Wadi hydrology (Wheater, 1997) has become a part of the UNESCO-sponsored International Hydrological Program (IHP).

Islands

There are numerous inhabited or uninhabited islands in seas and oceans of the arid zones of the world. These islands are fragile systems whose fragility relates to small size, exposure to oceanic storms and other natural disasters, isolated biota, excessive exploitation of mineral and renewable resources, and attractiveness to tourists. The vulnerability of island biota (including indigenous humans) to exotic pests is a matter of special concern (Brookfield, 1980). Socotra Island (Yemen) has very special and particularly interesting flora, including numerous endemic species, and deserves special conservation measures. Coral islands are often low-lying and hence susceptible to oceanic surges and would be particularly vulnerable to likely rise in sea level as a consequence of global warming.

ARIDITY

Aridity may be conceived as state of imbalance between limited water resources, and excessive water expenditure. Temporary aridity may occur in all climatic regions when incidents of rainfall failure (drought) happen. But aridity is a feature of world drylands where water deficit prevails during all the year (extremely arid) or during most of the year (arid and semi-arid). Aridity may be assessed on the basis of (1) climatic variables (aridity index) or (2) measure of days during which water balance allows plant growth (growing season).

Low rainfall is the most obvious climatic feature related to aridity, but it is the effectiveness of rainfall (P) that matters: rainfall associated with low temperature, high humidity and low evapotranspiration potential is more effective than that associated with high

temperature, low humidity and hence high potential evapotranspiration (PET). Several formulae have been proposed to calculate an aridity index (AI), the simplest being the ratio P/PET . Values of less than one indicate a degree of moisture deficit. The World Atlas of Desertification (UNEP, 1992) sets the limits of world drylands as:

1. Hyper-arid: $P/PET < 0.05$.
2. Arid: $P/PET < 0.20$ (annual precipitation 200 mm in winter rainfall territories and 300 mm in summer rainfall territories).
3. Semi-arid: $P/PET < 0.50$ (annual precipitation 500 mm in winter rainfall territories and 800 mm in summer rainfall territories).
4. Dry sub-humid: $P/PET < 0.65$.

According to these categories, the world total drylands comprise 47.2% of the world land area; 7.5% hyper-arid; 12.1% arid, 17.7% semi-arid; and 9.9% dry sub-humid.

FAO adopts as a basis for defining and classifying drylands, the number of days during which plant growth may proceed. Regions with less than 120 growing days per year are drylands; arid lands have a growing period of up to 74 days, and semi-arid lands have 75-119 days growing period. Dryland climates are characterized by low and highly variable rainfall level (FAO-RNEA, 1994). These are reflected in limited and uncertain levels of crop and livestock production. This perception of dryland relates to land bio-productivity that is mainly dependent on volume and season of rainfall. Water is the limiting factor for plant growth in arid territories.

PRINCIPAL ENVIRONMENT HAZARDS

Drought

Drought is generally perceived as the incidence of below-average availability of natural water. Below average has a physical meaning (below the long-term normal) and a societal aspect (below the expected volume that would satisfy the needs of agriculture, livestock and domestic use). Manifestations include annual rainfall less than normal, reduced river flow, and reduced groundwater availability. Incidents of drought are natural hazards that may be disastrous. Riebsane et al. (1990) estimated that the 1988 drought in USA caused losses of about \$40 billions, making this single-year drought the costliest disaster in American history (Wilhite, 1996).

Management of drought is similar to management of other natural hazards; it comprises three principal elements: *an early warning (forecast) mechanism*, *societal preparedness* (society organized and drilled to face the event), and *an enabling mechanism that would provide support and relief to menaced communities*. Early warning is a key element (Wilhite, 1996).

Distinction is made between drought (1-2 years with below-average rainfall), and desiccation, dry

period lasting for a decade or more, (UNSO, 1992). The often quoted example is the failure of rainfall in the Sahel region (Africa); for the 25-year period 1965-'90 rainfall decline, as compared with the long-term average (1901-'92), was between 20 and 40% (Hulme and Kelly, 1993). Drought is an aspect of inter-annual variations that is a usual attribute of low-rainfall climate, but protracted drought (desiccation) may herald a degree of climate change.

Desertification

Article 1 (a) of the UN Convention to Combat Desertification (CCD) states that desertification means land degradation in arid, semi-arid and dry, sub-humid areas resulting from various factors, including climatic variation and human activities. Article 1 (e) defines land as the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system. Article 1 (f) defines land degradation as the reduction or loss of the biological or economic productivity of rainfed cropland, irrigated cropland, or range pasture, forest and woodland resulting from land uses or from a process or combination of processes arising from human activities and habitation patterns, such as (i) soil erosion caused by wind and/or water, (ii) deterioration of the physical, chemical and biological or economic properties of soil, and (iii) long-term loss of natural vegetation.

Land degradation is perhaps a clearer term than desertification, but desertification is a broader concept than earlier terms like desert creep and encroachment of the Sahara (Bovill, 1921; Stebbing, 1937, 1938, 1953). These terms suggest that deserts extend their areas beyond their natural (climatic) limits onto bordering territories. This perception is valid only as regards mobile sand bodies that move from their origin in the desert and overwhelm farmlands and settlements in oases or in productive lands out-skirting the desert. This is a small part (about 10%) of the problem. Desertification is initiated in productive lands that eventually become less productive or non-productive (desert-like) and thus add to the desert areas.

Symptoms of desertification are different in different types of land-use in dryland regions that are prone to degradation: in irrigated farmlands it is often due to imbalance between excessive irrigation and inefficient drainage (water-logging, salinization); in rainfed farmlands, it is often manifested as soil erosion, loss of organic matter and nutrients, etc.; in rangelands, it includes reduction of bio-productivity, invasion of non-palatable species, poorer livestock, etc. according to FAO (1993), desertification should be viewed as a breakdown of the fragile balance that allowed plant, human and animal life to develop in arid, semi-arid, and dry, subhumid zones. This breakdown of the equilibrium, and of the physical, chemical and biological processes that sustain it, represents the start of a process of self-destruction for all elements of the life

system. Thus, soil vulnerability to wind and water erosion, the lowering of the watertable, and the impairment of the natural regeneration of vegetation, the chemical degradation of soil - they all are immediate results of desertification - worsens the situation. Desertification feeds on itself.

Two questions may be posed. The first is "can desertification be stopped?" The answer is yes, provided that management of land is based on a packet of measures that ensures sustainable development of land resources. Because of the yes answer, Agenda 21 (UNCED, 1992) included Chapter 12 (managing fragile ecosystems: combating desertification and drought), and the CCD called upon countries menaced by recurrent drought and desertification to elaborate national plans-of-action.

Action programs for combating desertification embrace four classes of interrelated actions: (i) *Preventive measures* that ensure that use of land-and-water resources is sustainable, these are conservation measures that would protect the productive system against excessive use; (ii) *Corrective measures* that redress partly damaged land system and restore its productivity; (iii) *Rehabilitation measures* that aim at reclaiming lost (severely damaged) land; (iv) *Development of natural resources of drylands*, including extremely arid lands (natural deserts), this would include non-agricultural land use. These action programs should be set within national land-use plans with boundary limits based on land capability (land suited for pasture should not be transformed to farmland as this would exacerbate their fragility) and requirement of sustainable use.

Sustainable development of natural resources, including land resources in territories prone to desertification, needs to be based on integrated sets of measures and guidelines for action that may be grouped under three packets of components. (1) *Monitoring and assessment* that collect and provide basic data and information on quantity and quality of resources, on the inherent processes that operate in resource ecosystems, and on the state of life-support systems. Monitoring (survey and inventory should precede the planning of projects (next component) and should also follow the implementation and management of projects to assess its impacts and status. (2) *Management of actions and programs* of development and corrective measures address the four classes referred to above (prevention, correction, rehabilitation and development). (3) *Supporting measures* include: research, education and training (manpower development), institutional arrangement including capacity-building, legislative set-ups, awareness and public participation, mobilization of resources, etc.

Action programs for combating desertification and for combating degradation of all types of fragile ecosystems should be based on management modalities that combine government control (legal instruments), government assistance (including financial support) and

guidance (land-use policies), supportive national development schemes (railways, roads, water conservation projects), application of sound technologies and scientific knowledge; in short, development of natural resources within the framework of an ecologically sound, land-use policy and ensuring positive participation of people concerned. The latter is a cardinal element, and FAO (1993) sets as the main guiding principle in sustainable development and combating desertification the promotion of voluntary and responsible popular participation, through measures that are:

- *Legislative* (rights and duties linked to the use of land resources, access to property and usufruct, association and organizational rights);
- *Economic* (working with markets, prices, access to credit and the means of production, transport and storage infrastructure);
- *Social* (access to education and training, improved public health, support for rural organizations sensitizing the population to their roles);
- *Institutional* (decentralization, national and local mechanisms for rural development, combating desertification, etc.)

The second question asks if desertification is a global issue? Distinction may be made between two types of global issues, *systemic* and *cumulative* (Botkin, 1989; Turner et al., 1990). The former interferes with one of the general processes of the Planet Earth; it may be caused by actions in a few (limited) places of the biosphere but it affects the entire biosphere. Examples of systemic global issues include climate change (global warmth) and depletion of the stratospheric ozone. Cumulative global issues are geographically widespread, present almost everywhere, and are global in their areal extent. Examples of cumulative global issues include loss of biodiversity, population explosion, land degradation (desertification and deforestation), epidemic diseases, etc.

Desertification qualifies for both cumulative and systemic global issues. It is geographically widespread; dryland territories in some 100 countries in all continents are prone to desertification. These areas include developed countries (USA, Australia, Spain, etc.) and developing countries in Africa, Asia, and Latin America. It directly relates to the systemic process of climate in several ways.

1. Deserts and desertification-prone territories are sources of atmospheric dust that may spread far beyond the source, i.e., land, (Morales, 1977). Atmospheric dust modifies the scattering and absorption of solar radiation in the atmosphere; its effect on temperature depends on the altitude at which it is borne (Bryson, 1972). Climatic impacts of particulate substances (aerosols) suspended in the troposphere may be no less than that of many other pollutants, including greenhouse gases (IPCC, 1996).

2. Impacts of impoverishment of plant cover on ground-surface energy budget and on the temperature of near-surface air were subject to many studies (Jackson and Idso, 1975; Balling, 1988, 1991; Schlesinger et al. 1990). Two processes are involved, i.e., increased surface albedo (cooling effect) and reduced removal of soil moisture by evapotranspiration (warming effect). For a comprehensive review of the links between desertification and climate, see Williams and Billing (1996).

SCIENCE AND TECHNOLOGY

Brief History

From 1950 to 1960, UNESCO led an international program of arid-zone studies. The object was to promote and stimulate research in various scientific disciplines which have a bearing upon problems of arid regions. The ultimate aim was to improve the living conditions of mankind and, in particular, the people living in desert and semi-desert regions. The program and the world-wide interest it created, produced some 30 volumes of Arid Zone Research covering hydrology, plant ecology, energy resources, human and animal ecology, climatology and microclimatology, etc. About 200 desert research units in some 40 countries were established.

An international program on biological studies (IBP) led by the International Council of Scientific Unions (ICSU) from 1964 to 1974 contributed to studies of desert biomes (as one principal biome of the biosphere) and other aspects of arid-land ecology and conservation. In 1971, UNESCO initiated a broad-based program (Man and the Biosphere: MAB) with projects (Projects 3 and 4) addressing issues of arid lands and their people. This sustained international interest in the science of arid lands, and considerable volume of knowledge was built up during the 1950-'80 decades. But only a little of this knowledge seemed to have reached fruitful application, as was dramatically illustrated by the catastrophic events of the 1968-'73 droughts that menaced the Sahel countries of Africa and that extended in subsequent years to the Sudano-Sahelian belt, from the Atlantic to the Horn of Africa.

In 1974, the UN General Assembly had two resolutions. The first called for worldwide collaborative effort in fields of science and technology relevant to control of desertification, and urged developed countries to assist desertification-prone countries in developing their indigenous scientific capabilities that would enable the assimilation and application of available wealth of knowledge. The second decided to hold a UN Conference on Desertification (UNCOD), which was held in Nairobi (Kenya), 29 August - 9 September 1977, and produced a Plan-of-Action to Combat Desertification (PACD), a technically elaborate document (28 recommendations). Section F of the PACD addressed strengthening science and technology at the national level, (Recommendations 18-20).

In its subsequent follow-up of the implementation of the PACD, the UN General Assembly in 1980 called on United Nations Environment Programme (UNEP), in cooperation with UNESCO and other UN bodies and private foundations, to develop programs of research and training at the national, regional and international levels, (see UNEP document, December 1985. Research and Training for Desertification Control).

Agenda 21 adopted by the UN Conference on Environment and Development (1992) included Chapter 12 (managing fragile ecosystems: combating desertification and drought). This chapter describes six programs of action; Program A addresses strengthening the knowledge base and developing information and monitoring system for regions prone to desertification and drought, including economic and social aspects of these ecosystems.

The UN Convention to Combat Desertification (CCD) in its Articles 16-19 addresses the following areas:

16. Information collection, analysis and exchange.
17. Research and development,
18. Transfer, acquisition, adaptation and development of technology.
19. Capacity building, education and public awareness.

Article 24 establishes a Conference of Parties Committee on Science and Technology, and Article 25 requests the Committee to assist in networking of institutions, agencies, and bodies with a view to ensuring that the thematic needs set out in Articles 16 to 19 are addressed.

This brief historical review (1950-1994) shows that the international community sustained its concern with the roles that science and technology (including information, education, training, and awareness) can play in national, regional, and world endeavours to combat desertification and manage drought.

Worldwide Issues

Impacts of desertification and recurrent drought have local/national manifestations and their management is primarily a national concern. For this reason international documents (1977 UNCOD Plan-of-Action, 1992 UNCED Agenda 21, UN Convention for Combating Desertification) stress the central importance of national action plans. But these manifestations are spread worldwide and certain aspects may be better addressed at regional or sub-regional levels. Technical issues require international endeavour and/or systems for effective exchange of information, these include:

- Recurrent drought,
- Combating land degradation,
- Movement of sand formations,
- Monitoring and assessment of desertification,
- Development of deep-seated groundwater resources,
- Desalination of salt and brackish water.

Drought: Early Warning Systems

Recurrent drought is a natural hazard as it relates to year-to-year variation in rainfall, which is an inherent attribute of climate in arid regions. Management of natural hazards requires three elements: *an early warning system, societal preparedness, and an enabling mechanism* to provide support to menaced societies. The latter two elements may be carried out at national level within the framework of national action plans.

National meteorological services have facilities of daily weather forecast and may have access through meteosats (weather monitoring satellites) to information for several-day forecasts. FAO and WMO have programs that provide countries with information derived from meteo-satellite imagery that could be used as rainfall forecast (weeks). USAID initiated a famine early warning system (FEWS) project for drought-menaced African countries. National early warning system is available in a few countries of Africa (e.g., Ethiopia). But a system of drought early warning (a few months ahead) needs to operate within an international facility.

An early warning system for climate anomalies such as failure of rainfall (drought) or excessive rainfall (floods) needs to be set on international bases, as it has to relate to teleconnections between distant climate regimes. Available studies (see Glantz et al., 1991) indicate the likely relations between the ENSO phenomena of the Southern Hemisphere and climatic anomalies in various parts of the world, and the likely relations between the North Atlantic climate and ocean phenomena and the climatic anomalies in the Indian Ocean (monsoon climate) and in the Mediterranean basin. An international facility, supported by world bodies (WMO) and national agencies, could provide to all countries regular flow of information relevant to climatic anomalies

International Research Centers

International science has functions to be carried out that relate to two areas. The first relate to technological innovations and development, the second to monitoring and assessment.

Combat of desertification (preventive, corrective, rehabilitation and development programs, see Section 3.2) needs to be based on sound scientific and technological bases. A wealth of knowledge is available for initiation of action, but gaps remain either because of actual shortages of knowledge or because of lack of indigenous mechanisms that transfer available knowledge to local implementation. The latter situation prevails in most of the desertification prone developing countries.

Experience of the past years (since UNCOD, 1977) showed that we lack means for worldwide monitoring and quantitative assessment of desertification. Available figures (Dregne et al., 1991) are based on expert estimates and depend on limited case studies. Such figures remain questioned. This gap requires a

worldwide system of benchmarks and a set of agreed indicators to be monitored.

These functions may be carried out by a network of international research centers set in the main eco-geographical regions of the world drylands. For instance, Kassas (1977) suggested eight eco-geographical regions: Australia, Central Asia, Irano-Indian region, Arabian Peninsula, North Africa and Southern Europe, South Africa, North America, and South America. These divisions may be modified for operational convenience, but should remain eco-geographically based and not geo-politically based. These centers should be international (similar to the network of international agriculture research centers). Their institutional arrangements should provide them with political immunities and independence; their international status will allow the flow of knowledge and technological innovations produced by these centers to all countries where needed. Each center will:

- (i) Provide the countries of its region with technical and scientific assistance required for planning and implementation of national programs of action, assist countries in their plans for capacity-building, including training of technical and management personnel.
- (ii) Carry out research programs that aim at filling gaps in scientific and technological knowledge relevant to sustained development of land and water resources in drylands, and establish experimental fields and sites to test and demonstrate the application of the research results.
- (iii) Act as a clearinghouse for technical means for stabilizing sand bodies, use of low quality water for irrigation, new species and varieties of species with capacity to tolerate salinity and/or aridity, use of new and renewable sources of energy, and designs of environmentally sound human settlements, etc..
- (iv) Establish and operate a network of benchmark sites for monitoring and assessment of desertification, regional networks will be parts of a worldwide system.

Facility for Water Technologies

In a new appraisal and assessment of world water resources for the 21st Century, Shiklomanov (1998) shows that freshwater available to countries in the arid regions of the world ranges from very low (less than 2000 m³ per capita per year) to catastrophically low (less than 1000 m³ per capita per year). At the present time, 76% of the total population has specific water availability of less than 5000 m³ per year per capita, with 35% having very low or catastrophically low water supplies. This situation will deteriorate further in the beginning of the next century; by 2025 most of the Earth's population will be living under conditions of low or catastrophically low water supply.

This 1998 new appraisal shows that of the total 1386 million cubic kilometers of water (Earth's hydros-

phere) 97.5% is saltwater and 2.5% freshwater. The greater portions of this freshwater are 68.7% in the form of permanent ice (Antarctic, Arctic and mountain regions) and 29.9% in groundwater, mostly deep seated. Only 0.26% of the total freshwater of the Earth is in lakes, and river systems where water is accessible for our economic needs (64,000 km³), and this very small portion is not evenly distributed.

Shortage of freshwater is a truly global problem felt today in the regions of drylands and shall be felt tomorrow worldwide. An international effort needs to be waged with the aim of increasing the share of water available to the world life-support systems. Three areas of *technological advancement* need to be addressed with a view to make the tapping of additional portions of freshwater economically viable: (1) further development of technologies for desalination of salt and brackish water, (2) further development of *pumping technologies* for hauling deep-seated groundwater, (3) developing a means for *transport (towing) bodies of ice* from northern and southern oceans to territories of water deficit. In all these areas, technological breakthroughs are required including use of non-conventional sources of energy.

A world facility (with support of an international center or an international program with a network of centers) needs to be established and provided with means and with generous resources that will enable it to deliver the required results.

REFERENCES

- Balling, R.C.J. 1988. The climate impact of Sonoran vegetation discontinuity. *Climate Change* 13: 44-109.
- Balling, R.C.J. 1991. Impact of desertification and regional and global warming. *Amer. Met. Soc.* 72: 232-234.
- Botkin, D.B. 1989. Science and global environment. p. 3-14. In Botkin, D.B., et al. (Ed.). *Changing the Global Environment*, Academic Press.
- Bovill, E. 1921. The encroachment of the Sahara on the Sudan. *J. African Soc.* 20: 175-188; 289-269.
- Brookfield, H.C. 1980 (Ed.). Population-Environment Relations in Tropical Islands: The Case of Eastern Fiji. *Technological Notes* No 13. UNESCO, Paris. 227 p.
- Bryson, R. 1972. Climatic modification by air pollution. p. 133-174. In N. Polunin, (Ed.) *The Environmental Future*. MacMillan, London.
- Cotton, C.A. 1947. Climatic Accidents in Landscape-Making. Whitcombe & Tombs, Christchurch, N.Z. 240 p.
- Dregne, H.E., et al. 1991. A new assessment of the world status of desertification. *Desertification Control Bull.* 20: 6-18.
- Evenari, M., L. Shanan, and N. Tadmor. 1971. The Negev. Harvard University Press, Cambridge, USA. 345 p.

- FAO. 1993. Sustainable Development of Drylands and Combating Desertification: *FAO Position Paper*. Food and Agriculture Organization, Rome. 28 p.
- FAO-RNEA. 1994. A Systems Perspective for Sustainable Dryland Development in the Near East Region. FAO-Regional Office for Near East Asia, Cairo. 49 p.
- Glantz, M., R.W. Katz, and N. Nichols. 1991 (Ed.). *Teleconnections Linking Worldwide Climate Anomalies*. Cambridge University Press, Cambridge, UK. 535 p.
- Hulme, M. and Kelly. 1993 Exploring links between desertification and climate change. *Environment* 35: 4-11; 39-45.
- IPCC. 1996. *Climate Change: The Science of Climate Change*. Camb. Univ. Press.
- Jackson, R.D., and S.B. Idso. 1975. Surface albedo and desertification. *Science* 189: 1012-1013.
- Kassas, M., and K. Imam. 1954. The wadi bed ecosystem. *J. Ecology*, 42: 424-442.
- Kassas, M. 1956. The mist oasis of Erkwit. *J. Ecology*, 44: 180-194.
- Kassas, M. 1972. A brief history of land-use in Mareotis region, Egypt. *Minerva Biological* 1: 167-174.
- Kassas, M. 1977. Arid and semi-arid lands: problems and prospects. *Agro-Ecosystems*, 3: 185-204.
- Kassas, M. 1995 Desertification: a general review. *J. Arid Environ.*, 30: 115-28.
- Kassas, M. 1998. Fragile ecosystems in Near East countries: problems and management. In B. Gopal et al. (Ed.), *Ecology Today*, Int. Sc. Pub., New Delhi.
- Kates, R.W., D.L. Johnson, and K.J. Haring. 1977 Population, society and desertification. p. 261-317. In *Desertification: Its Causes and Consequences*. United Nations Environment Programme, Nairobi, and Pergamon Press, New York.
- Monod, Th. 1954. Modes contret et diffus de la vegetation saharinne. p. 35-44. In J.L. Cloudsley-Thompson (Ed.), *Biology of Deserts*. Institute of Biology, London.
- Morales, C. (Ed.) 1977. Saharan Dust: Mobilization, Transport, Deposition. SCOPE-Swedish Academy of Sciences. NFR, Stockholm.
- Riebsame, W.E., S.A. Jr. Chagnon, and T.R. Karl. 1990. Drought and Natural Resources Management in United States: Impacts and Implications of the 1987-89 Drought. Westview Press, Boulder, Colorado.
- Schesinger, W.H., J.R. Reynolds, G.L. Cunningham, L.E. Huenneke, W.M. Jorrell, R.A. Virginia, and W.G. Whitford. 1990. Biological feedback in global desertification. *Science*, 247: 1043-1048.
- Shiklomanov, I.A. 1998. World water resources: A new appraisal and assessment for the 21st century. UNESCO, IHP.
- Stebbing, E.P. 1937. The threat of the Sahara. *J. African Society*, supplement to Vol. 36 London. 36 p.
- Stebbing, E.P. 1938. The man-made desert in Africa. *J. African Soc.*, supplement to Vol. 37. London. 40 p.
- Stebbing, E.P. 1935. The Creeping Desert the Sudan and Elsewhere in Africa. McCorquodale, Khartoum, Sudan. 165 p.
- Troll, C. 1935. Wüstensteppen und Nebeloasen im Südnubischen Küstengebirge. *Zeitschrift der Gesellschaft für Erdkunde zu Berlin*, p. 741-281.
- Turner, B.L., et al. 1990. Two types of global environmental changes. *Global Environment Change*, 1: 14-22.
- UNCOD. 1977. United Nations Conference on Desertification. Nairobi 29 August, 9 Sept. 1977. *Round-up Plan of Action and Resolutions*. United Nations, New York, 1978. 43 p.
- UNCED. 1992. Report of the United Nations Conference on Environment and Development. Vol. I, United Nations, New York.: 486 p.
- UNEP 1992. *World Atlas of Desertification*. Edward Arnold, London. ix+69 p.
- UNESCO, *Arid Zone Research*, Vols. I-XXX, 1952-1962.
- UNSO. 1992. Assessment of Desertification and Drought in the Sudano-Sahelian Region. United Nations Sudano-Sahelian Office, New York. xv+102 p.
- Wheater, H.S. 1997. Wadi hydrology: process response and management implications. p. 1-13. In *Proc. UNESCO/NWRC-ACSAD Workshop on Wadi Hydrology*, Cairo, June 1997.
- Wilhite, D.A. 1996 A methodology for drought preparedness. *Natural Hazards* 13: 229-252.
- Williams, M.A.J., and R.C. Jr. Billing. 1996. Interactions of Desertification and Climate. United Nations Environment Programme (UNEP) World Meteorological Organization (WMO), and Edward Arnold, London. 270p.

A Social Contract for Arid Zones Development: Conceptualization to Implementation

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ABSTRACT

This conference has a challenging theme that requires a variety of approaches involving, behavioral, economic, educational, cultural, and technological aspects. All peoples of the world look hopefully at "sustainable development" as their breakthrough to a better life. Thus, it is important to look into the *control factors for sustainable development*. These include the necessity of establishment of a "social contract for sustainable development", which is defined as "the common view for development priorities which should be shared between" the political leadership, the state administration, and the public (beneficiaries of development). It means that everybody understands the goals, objectives, and development priorities of the country's sustainable development. Thereafter, scientists and technicians, as well as the state administration technocrats, work out planning and choice of appropriate technology, as well as implementation and monitoring of plans-of-action.

Consequently, the political system gets national support as well as socio-impolitical stability; furthermore, development projects become attractive to capital resources (national and international). Thus, the necessity to prepare Egyptians to use information, knowledge, and the skills for dealing with the development challenges in the Third Millennium becomes imperative and consequently policy changes in the human resources development should have a top priority in the Egyptian sustainable development plans. Furthermore, preparedness for the interaction with the "New World Order" and "Globalization" issues becomes imperative.

INTRODUCTION

The New World order is composed of several elements, namely freedom of trade, hegemony of technology and finance, and preservation of human rights, democracy, and the environment. Due to the interactions of these elements with sustainable development issues in any country, the clarity of the goals of development becomes imperative. Moreover, development goals had to be *shared with the whole nation as well as with the international funding organizations*.

Eventually, one of the most important goals of the social contract for development in Egypt should be the preparation of Egyptians to cope with the challenges of development in the Third Millennium. These challenges can be summarized as follows:

- Secure socioeconomic stability, peace, and security (regional and international).
- Secure needs for food, shelter, and a job for everybody.
- Restore the environmental safety in the Valley and control pollution in the new areas of development in the arid zones.
- The capability to assimilate high technology for development, the responsibility of which rests between the mother's role in establishing technology as a human value for development, and sharing that with the father and the school-teacher, all through the education system. The other sector of technology assimilation is the assimilation by the establishment, whether public or private production units. The policy and implementation programs are the responsibility of the Government and are labeled "the National Technological Policy".

Such challenges entail serious examination of the following issues:

1. Prompt and appropriate changes and orientation of the education and culture policies towards the use of the *available natural resources rather than the present orientation of development to the needs of the society*.
2. Although effective population control measures seem to have stabilized population growth, yet careful, prompt, and persistent birth control policies should be implemented to maintain and or decrease the present birth rate.
3. The perpetual exhaustion of the natural resources of the world and the eventual need for new materials should open the doors for human resources' scientific development.
4. Ensure the rapid and effective assimilation of high technology for development.
5. The acceptance and interaction with the principles of globalization within the context of preservation of the cultural roots from the effects of expected social derangements, which results from the application of high technology.
6. Establish and maintain peace and security in the region.

Consequently, the following parameters should be examined in order to identify *development objectives*: population and demographic issues, climate characteristics of the country, geopolitical features of the

country, optimal exploitation of the existing natural resources, securing energy resources for development, and synchronizing implementation of development infrastructure projects.

Population and Demographic Issues

During the last three decades, Egypt has enjoyed a reduction of the birth rate. Assuming the maintenance of this rate, and considering the expected population increase during the coming 20 years, 32-35 million Egyptians are to be added to bring up the total population to 96 million. The uneven and high population density in rural as well as in urban areas in the Nile Valley will keep that area among the most heavily populated areas of the world. The arid and desert areas in Egypt account for 95.5% of the surface area of the country and are inhabited by less than a million people (one of the most low population density in the world). The urgent need for information packages about the desert to be infused to the existing population, as well as to the expected 35 million newcomers by the year 2020, is highly needed. *Evidently, correction of such an imbalance is achievable through examining the opportunities of developing the arid and desert zones in Egypt.*

Climate

Egypt's surface area is about one million square kilometers, extending from the 22nd to the 26th meridians. It has 305 days a year of sunshine, and 95% of the country surface area is arid (Western Desert, 681,000 km²; Eastern Desert, 223,000 km²; Sinai, 61000 km²; and the Green Valley, 40,000 km²). While, the north Mediterranean seashore enjoys 150 mm of rainfall, the rest of the country has only a few millimeters of rainfall. The middle zone of the country has 5 mm of rainfall. The rest of the country gets spells of rainfall leading to occasional floods that flow to the Nile Valley or to the Red Sea or seeps down to the underground reservoirs.

The country's weather has four seasons and a variable degree of dryness and humidity in summer, which offers a relative agrotechnical advantage. It is evident that the desert climate is different from that of the Valley and that of the seashore. Therefore, the fauna and flora in the Valley, at the seashore and in the arid zones in Egypt, are diverse.

Geopolitical Features

As the Nile water resources come from equatorial and Abyssinian territories, bilateral and multilateral cooperative agreements (cultural as well as economic) have to maintain, regulate, and consolidate the national water rights of the Nile Valley countries. Artificial rain technology offers the Egyptian desert an opportunity to increase the rainfall yield in these arid zones. Such water can replenish and add to the underground water reserves in arid areas. It is obvious that the application

of artificial rainfall technology points to the need for an international agreement to regulate the ultimate and future use and benefits of this technology. Recent reports indicate the economic feasibility as well as the environmental safety of the technology of artificial rain. Being in the crossroads of air, maritime, and land communications that link four continents together entitles Egypt to be regarded as the cradle of civilizations.

Exploitation of Egypt Natural Resources

Illiteracy has dropped substantially, but it is still higher among females than males, and higher in rural than in urban regions. Thus, the elimination of illiteracy, especially among women, is a vital concern. Confronting the challenge of acquisition of high technology requires the introduction of the population into the information era through changing the education and culture policies. Among Egyptians, the interest and desire as well as the necessity of looking into the future of desert development were lacking, neglected and of low priority due to cultural, historical, and socio-political reasons.

The main reasons for this situation could be identified. The existence of vague vision of sustainable desert development among the Egyptian intelligencia and technocrats can be attributed to inadequacy of the availability of information about the natural resources in Egypt. Until the early decades of this century, the socio-political relationships between the Valley and desert dwellers were unstable. The psychological attitudes of the Egyptians came from the fact that all invasions of Egypt came through the deserts, thus creating psychological conditions of "Desert Phobia". There was a lack of the establishment of the development infrastructure in the desert, combined with the severity of the desert climate and the scarcity of water resources.

Lack of involvement of the Egyptian intelligencia in desert development is attributed to the fact that desert development has a low priority level among Egypt's development plans until the recent announcement by the political leadership of developing the arid zones. In addition, there were inadequate databases about Egyptian deserts in libraries and information resources. Reluctance and hesitation of economists and planners' interest in desert development trends can be attributed to the exhaustion of Egypt's financial resources in long-standing political regional conflicts; during the last five decades, desert development projects fulfilled partially their economic objectives.

The natural resources include: *Water*-surface, underground, seawater, and rainfall; *Energy*-hydroelectric, solar, wind geophysical and thermal resources; *Land*-valley, deserts, and seashores; *Mineral resources*-metals, phosphates and stones (granite, marble, alabaster, sand, limestone, etc.); *Oil and natural gas*. Transfer of oil, gas, and water in pipes prevents waste spillage and evaporation and offers chances of better usage control.

Cultural and Heritage Resources

Although Egypt has 45% of all the world's historical heritage, only a small part has been in display. An ambitious strategy for the development of this resource has to be urgently thought of such a strategy should be based upon covering all the discovered historical sites by a network of tourist services, including a museum for each dynasty site, and a modern and comfortable tourist infrastructure network to cover all the historical sites in Egypt. Whether explored or not, financing such a gigantic project shall be possible, as Egypt enjoys now a milieu of sociopolitical stability as well as steady economic growth. Furthermore, the Egyptian civilization has been an outstanding feature of a perpetual nature in the world's panorama of civilizations that offers Egypt the opportunity to stand as a focal platform where civilization confrontations would change into effective civilization integration, a cultural exercise, which is strongly related to the principles of globalization and preservation of world peace and human rights.

Climate Advantages

Egypt enjoys a temperate climate throughout the year, which allows the country (Valley and arid zones) to have a sort of a natural protected type of agriculture, thus, offering agro-production and its industries chances to challenge and meet exportation competition in foreign markets. Furthermore, the stability of barometric pressure during wintertime provides a superb chance for the development of health tourism and the use of spa resources of the country and the desert.

There is no doubt that the future energy needs for development will exceed the available existing conventional energy resources and their known reserves. Therefore, adoption of strategies of rational use of energy becomes mandatory. Renewable sources of energy such as solar, wind, biogas, and geophysical resources should attract serious attention and should be promptly looked at. Research and development, as well as education and training, should receive a priority in future high and university education programs.

Establishment of the infrastructure projects should precede or run parallel with the implementation of the main development projects. Such a policy will economize in terms of construction time as well as attracting early and prompt urbanization of the development areas, both of which have economic and psychological impacts, if due consideration is to be given to the problems of assimilation of technology, as well as to the optimal and rapid adaptation with the new socioeconomic world changes. Furthermore, in learning from other countries' experience in desert development, a strategy for the preparedness of Egyptians to develop the desert could be formulated and adopted. It is obvious that sociological and behavioral studies of Egyptians are urgently needed in order to set such a strategy.

POLICY CHANGES

The present concepts of desert development among the Valley dwellers (education and culture policies) require changes in the rest of existing policies in order to meet the requirements of desert development. Twelve policies have to be urgently looked at, and necessary changes are to be included without delay or hesitation.

Policy Changes in Education

Such changes must cope with the challenges of the Third Millennium, accepting the interaction with the principles of globalization, within the context of preservation of the cultural roots and accepting the interaction with high technology. Priority and consideration must be given to the elements of power shift and development, where brainpower is the most essential power of the development process. Priority should be given to the preparation of the different categories of teachers that can deal with the challenges of the Third Millennium with a special priority to preparatory, kindergarten, and technical schoolteachers. Eradication of illiteracy, especially among women in the child-bearing age group, and provision of information about the desert to this particular category of people. This involves:

- Introducing the whole population to the era of information and informatics.
- Introduction of all versions of education, e.g., open, continued, distance, and continuous teachers training and education systems.
- Changing the education policy from memorization to learning systems.
- Integrating a cultural component within the given education curricula.

Cultural and Tourism Policy Changes

Suitable packages of information about desert development and its flora and fauna should be introduced to all Egyptians in order to create psychological compatibility and a socio-behavioral balance with desert environment. Utilization of the desert climate in development desert-health resource should be promoted, as well as development of a cultural platform for civilization integration rather than civilization confrontation.

Development of a network of tourist sites in all geographical areas of historical heritage, combined with a local museum which collects all the heritage of the ruling dynasties as well as the provision of tourist services and facilities is a priority. Such a network will open up the optimal utilization of the historical heritage of Egypt.

Science and Technology Research Policies

The challenges of the desert development as well as its natural resources are the axial forces of identifying the research orientation and priorities and enforcing assimilation of high technology among the individuals and the institutions by all available means.

Other approaches include development of:

- Water resources and use as well as its transfer in the desert (network of pipes to prevent of water loss).
- Desalination and recycling research projects.
- Renewable energy resources (solar and wind).
- Desert agro-industrial and biotechnology research, with special reference to gazelle, ostrich, and crocodile animal husbandry; off-shore fisheries research and development would bridge the protein gap in the short or long term.
- New material research semi- and super-conductivity, etc.
- Health promotion research in the desert, i.e., desert medicine.
- Identification of the mineral resources and reserves through geophysical and geological surveys; the most important mineral ores are phosphates for phosphoric acid industry, silica for semi-conductor and glass industries, stones such as granite, famous for its low radioactive contamination (competitive advantage); limestone and clay for cement industry (construction and pipe industries); and alabaster and marble.

All such resources require high technology and a cheap system of transportation in order to survive free markets competition and require skilled manpower and efficient marketers; gems and precious stones (laser industry); metals (iron, gold, and others).

Artificial Rain Research

The application of this high technology can provide the western desert with huge amounts of rain yield (200 billion cubic meter). Such quantities could replenish the underground water reservoirs. Research and development in this field although expensive, but in the long term has endless advantages.

Health Promotion Policy in the Desert

Concurring with the concept that "prevention precludes the need for treatment", six major desert health problems require immediate health services planning and restructuring: sun exposure diseases; desert occupational industrial diseases; emergency medicine in the desert (road accidents and the associated system of telecommunication and transportation); toxicological accidents (plants, reptiles and plants); water scarcity diseases; and zoonotic diseases.

Agro-Industrial Policy

Integration between agro-industrial, infrastructure, industrial, and marketing policies is highly recommended. Research for the choice of plants suitable to sustain scarcity of water, dryness, salinity, and high temperature is needed. Genetic engineering technology is instrumental in this respect. Other measurements

should seek to intensify measures against locusts and other desert pests, determine water requirements for each plant and animal, and promote animal husbandry (camel, ostrich, sheep, goats, crocodile, gazelle and fisheries along the seashores), all of which require immediate and prompt research and development activities. Agro-industries of the desert can enjoy the opportunity of pollution-free products that are highly competitive in world markets. To ensure success in desert agro-industries, cooling, package, and efficient transport as well as communication systems should be available.

Water Use and Resource Policy

As water is the vital resource in desert areas, policies should seek to:

- Establish and complete the studies of the geophysical surveys of the desert underground water as well as its mineral resources.
- Restructuring the water-use system and its regulations as well as implementation of water pollution-protection law in the desert.
- Promotion of desert behavioral attitudes towards water use in the desert (culture, education, technology, and behavioral and sociological attitudes).
- Desalination technology for sea and underground water resources.
- Recycling of used or wastewater technologies.
- Formulating and strengthening politico-cultural relations with the Nile river basin countries

Industrial Policy

Agro-industries should be of a high technological standard, exploiting the advantages of a virgin environmental milieu. Furthermore, development of production unions among small-sized producers and farmers should be encouraged and supported. Coordination between education and industrial policies for the development of technical manpower is essential. Research and development policy changes are needed in the following: housing planning and related industries; textile, electronic, car and internal combusive engine industries; and refrigeration and cooling industries. Thus, its products and goods can suit and withstand the desert environment and climate.

Youth Activities in Desert Development

Involvement and understanding the social contract for desert development for youth should involve: (i) availing of packages of information, skills, and training necessary for desert development; (ii) youth summer activities directed and utilized in the infrastructure projects, e.g., railways, roads, animal husbandry, fisheries, fixation of sand dunes, and agricultural projects such as olive, palm and cactus plants; (iii) "learn and own" policy to encourage, promote, and attract youth to

work acquires desert skills to be able to settle in the desert projects; and (iv) new land for agriculture, which has a relative advantage of seed production technology.

Infrastructure Development Policy

Priority should be given to railways which cover all expected mineral resources sites as well as human settlement areas. Time-saving, capital expenses and cheap transport cost as well as safety of passengers and perishable products can be achieved. The railways and other surface and air communication networks should precede or at least be concomitant with the commencement of the implementation of the new projects. Time, capital expenses, and cheap transport cost as well as safety of passengers and perishable products can be controlled.

The choice of telecommunication system in desert development should rely on renewable energy as well as on the most advanced although expensive types of mobile and satellite systems. Planning and implementing all measures of environmental pollution control from industrial and/or human use should be achieved. All the suggested policy changes should eventually reflect on the different policies of education and culture.

Economic Policy

For sustainability and successful desert development of agro-industrial projects, the following requirements are to be provided:

- A reasonably good, efficient, durable infrastructure setup should be implemented that is concomitant with or, better yet, preceding the implementation of the projects in the desert.
- More investment in the educational system (public and private) in order to develop and prepare technologists and skilled labor for desert development (education and culture policy changes will be required).
- In addition to establishing large corporations, the formation of producers unions is needed to promote and sustain production of agricultural products or other ingredients of raw materials.
- Small-sized projects, industrial or agricultural, cannot withstand the complexity of marketing, capital equities, high technology and capital expenditure. Therefore, producers unions should be resorted to. Furthermore, linkages to agro-industries should be encouraged.
- Consideration that the optimal and economically feasible size of a desert farm in Egypt is 20 feddans should be subjected to more confirmatory studies.
- More and endless efforts exerted to open new markets, to join economic blocks, and to utilize optimally the foreign aid programs must be exerted.

Foreign Policy

Egypt should continue to develop and establish strong political ties, economic and cultural relations with all the Nile Valley countries, and establish and join the Arab and African economic blocks, as well as provide information coverage about the major development issues and environmental protection policy experience in Egypt. It should exert more social and political pressures to rid the desert from land mines, and join and participate in formulating and applying international treaties regulating use of space, oceanography, underground water, and artificial rain technology.

Legislative Policy

Such issues should include: restructuring and formulation of legislation for the desert, e.g., land ownership legislation in the desert; developing a new investment legislation for desert development; adding clauses to the criminal law to meet the needs for water-use crimes in the desert; and planning the legal and property registration services in the desert.

REFERENCES

- Shoura Assembly Reports (S.A.R.):
- Development of human resources in Egypt. 1982. Shoura Assembly Reports.
 - Development of women "A Prerequisite of Socioeconomic Development". 1984.
 - Towards cultural policy for Egyptians. 1985.
 - Towards an advanced educational policy. 1993.
 - National project for development Sinai. 1995.
 - A project for sustainable development of Upper Egypt 1996.
 - The strategy of vocational education in Egypt. 1998.
 - Towards a strategy of preparing Egyptians for developing the desert. 1999.
- El-Ganzoury, K. 1997. A Document on "Egypt's Development and the Third Millennium". Cairo, Egypt.
- Hebaish, A. 1997. Technological policy, Egyptian Academy of Science and Technology. Cairo, Egypt.
- Huntington, S. 1997. The clash of civilizations and remarking of world order. Touchstone Books, Simon & Schuster.

B. CONCURRENT SESSIONS

I. Soil Conservation and Degradation

Managing Irrigated Sandy Soils in Arid China

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ABSTRACT

Sandy soils are extensive in the arid north-central China region. Controlling wind erosion has been a major research objective on both dryland and irrigated soils since 1978. More recently, in an attempt to expand irrigation to sandy lands in proximity to rivers such as the Yellow River, techniques have been devised and tested to control wind erosion on individual fields. Much of the research deals with modification of the checker-boarding system that has been long used to protect transportation routes from sand encroachment. Alteration in the spacing of the checkerboard pattern from 1 m to 40 cm has been effective in protecting field borders, irrigation, and drainage canals from erosion. Plastic barriers in rice paddies also appear promising. For sandy soils irrigated by the silt-laden Yellow River water, surface soils can be changed to medium-textured soils in a few years. Controlling wind erosion in the early years of sandy land development is critical.

INTRODUCTION

Sand dunes and deep sandy plains are extensive throughout dry northern and western China. Most of them have been used for thousands of years for grazing

of sheep and cattle. As the population has increased rapidly in the last several decades, grazing land has been converted into cropland, particularly in the Inner Mongolia region and Shaanxi Province (Zhu, 1995). The result of that change in land use in China and elsewhere in the world's drylands is that good grazing land has been transformed into fragile cropland. Additionally, grazing pressure on the remaining rangelands has degraded them. Dunes formerly fixed by vegetation have become mobile, invading villages and covering roads.

Sand dune stabilization and wind erosion control are now major - and expensive - programs. Wind erosion is the principal desertification process in China. A massive program of tree planting was initiated in 1978 with the goal of afforesting 35 M ha by the year 2050 (Sanbei Bureau, 1989). The project is called the Sanbei Regional Shelterbelt Project. It operates in the northeast, north, and northwest of the country. Ultimately, the project will provide a "Green Great Wall" to accomplish the same objective as the shelterbelt projects in the Soviet Union and the USA in the 1930s. This paper reports on new irrigation developments on the sandy soils of the Ningxia Hui Autonomous Region in Central China (Fig. 1).

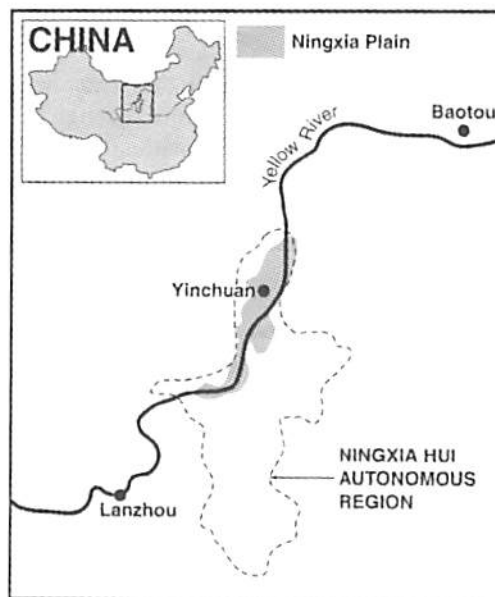


Fig. 1. Location map for Ningxia Hui Autonomous Region and the Ningxia Irrigated Area on the Yellow River.

IRRIGATED SANDS

Until recent decades, coarse sands were not normally irrigated due to their high permeability, low fertility, and low water-holding capacity. That policy has changed as the need for more food production has increased. A large afforestation program in 1978 was initiated, in part, to protect irrigated sandy oases in the desert from wind erosion damage. Most oases now are criss-crossed with lines of trees, giving the appearance of a giant checkerboard pattern.

Tree planting is being done on a truly spectacular scale in the arid regions. Roads in and around oases are bordered by as many as eight rows of trees, usually popular species. Both lined and unlined irrigation canals have trees planted along them. Those trees transpire tremendous amounts of water that seeps out of the canals. The aesthetic appeal of a shaded and cool oasis undoubtedly is very high, but the cost in water lost and increased soil salinization also is high (Dregne, 1988).

In the southeast part of the 250,000 ha Yinchuan irrigated Plain is a continuous area of low sand dunes that covers about 30,000 ha (Mei, 1989). Until recently, irrigation was largely confined to moderately fine soils in the Plain. Increased food demand and the availability of water from the Yellow River has led to a Government decision to extend irrigation to the sandy soils. All irrigation presently is by surface ditches; sprinklers and drip systems are uncommon.

Yinchuan Plain

The Yinchuan Plain lies between the Helan Mountains on the west and the Yellow River on the east. It is a subsided graben filled with 1,600 meters of Quaternary deposits. The Plain has a south-north gradient of between 1 to 2000 and 1 to 10000. Numerous lakes and marshes dot the landscape. Groundwater tables are high.

According to UNESCO, the Plain is classified as arid, with a continental climate of cold winters, warm summers, and an annual precipitation of 210 mm; the rainy season is from May to September. Annual duration of sunshine approximates 3,000 hours and pan evaporation is around 1,400 mm. The frost-free growing season is about 170 days. Principal crops are paddy rice, maize (corn), wheat, fruits, and vegetables. Fishponds are common.

Irrigation has been practised successfully in the Yinchuan Plain for over 2,000 years. In 1985, 43% of the soils were saline, a decline from the high of 67% in 1963. The drop in secondary salinization is attributed to an improved drainage system and a concerted effort to reduce soil salinity.

River Sediment

Sediment levels in the Yellow River in Ningxia are between 3 and 7 kg/m³, which is enough to pose a perpetual problem of cleaning irrigation canals to maintain designed flows. Silt in the irrigation water has, over the

centuries, raised surface elevations as much as 2 m or more. The source of nearly all of the silt is the Loess Plateau, which represents about 80% of the watershed of the Yellow River. Water erosion in the Loess Plateau is very high, with some land is said to be eroding at a rate of 300 tons/ha/year or more (Yang, 1989).

Although river sediment is believed to have played a large role in bringing an end to Mesopotamian irrigation in the 13th century (Jacobsen and Adams, 1958), it can have, and has had, a generally beneficial effect on Ningxia irrigation. The endless requirement for regular cleaning of canals is a big disadvantage, but siltation of reservoirs is an even greater problem because there is no economical way to clean reservoirs. On the other hand, silt in Ningxia has increased the fertility of irrigated soils and, importantly, raised the land surface level above the watertable.

RECLAIMING SANDS

The greatest benefit of silt has been to improve the texture of sandy soils. The Ningxia Water Conservancy Department is now open to cultivation of sandy lands that were previously believed to be unacceptable for irrigation. Within a few years, coarse sands have been transformed by silt in the water into loamy sands and sandy loams. The improvement process is a function of the sediment load and the depth of irrigation water applied; 40 cm of irrigation water carrying 5 kg/m³ of silt will deposit about 0.2 cm of silt in one year. Silt increases water and nutrient-holding capacity and reduces the wind erosion hazard.

In Ningxia, wind erosion control during the sandy land development stage is accomplished by checkerboarding the sides of canals and ridges between fields. When used in this situation, the individual squares are reduced from the customary 1 × 1 m spacing of plant stalks to around 25 × 25 cm. The closer spacing is needed to better protect the ridges. Windbreak planting accompanies the checkerboarding process. Checkerboarding can be discontinued after the trees have grown enough to be effective as windbreaks. Checkerboarding is labor-intensive at present. It should be possible to design a machine to press the plant stalks or a substitute material into the sand. Mechanization is essential to make the checkerboarding cheap enough to use where labor costs are high.

Subsoil Barriers

Creating barriers impermeable to water loss in sandy soils has long been an attractive concept. Barriers placed at depths of 20 to 40 cm would be an effective way to produce a situation approaching hydroponics in the field. Water-use efficiency should be high due to allow evaporation from the soil surface and little or no loss by leaching. Fertilizer efficiency would be high also in the absence of leaching. The main problem would be to avoid a toxic accumulation of salt and the development of anaerobic conditions. In principle,

those disadvantages could be overcome, but the cost of doing so could be significant, to say nothing of the cost of laying the barrier and replacing it. Machines have been developed to spray an asphalt barrier and to lay a plastic film.

The Institute of Desert Research of the Chinese Academy of Sciences in Lanzhou has been experimenting with use of plastic film in paddy rice production on coarse sandy soils (Huang et al., 1995). The most promising procedure at present is to lay a plastic film on a leveled sand dune, cover it with 25 cm of dune material, and allow irrigation water to move laterally through field banks to a lower area. Permitting water to flow out of the paddy field helps to prevent salt accumulation. That system does, however, increase water use. No tillage is done, but fertilizer and manure are applied. Yields of rice are approximate by 10,000 kg/ha.

According to an input-output financial analysis by Huang et al. (1995), input exceeds output in the first year, but the system becomes quite profitable in the second year. Experiments have not been conducted long enough to determine the durability of the plastic film.

DISCUSSION

Sandy soils are widespread in the north and west of China, where the climate ranges from hyper-arid to semi-arid, winds are strong, and wind erosion is a major threat. Until recently, few sandy soils were irrigated because of wind erosion and the low water-use efficiency associated with surface irrigation. As population pressure has increased and the need for food has gone up, more and more attention has been placed on sand dune landscapes in regions where water supplies are good. One of these regions is along the Yellow River in the Ningxia Hui Autonomous Region.

The Yellow River is the muddiest river in the world, ranking first in annual sediment load and average silt concentration (Mosely, 1985). Silt in irrigation water confers advantages and disadvantages. When used on sandy soils, silty water carries the major advantage of improving the physical as well as the nutrient

conditions of the soil. Ningxia is using that advantage, along with research that has been done on wind erosion control, to extend its irrigated area and increase crop production. It will require several years to raise productivity to the level of finer textured soils, but modifying checkerboard techniques already is controlling wind erosion.

Making subsoil barriers economically viable is a more difficult task. The procedure has been tested in other countries on high-value crops, but has been limited by its cost. Nevertheless, the idea is attractive.

REFERENCES

- Dregne, H.E. 1988. Irrigation development in north-western Xinjiang. *Chinese J. Arid Land Res.* 1: 185-190.
- Huang, X., L. Xinmin, Z. Halin, H. Zongying, and Y. Zhezhu. 1995. Eco-techniques of water-saving rice cultivation on sandy land. *J. Arid Land Studies.* 55: 227-230.
- Jacobsen, T., and R.M. Adams. 1958. Salt and silt in ancient Mesopotamia. *Science.* 128: 1251-1258.
- Mei, C. 1989. Oasis construction in arid regions: The basis for promoting economic development of surrounding regions. p. 187-188. *Arid Land Resources and Environment*, Inner Mongolia Forestry University, Hohhot.
- Mosely, P. 1985. Upstream-downstream interactions as natural constraints to basin-wide planning for China's River Huang. In: J. Lundqvist, U. Lohm, and M. Falkenmark (Ed.) *Strategies for River Basin Management*. Dordrecht; Reidel.
- Sanbei Bureau. 1989. A rising green great wall. Dadi Publ. House, Beijing. 173 p.
- Yang, Q. 1989. The physical-geographical zone of the Loess Plateau. *Chinese J. Arid Land Res.* 2: 283-292.
- Zhao, S. 1994. *Geography of China*. John Wiley & Sons, New York. 332 p.
- Zhu, J. 1995. Desertification and its control in China. p. 382-384. X. Xuncheng, and H.E. Dregne (Ed.) *The past, present, and future of deserts*. China State Science and Technology Commission, Beijing.

Wind Erosion as Related to Some Soil Conservation Practices in the Northwest Coastal Zone, Egypt

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ABSTRACT

The northwestern coastal zone of Egypt is subjected to wind erosion hazards. Such a region was selected to study the effect of tillage system and land use on quantity and quality of soil loss by wind erosion. Two types of land use and three tillage practices were evaluated. Wind speed and direction were recorded. The measured active wind speed, between 5 m/s and 14.29 m/s, represented 27.77% of the time. Samples of the eroded materials were collected at 16 intervals during the study period from four heights between 0.1 and 1.0 m above the soil surface using "Big Spring Number Eight" samplers. The quantity of soil loss varied according to sampling period, sampler height, type of land use, and tillage systems.

The intensive tillage treatment conducted by farmers under fig trees produced the highest annual soil loss (10.6 ton ha⁻¹). Perpendicular tillage to the erosive wind direction reduced wind erosion losses by 39% as compared with parallel tillage with the erosive wind direction. The annual soil loss under old fig trees was greater than that from under olive trees by 92.9%. Coarse sand enrichment ratio (ER) values were < 1 in all treatments; however, fine sand, silt and clay ER values were > 1. The ER values of fertility constituents varied among treatments, but ranged between 1.01 for cation exchange capacity to 2.93 for total nitrogen.

It can be concluded that tillage practices should be conducted perpendicular to the erosive wind direction. Also, olive trees are more efficient for controlling wind erosion than fig trees under northwest coast conditions.

INTRODUCTION

The northwestern coastal zone of Egypt has been subjected to agricultural expansion. The region is subjected to wind erosion hazards because of high wind speed, low rainfall, and high soil erodibility (FAO/UNDP, 1970). Accelerated wind erosion develops after land-use which disturbs the natural equilibrium between climate, soil and vegetative environment. Arroug (1994) used the wind erosion equation of Woodruff and Siddoway (1965) to estimate soil loss by wind in El-Omayed area on the N.E. coast. He showed that the value reached 100 t.ha⁻¹yr⁻¹. In a short-term study, Wassif (1997) showed that the amount of airborne

materials expressed as tons per 100 m width was 0.783 for bare soil (south Abou-Lahu) for 93 days. Also, he found that the enrichment ratios for organic matter, total nitrogen, available phosphorus and exchangeable potassium were greater than one.

There are several conservation measures to control wind erosion. Zobeck et al. (1989) indicated that different cropping and tillage methods produced different soil aggregate and wind erosion potentials. Hagen and Armbrust (1992) found that threshold friction velocity and trapping of siltation discharge depended on ridge height and spacing, as well as wind speed and direction. Bilbro and Fryrear (1995) concluded that soil cover and tillage practices are effective in reducing wind erosion.

In Egypt, there is limited information about the long-term quantitative data on soil loss by wind erosion. Therefore, this study aimed to evaluate the quantity and quality of soil loss due to wind erosion under different tillage systems and land use through 30 months at Fuka area, NE coast, Egypt.

MATERIALS AND METHODS

The area of the selected farm was about 33 ha (300 × 1100 m) and surrounded by 1.5 m high rubble-stone fencing and stony soil as non-erodible area. The treatments were as follows:

- A. *Perpendicular tillage* on the mean erosive wind direction under fig trees.
- B. *Parallel tillage* to the mean erosive wind direction under fig trees.
- C. *Intensive tillage* conducted by the farmer (traditional) under fig trees.
- D. *Intensive tillage* conducted by the farmer (traditional tillage) under olive trees.

The fig trees in A and B treatments were 3-years old, and their average height was 1.5 m, while the fig and olive trees in C and D treatments were 10-years old, and their average height was 3 m. The soil was plowed by chisel plow to about 15 cm depth for every treatment.

Samples of the eroded soil particles were collected through 16 intervals from April 1, 1995 to October 8, 1997 using "Big Spring Number Eight" traps at heights of 0.1, 0.5, 0.75, and 1 m above the soil surface, as described by Fryrear (1986). The traps were positioned in each treatment to collect the eroded materials

throughout the study period. The samples of eroded soil materials were dried at 55° for 72 hours before weighing, and then laboratory analyses were conducted. Climatological measurements were obtained from recording automatic weather station placed 3 m above the soil surface in the mid-point of the study area.

Surface soil samples (0-5 cm) were collected from the study area. Composite soil samples were prepared to represent two locations, i.e., A+B and C+D treatments. The composite soil samples and collected eroded materials were determined for particle-size distribution using the pipette method, aggregate size distribution, percentages of dry non-erodible fractions (>0.84 mm in diameter) CEC, exchangeable Na, K, Ca, and Mg, organic matter, total nitrogen, and available phosphorus and potassium (Page et al., 1982; USDA, 1988). Soil roughness factor K (Woodruff and Siddoway, 1965) was determined

RESULTS AND DISCUSSION

Site Descriptions

The main climatic elements during the experimental period are indicated. The average daily temperature varied from 12.9°C in February 1997 to 26.4°C in July 1997. The average wind speed varied from 4.53 ms⁻¹ in July 1996 to 2.19 ms⁻¹ in November 1997, with a monthly mean of 3.68 ms⁻¹ during the study period. Therefore, such an area is under arid and semi-arid conditions with torric soil moisture region and thermic temperature regime. Dryness prevails through most of the year and the wet periods are comparatively small. Hour numbers of < 0.5, 0.5-5, 5-10, and > 10 ms⁻¹ wind speed during study period were 803, 9535, 3899, and

76, respectively. Wind speed as high as 14.29 ms⁻¹ was recorded during September, 1997.

The measured active wind speed between 5 to 14.29 ms⁻¹ represented 28% of the study period. The frequency of wind speeds exceeding 10 ms⁻¹ was highest during February and March, 1997. The most erosive period occurred from March through July, 1997. The dominant wind direction from west to north represented 23.8% of the total wind direction.

The natural vegetation of the experimental site is mostly composed of scattered desert shrubs. The field surface of the study area is almost flat. The soil of experimental site is calcareous; sandy loam to sandy clay loam in texture, poor in organic matter, low in fertility and highly erodible.

Soil Loss Quantities

Eroded soil particles were collected 16 times during the study period from April 1, 1995 to October 8, 1997 at 0.1, 0.5, 0.75, and 1 m heights for the various treatments under consideration. For every measurement period, the quantity of eroded soil particles decreased with increasing sampler height, (Fig. 1). Consequently, the bulk of the eroded soil particles were carried close to the soil surface. This phenomenon is verified by the results obtained by Fryrear and Saleh (1993). Moreover, the quantity of soil loss at every height increased by increasing the period of measurement. Also, the differences in the amount of eroded materials were related to hours of erosive winds, soil surface conditions, and the treatments.

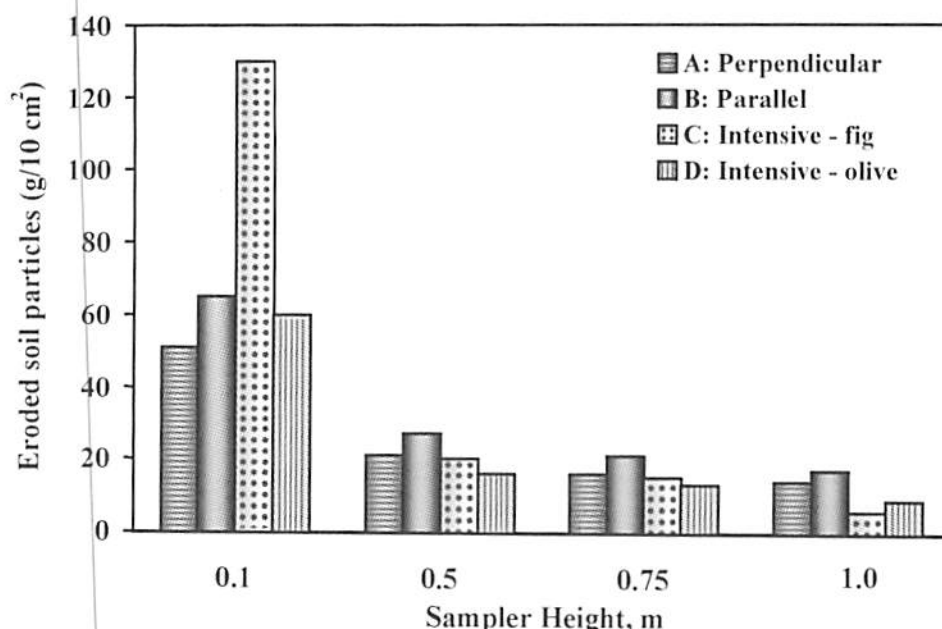


Fig. 1. Total amount of eroded soil particles at different heights at Fuka area.

The relationships between the amounts of eroded soil particles, Y (gm.cm^{-2}), collected during the study period, and height above soil surface, X (meter), were tested using linear, logarithmic, exponential, and power equations. It was found that the power equation is recommended to be used to describe such relationship. The fitted equations were significant at the 0.01 significance level. In this respect, Fryrear and Saleh (1993) and Vories and Fryrear (1991) reported that power equations described the quantity of eroded materials transported by wind above the soil surface.

The total amount of eroded soil particles Q (gm.cm^{-1} width) was obtained by integrating the fitted regression equations over heights from 0.1 to 1.0 m above the soil surface. There was great difference in amount of eroded soil particles according to the type of treatments. The amount of soil loss as affected by the treatments under consideration could be arranged in the descending order as follows: $C > B > A > D$ treatment, respectively.

Concerning the annual soil loss, data reveal that the perpendicular tillage with the erosive wind direction reduced soil loss due to wind erosion as compared to tillage parallel to erosive wind direction. It is clear that the annual soil loss from **B** treatment was higher than **A** treatment by 30%. Consequently, perpendicular tillage with the erosive wind direction was more effective than parallel tillage to the erosive wind direction in reducing annual soil loss. This may be due to the effect of ridges varies as the wind direction changes (USDA, 1988), where soil roughness factor (K') was 0.5 and 1 for perpendicular and parallel tillage, respectively.

Also, the annual soil loss from **C** treatment was greater than that from **A** and **B** treatments by 34.4 and 3.3%, respectively. The value of soil roughness factor varied between treatments depending upon the intensity of tillage operations. Therefore, the soil of **C** treatment is very susceptible to wind erosion. In this respect, Saleh (1994) indicated that the differences in measured erosion reflect the combined effects of soil roughness

and soil structure. He concluded that surface roughness significantly reduces soil erosion by wind.

Concerning the relation between soil loss and land use system, the annual soil loss under old fig trees (**C** treatment) was greater than that from under olive trees (**D** treatment) by 92.9%. This is due to the fact that olive trees provide a dense cover all over the year. Also, the annual soil loss from **A** and **B** treatments were higher than that from **D** treatment by 43.7 and 86.8%, respectively. This may be due to the effect of tree height in reducing soil loss by wind. Therefore, plant cover did provide suitable protection to the soil from wind erosion.

Soil Loss Quality

The eroded materials for each height were mixed to represent composite sample for every treatments. Concerning dry sieving of the soil surface layer (0-5 cm), the particles size $< 100 \mu\text{m}$ was 29.0 and 37.6% for both sites of the treatments. It was higher for **A** and **B** treatments than **C** and **D** treatments. Moreover, mean diameter of particles (M_D) were obtained from the size distribution curves as suggested by Chepil (1957). Soils of **C** and **D** treatments has lower M_D value (175 μm) probably due to excessive tillage for big fig and olive orchards to conserve the water in the soil.

In this respect, Chepil and Woodruff (1963) reported that excessive and improper tillage often causes excessive soil loosening and pulverization. Our indicated wind-blown materials moved in three different ways, i.e., *surface creep*, *saltation*, and *suspension*. The values of each type varied considerably with increasing the height of the sampler. Percent of suspended particles ($< 100 \mu\text{m}$) increased with increasing the sampler height and varied according to the treatment between 47.15 to 96.9%.

In general, movement of particles by saltation was the same for all treatments, but some variation was found in the proportion of particles carried at different heights; their amounts decreased rapidly with height

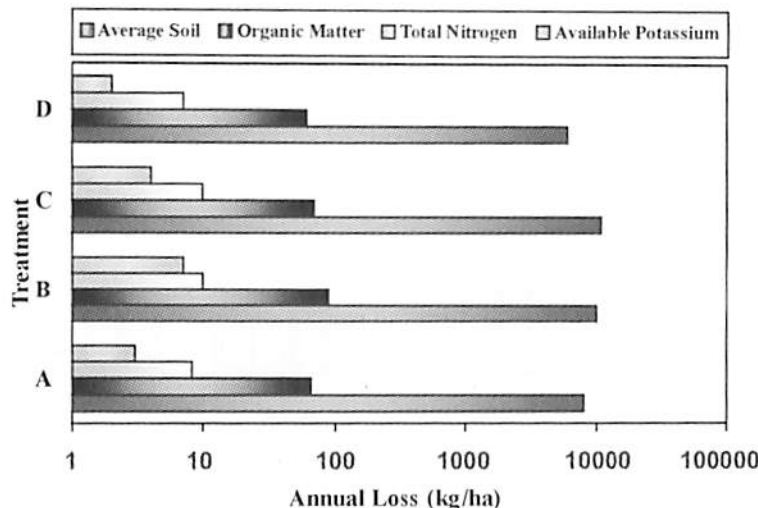


Fig. 2. Average losses for four treatments (see text and Fig. 1).

above the soil surface. Eroded materials carried by surface creep widely varied according to treatments. Their values were particularly high for C and D treatments and least for the other treatments. This may be due to the effect of ridges on lowering the total rate of soil flow and virtually eliminating surface creep.

Increasing the roughness of soil surface for A and B treatments reduced the rate of movement by surface creep. A rough soil surface trapped most of the surface creep, but failed to reduce the movement in saltation and suspension to the same degree. Consequently, the relative proportion of each type of movement varied greatly for different treatments. The greatest proportion of the movement in all cases examined was particles in suspension.

The MD values decreased with increasing sampler height. The values decreased about 39 and 50%, respectively, with increasing BSNE sampler height. This variation may be due to the mode of particle transportation, where the large particles moved by saltation at a sampler height of 0.1 m. The MD values for the soil surface layer were greater than for the wind-blown materials. Therefore, loss of fine particles was greater than the loss of coarse ones because suspended materials (<100 mm) contained silt and clay particles that are easily transported by wind. In this respect, Zobeck and Fryrear (1986) stated that aggregates' mean diameter decreased with increasing sampler height. Such results are in harmony with that reported by Fryrear and Saleh (1993).

Concerning the dispersed particles size groups of the wind-blown materials, the enrichment ratio (ER) values were <1 for coarse sand in all treatments; however, values of fine sand, silt, and clay were greater than 1. It is clear that the coarse fraction depleted, whereas silt and clay fractions were positively enriched as sampler height increased. This is due to silt and clay particles being smaller and more easily transported by wind.

Cumulative frequency percentage for each sample was drawn as a cumulative curve using probability graph paper. From the curves, seven phi-percentiles; namely, $\phi 5$, $\phi 16$, $\phi 25$, $\phi 50$, $\phi 75$, $\phi 84$, and $\phi 95$ were obtained. Then, the grain size parameters were calculated according to Folk and Ward (1957) for mean size (MZ), and sorting ($\sigma 1$). The MZ values for the eroded materials varied from very fine sand to coarse silt, while the mean size values of the soil surface layer (0-5 cm) for both sites varied from fine sand to medium sand; MZ values of fine grains increased with increasing sampler height.

This result is related to the fact that most of the fine particles are present in the form of suspension at higher elevation from the soil surface. Sorting values indicated that the eroded materials are well sorted, moderately well sorted, and moderately sorted, except some poorly sorted material collected at lower heights. The soil surface (0-5 cm) was poorly sorted because this alluvial soil is formed as a result of water action. In this

respect, Inman (1952) reported that sediments transported by wind are well sorted while water deposits are poorly sorted.

As a measure of the selectiveness of the erosive process, the ER was calculated by dividing the concentration of fertility constituents in the wind-blown materials into its concentration in the soil surface layer, 0-5 cm, both on an oven-dry basis. The obtained data show that the ER values varied among treatments, between 1.01 for CEC and 2.67 for OM. The average ER values, regardless of treatments, were 1.10, 2.31, 2.05, 1.20 and 1.16 for CEC, OM, total N, available P, and available K, respectively. This may lead to soil degradation and decrease its productivity over a period of several years. In this respect, Zobeck (1991) reported that the ERs of eroded materials ranged from 1 to 3. He referred to the higher ER of nutrient content, OM, and CEC to the selectiveness of soil erosion that transport fine materials.

Fertility index loss per year for total N, and available K as well as OM, was obtained by multiplying the fertility index concentration of eroded materials throughout the collected heights of 0.1 and 1.0 m by the annual loss of wind-blown materials (Fig. 2). It is noticed that fertility index loss remarkably varied among treatments and nutrients. The annual loss followed the order OM > TN > K. Concerning the effect of treatments on the fertility index loss, the greatest value was obtained in case of B treatment. Consequently, the selective removal of essential plant nutrients and OM in wind-blown materials is dependent upon cropping system and the direction of tillage practices. Therefore, the application of the proper conservation measures is essential to conserve soil from wind erosion hazards.

CONCLUSIONS

The data presented in this study clearly show that the quantity of soil loss due to wind erosion is greater than the tolerable level in some cases. It contains high percentage of soil particles < 0.1 mm. Also, the ERs for essential nutrients and organic matter are greater than 1. The cumulative loss of soil nutrients and organic matter lead to degraded soil over a period of several years. Consequently, land degradation could be take place in the northwest coast due to wind erosion.

As has been shown, perpendicular tillage with the erosive wind direction constitutes an effective measure for wind erosion control. It is also clear that soil loss under olive trees is less than that of fig trees. Therefore, the strong relationship between the incidence of wind erosion and tillage practices suggests that it is possible to recommend this measure to control wind erosion, particularly since the Bedouins favor soil conservation practices that are low cost, simple to implement, and relying on local skills and inputs.

REFERENCES

- Arroug, S.M.M. 1994. Relation of some soil properties to its erodibility. *Ph.D. Thesis*, Fac. Agric., Ain Shams Univ., Cairo, Egypt.
- Bilbro, J.D., and D.W. Fryrear. 1995. Techniques for controlling fugitive emission generated on cultivated land by the wind. p. 1-16. The 88th Annual Meeting of Air and Waste Management Association, San Antonio, Texas, June 18-23, USA.
- Chepil, W.S. 1957. Sedimentary characteristics of dust storms. III. Composition of suspended dust. *Am. J. Sci.* 255: 206-213.
- Chepil, W.S., and N.P. Woodruff. 1963. The physics of wind erosion and its control. *Adv. Agron.*, 15: 211-302.
- FAO/UNDP 1970. Pre-investment survey of the north-western coastal region, U.A.R., Special studies, ESE: SF/VAR. 49, *Technical Reports*: 1, 3, 5.
- Folk, R.L., and W.C. Ward 1957. Brazos River Bar: A study in the significance of grain size parameters. *J. Sed. Petr.* 27 (1): 3-26.
- Fryrear, D.W. 1986. A field dust sampler. *J. Soil Water Conserv.*, 41 (2): 117-120.
- Fryrear, D.W., and A. Saleh. 1993. Field wind erosion: Vertical distribution. *Soil Sci.* 155 (4): 294-300.
- Hagen, L.J., and D.V. Armbrust. 1992. Aerodynamic roughness and saltation trapping efficiency of tillage ridges. *Transactions ASAE*, 35 (4): 1179-1184.
- Inman, D.L. 1952. Measures for describing the size distribution of sediments, *J. Sed. Petr.* 22:125-145.
- Page, A.L., R.H. Miller, and D.R. Keeney. 1982. *Methods of soil analysis*. Part 2, No. 9. Agron. Amer. Soc., Agron. Madison, Wis., USA.
- Saleh, A. 1994. Measuring and predicting ridge-orientation effect on soil surface roughness. *Soil. Sci. Soc. Am. J.*, 58 (4): 1228-1230.
- USDA/SCS. 1988. National agronomy manual: wind erosion. Part 502. Title 190. Washington, D.C. USA.
- Vories, E.D., and D.W. Fryrear. 1991. Vertical distribution of wind-eroded soil over a smooth, bare fields. *Transactions ASAE*, 34 (4): 1763-1768.
- Wassif, M.M. 1997. Some observations on wind erosion in Egypt. p. 59-78. In: M.V. Siva-Kumar, M.A. Zöbisch, S. Koala, and T. Maukonen (Ed). Wind Erosion in Africa and West Asia: Problems and Control Strategies. *Proc. expert group meeting* 22-25 April, 1997. Cairo, Egypt. (ICARDA).
- Woodruff, N.P., and F.H. Siddoway. 1965. A wind erosion equation. *Soil Sci. Soc. Am. Proc.*, 29 (5): 602-608.
- Zobeck, T.M. 1991. Soil properties affecting wind erosion. *J. Soil Water Conserv.*, 46 (2): 112-118.
- Zobeck, T.M., and D.W. Fryrear. 1986. Chemical and physical characteristics of windblown sediment. I. Quantities and physical characteristics. *Transactions ASAE*, 29 (4): 1032-1036.
- Zobeck, T.M., D.W. Fryrear, and R.D. Pettit. 1989. Management effects on wind-eroded sediment and plant nutrients. *J. Soil Water Conserv.*, 44 (2): 160-163.

Irrigated Soils Degradation: Assessment and Monitoring

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ABSTRACT

In Russia, irrigated soils make up 4% of plowed land area and provide a tax of 15-20% from agricultural production. The characteristics, direction, features, and scales of the main categories of soil degradation (physical, chemical, mineralogical) under the effect of irrigation are described. Quantitative parameters of a normal condition of irrigated soils, and various negative kinds of soil changes and rates of their development for different degradation degrees (light, moderate, severe, and very severe) are given.

Degradation degree of irrigated soils is evaluated by reduction of agricultural crop yields and a decrease of soil's ability to execute functions in the biosphere. Main parameters (static ones: the contents, area, as well as dynamic ones: rate of processes development and content change) required for revealing the main kinds of irrigated soils degradation were developed. Simultaneous evaluation of soil degradation is determined by a parameter or a number of parameters possessing maximum degradation degree.

Early diagnosis of negative transformations by irrigation is facilitated by the study of micro- and meso-levels of soil profile. The convertible and irreversible processes of soil degradation occur. Convertible changes with irrigation are: contents of humus, water-stable aggregates, gypsum, salts, nutrients, and groundwater level. Irreversible soil processes are: microstructure destruction, adverse transformation of organic substances (content reduction of total and reactive-capable microforms, dispersion increase, separation of coagulative and depressive micro-forms) and mineral plasma (clay loss, super-dispersion of labile minerals, and cutan appearance).

The total area of irrigated soils of Russia make 5-6 M ha; 19% is flooded and 14% is salinized, while loss of humus and carbonates and compaction (rarely salinization), deterioration of physical properties and structure take place over large areas. In some regions up to 50% of irrigated area is degraded. It is necessary to monitor irrigated soils for degradation process diagnostics. Its functions and objectives are determined, and the scientific basis of monitoring organization and realization is worked out.

INTRODUCTION

In the world 70% of water utilized by humankind is used on irrigation. In the last 30 years irrigated area in Russia increased five times and makes up 5-6 M ha.

Irrigation is one of the most powerful anthropogenic factors which influences soils, waters, and environment. On the one hand, irrigation provides favorable conditions for plants, but irrigation frequently results in soil deterioration. Irrigated soils are specific anthropogenic-natural bodies. In secondary hydromorphic conditions, their type changes: irrigated meadow soils or Solonchaks are formed in automorphic conditions (at natural drainage), but differences from natural soil evolution of pluvial epoch changes of typical or sub-typical level are not marked. In spite of created humid conditions, soil converging of various natural zones do not occur.

METHODS

A soil zonal sequence: *chernozems, chestnut soils, trinomial solonetz complex, brown desert steppe soils* located in different geomorphological conditions in steppe zone of Russia was the research objective. The investigated soils had light, medium and heavy loam texture. Irrigation terms make up from 10 to 100 years. Impact of irrigation on different soil properties, especially on such insufficiently explored ones as humus condition, soil structure, mineralogical composition of coarse and clay fractions, were investigated. The total soil mass and different soil structural elements such as the inter-crack and the intra-crack masses and clay cutans were studied.

Irrigated Soil Degradation

Few kinds and categories of soil degradation are distinguished. *Physical soil degradation*: decrease of organogenic horizon thickness (at irrigation erosion), deterioration of agrophysical properties, including micro- and macrostructure, reduction of aggregation hydrophobicity, compaction, crusting, exceeding of critical groundwater table. *Chemical soil degradation*: reduction of humus content, carbonates, and nutrient elements, desalination, secondary salinity and sodification, deterioration of humus quality, increase of its mobility. *Mineralogical soil degradation*: increase of water peptized clay content, destruction, migration, and transformation of minerals, clay loss. Besides, soil degradation promotes increased leaching of salts, fertilizers, and toxic substances into groundwater, rivers, seas, oceans, and disturbs their natural balance leading to undesirable contamination. Four types of soil degradation are distinguished:

1. **Light**, actually not influencing soils, functions in biosphere and yield of agricultural plants.
2. **Moderate**, limiting soil functions, with yield decreases of 25-50%.

3. **Severe**, weak ability to function, decrease of crop yield of 51-75%;
4. **Very severe**, as a result of which soils lose properties and ability of functions in the biosphere, the yield decreases more than 75%.

Simultaneous evaluation of soil degradation is determined by a parameter or a number of parameters possessing maximum degradation degree. It also needs to specify adverse processes which have the highest rate. Nowadays, soil on this parameter can have a small degradation degree; however, because of accelerated deterioration, soil may quickly become strongly degraded. On the basis of our own research and numerous literary sources, quantitative valuation of various kinds of irrigated soils degradation depending on its degree is given. Five classes of ecological conditions of irrigated soils: *satisfactory*, *tense*, *conflicting*, *crisis*, and *catastrophic*, are proposed. The prevalence of various kinds of soil degradation is evaluated on a scale: *very seldom*, *seldom*, *frequently*, and *very frequently*.

Early diagnostics of negative transformations at irrigation is facilitated by study of micro- and meso-levels of soil profile. Convertible and irreversible processes of soil degradation occur. Convertible, controlled changes at irrigation are: content of humus, water-stable aggregates, gypsum, salts, nitrate substances, and groundwater level. Irreversible soil processes are as follows: microstructure destruction, adverse transformation of organic substances (content reduction of total and reactive-capable microforms, increase dispersion, separation of coagulative and dispersive microforms) and mineral plasma (super dispersion and cutan form occurrence).

These processes facilitate easing the connection between organic and mineral plasma and lead to destruction, migration, and transformation. The irreversible processes of de-structurization, compaction, humus destruction, and buffering capacity decrease are displayed to a maximum degree in secondary-hydromorphic chernozems with irrigation and are reduced in chestnut and brown desert-steppe soils, whereas secondary salinity and solonchetsity increase in this direction.

Quantitative evaluation of various kinds of deterioration in irrigated soil depend on the degree of degradation on the basis of own research (Prihod'ko, 1996) and other sources (Kovda, 1981; Kuznetsov et al., 1979; Pankova et al., 1996; Scheptukhov et al., 1997; Snakin et al., 1992; Sozinov et al., 1994; Val'kov, 1992).

RESULTS AND DISCUSSION

Humidification, Waterlogging, and Secondary Salinization

Before irrigation, the watertable in steppe soils was at a depth of 10-50 m. With poor drainage of steppe territories, groundwaters rose at a rate of 0.3-1 m per year. The water rises up with higher rate near the irrigation

channels and on the area watering from an open network, where the water loss makes up more than 60%. In 10-30 years, a hydromorphic water mode is created. Area of secondary hydromorphic irrigated soils makes of 37%, semi-hydromorphic -21% of total irrigated areas (Cadastr, 1993). Secondary salinization occurs with natural ones, which reach 5-16% in steppe zone and in desert steppe zone, it increases up to 60-80%. Here unfavourable changes such as re-salinization, over-humidity, bogging up, and solution sinkholes are observed (Oster et al., 1992).

In the soils with higher humidity, water-air regime deteriorates the content of O_2 decreases, toxic CO_2 amount accumulates, H_2S appears. In bogging soils, the rate of organic matter decomposition is delayed, gleying begins to start, and agriculture becomes impossible. In Russia, 19% of irrigated area is waterlogged, and 14% of the area has salinization. In depressions, bogging of irrigated soils is marked. Thus, growing of agricultural crops becomes impossible, and gleying processes are developed. Decrease of redox potential of 500 mV results in a strong degree of soil degradation (Table 1).

Compaction of irrigated soils frequently occurs. It means increasing of the bulk density of the upper horizons to higher than optimal values. The value of optimal density depends upon the soil structure and, for many agricultural plants, varies from 1.0 to 1.3 g/cm³ (Sozinov et al., 1994). An increase of density in the Ap horizon of more than 1.4 g/cm³ results in reduction of crop growth, difficulties in soil treatment, and impossibility of their restoration (e.g., >1.6 g/cm³ (Medvedev, 1991). More tight packing of aggregates under wheels of heavy agricultural machinery, formation of soil crust, and furrow pan are reasons for soil compaction. Clogging and closing of pores and cracks, as a result of increased low-aggregated clay content, and super-dispersion of smectite minerals may lead to compaction as well (Chizhikova and Gradusov, 1972; Prihod'ko, 1996).

Salinization is a more complicated when soil compaction is up to 1.6-1.7 g/cm³, with slickensides available and shifts of soil blocks relative to each other. These attributes are diagnostic criteria of salinization and can be developed for 15-25 years (Kolinsky, 1991; Citron, 1995). This can be explained by hydrophyllization of colloids, formation of highly dispersed soil polymers, and microaggregate cementation by soluble components Si, Mg, Al (Kovda, 1981). Slitogenesis can be explained by the process of grating, i.e., mechanical disintegration of clay mineral crystals which occur at critical density on the surface of blocks rubbed at soil swelling (Kozlovsky, 1991). Under dry conditions these soils are characterized by extreme density, massive structure, and cracking. Tenacity and plasticity are typical for humid conditions. Methods for slitization control are difficult and weakly developed.

Table 1. Indices and criteria of physical degradation and hydromorphism of irrigated soils.

Indices	Degrees of Soil Degradation				
	Absent	Light	Moderated Rate	Severe	Very Severe
Decrease of humus horizon thickness, %	<10	10 - 20	21 - 51	51 - 100	>100
Middle annual increase of eroded soils area, %	<0.2	0.2 - 0.5	0.6 - 1.0	1.1 - 1.5	>1.5
Soil mass loss, t/year	<5	6 - 25	26 - 100	101 - 200	>200
Soil compaction, g/cm ³	1 - 1.3	1.3 - 1.4	1.41 - 1.5	1.51 - 1.6	>1.6
Water penetration, m/day	>1.0	0.3 - 0.1	0.1 - 0.3	0.01 - 0.1	<0.01
Aggregate-dry-sieving, mm:					
>1.0	10 - 20	21 - 30	31 - 40	41 - 50	>50
0 - 0.25	60 - 80	50 - 59	40 - 49	30 - 39	<30
Critical groundwater table, m:					
Mineral	>5	3.1 - 5	2.1 - 3	2 - 1	<1
Sweet	>3	2.1 - 3	1.1 - 2	0.8 - 1	<0.8
Increase more than critical one, %	0	<15	16 - 30	31 - 50	>50
Groundwater rise, m/year	0	<0.2	0.2 - 0.4	0.5 - 0.7	>0.7
Yield lost, %	<10	10 - 24	25 - 50	51 - 75	>75

De-structurization is the most frequent phenomenon with irrigation. It can be found first of all micro-morphologically. In secondary-hydromorphic conditions, and at low level of cultivation, simplification of microaggregate structure and increase of microzonality in construction of plasma material and decreases of porosity take place. The expansion of lumpiness together with decreasing water resistance and the amount of agronomically valuable aggregates have been observed. Structure degradation is connected first with high intensity of artificial rain and duration of watering, long-time water standing on the soil surface, pressure of heavy agricultural machine and treatment of soils, which are not physically mature.

Dehumification

Humus conditions in irrigated soils are determined by the level of agriculture and quality of irrigation water. At low level of irrigation agrotechnology, humus stocks are reduced 10-30% of initial value during 20-30 years (Table 2). These are basically biochemical losses; with irrigation, large losses of humus stock are possible. In this condition, the content of humic acids connected with calcium is decreased, while fulvic acids are increased (Orlov et al., 1980). Chernozems as compared to the other steppe soils lose humus with irrigation faster that is determined by low increases of crops, smaller area of perennial grasses, and return of plant residues in soil for humus formation. In secondary-hydromorphic conditions at shallow mineral groundwater causing secondary soil salinity, changes of humus content and composition are more expressed.

Decarbonation

The presence of carbonates in top horizons promotes structure preservation. At irrigation by sweet water, the carbonate supply is saved. Irrigation by sodic water promotes CaCO₃ leaching from 0-1 m layer (Rozanov and Rozanov, 1986). With irrigation of sulfate-sodium water of minerals 3-4 g/l, the forming soil solution is saturated with CaCO₃, which favors preserving of soil carbonates (Krechetov and Nikolaeva, 1995).

The question about secondary salinization and solonization at irrigation is covered in the works of Aydarov, Baer, Buriukova, Dregne, Egorov, Kovda, Minashina, Novikova, Panov, Pankova, Rozanov, Samoylova, Szabolch, Zimovetz and other researchers. Where mineralization of groundwater exceeds the critical level and with absence of drainage, secondary soil salinization is developed. The critical level and mineralization of groundwater changes as the climatic zone changes. The more arid climate, the deeper groundwater table and with less minerals lest secondary soil salinization should be developed at groundwater mineral contents of 3-5 g/l will cause soil salinization in steppe zone at the groundwater Table 1 m; in dry steppe, 1.5 m. and semi-desert in 2.0 m.

Agricultural plants have a different salt and Solonetz resistance. The permissible concentration of salts in soil solution for salt-sensitive plants is less than 2 g/l, for salt-resistant ones, it is up to 13 g/l (moderately saline soils). On saline soils with mineral groundwater table closer the 10 m from the surface, drainage is required to be conducted simultaneously with creation of the irrigation system. In other cases, drainage is necessary to begin at the rise of mineral groundwater table up to 3-5 m.

Table 2. Indices and criteria of chemical degradation of irrigated soils.

Indices	Degrees of Soil Degradation				
	Absent	Light	Moderate Rate	Severe	Very Severe
NPK content decrease ¹	<1.2	1.2 - 1.5	1.6 - 2.0	2.1 - 5	>5
Decrease of humus stock at 20 yrs in humus horizon, relative, % ²	<10	10 - 20	21 - 40	41 - 80	>80
Danger of solonchaks, % CaCO ₃ content in 0-50 cm layer	<5	1.5 - 5	1.5 - 1	<1	0
Alkalinization ³ pH water	<8.0	8.8 - 8.5	8.6 - 8.9	9.1 - 9.5	>9.5
HCO ₃ - Ca, mg/eq.	<0.7	0.71 - 1.0	1.1 - 1.6	1.7 - 2.0	>2.0
Solonchaks ³ Adsorbed Na in:	<1 ²	1 - 3	4 - 6	7 - 10	>10
soil, % CEC	<3 ³	3 - 5	6 - 10	11 - 15	>15
in soil solution,	<0.5 ²	0.5 - 3.5	3.6 - 7.5	7.6 - 10.5	>10.5
aNa √ aCa	<1.0 ³	1.0 - 5.0	5.1 - 10	11 - 15	>15
Adsorbed Mg content, % CEC	<30	40 - 50	51 - 60	61 - 70	>70
Total toxic salts in Ap layer, %:					
- soils with sodium	<0.1	0.1 - 0.2	0.21 - 0.3	0.31 - 0.5	>0.5
- soils without sodium	<0.1	0.1 - 0.25	0.26 - 0.5	0.51 - 0.8	>0.8
Increase of saline soils area, % in year	<0.5	0.5 - 1	1.1 - 2	2.1 - 5	>5
Decrease of soil redox potential, mV ¹	<50	50 - 100	101 - 200	201 - 500	>500
Water soluble fluorine, mg/kg	<6	6 - 10	11 - 20	21 - 25	>25
Nitrification ability, mg/kg	>30	20 - 30	10 - 19	5 - 10	<5
Nitrates content, mg/kg	<40	40 - 60	60 - 80	80 - 100	>100

¹comparison with drylands (initial); CEC: cation exchange capacity; ²for soils with exchangeable Na content less 1%;

³in 0-30 cm layer.

Mineralogical Degradation

Intensification of the processes of destruction, disintegration and transformation of silt-fraction minerals results in an increase of clay content. Probably some part of clay minerals is also in the structure of strong units, which are destroyed under irrigation. As a result of these processes, the content of illites is most often increased, rather than one of labile minerals and chlorites in the clay fraction. At small reserve of easily weathering minerals, loss of clay fraction occurs under the effect of irrigation due to strengthening on of the processes of destruction and migration of clay minerals.

Magnesium chlorites and labile minerals of clay fraction are first to be destroyed as they are least tolerant of weathering. Following watering with sodic waters or at close groundwater table, containing sodium, super-dispersion of labile minerals takes place (Chizhikova and Gradusov, 1972; Prikhod'ko, 1996). This promotes their migration and causes soil physical property deterioration.

On slopes, irrigation soil erosion is developed. In order to prevent a decrease of soil thickness, the flow value is required not to exceed the rate of soil formation. Increase of infiltration properties with the help of cracking and artificial structureless soil mass reduces the surface flow at irrigation by 1.5-3 times, at runoff by 2-10 times (Kuznetsov et al., 1990).

Irrigation by sodic waters causes processes of alkalinization, solonchaks, structure reorganization, compaction, formation of surface crust, decrease of water

infiltration rate, strengthening of humus, and mineral movement. Similar processes are observed at irrigation by waters with mineral contents of 1-4 g/l (for Chernozems more than 0.5 g/l) sodium chloride composition; they are expressed to a lesser degree at irrigation by sulphate-sodium waters. The salt regime is of accumulative-pulse character: to the end of vegetative period, accumulation of easily soluble salts is marked, which are leached partially or completely with precipitation by autumn-winter-spring period. With mineral contents higher than 3 g/l after 15-20 years of irrigation, accumulation is made possible due to evaporation. In Russia 8% of the land is irrigated by waters with mineral content higher than 1 g/l, including 5% with concentrations of 1-2.3 g/l (Cadastr, 1993). The most effective method of simultaneous amelioration of such waters and soils is gypsum application, the use of acid with carbonates, as well as applying of calcium fertilizers dilution by sweet water (Khokhlenko, 1988). Different parameters of various soil degradation can be used for monitoring irrigated soils and the development of remediation measures.

Irrigated Soil Monitoring

There is need to organize new experimental stations where more complicated diagnostics of soil changes under anthropogenic effects will be investigated. The stations should be placed in such areas that could characterize irrigated territories accounting for local, regional, and global levels.

Control plots are required to be distributed in near-by channels, and central and peripheral irrigation zones, as well as in the areas which are most susceptible to degradation (depressions, erosion-subjected slopes, places of water runoff, suffusion areas, saline and Solonchic soils) and in adjacent drylands. There is need to organize new experimental stations where more complicated diagnostics of soil changes under anthropogenic effect will be investigated. The stations should be placed in such areas that could characterize irrigated territories accounting for local, regional, and global levels.

All information should be saved, processed, and generalized in the computer center by GIS technology; this information should be obtained mainly in the form of programs, models, and databases. There is a need in the future to organize new experimental stations where one can perform enhanced diagnostics. These data can be the basic components in geosystem monitoring. The stations should be placed in such areas that one could characterize the processes occurring in irrigated territories accounting local, regional, and global levels.

Estimation of Ecology of Irrigated Soils

Ecological conditions of the irrigated area of Russia was estimated. The criteria for assessment of five classes were the soil areas with unsatisfactory ameliorative state, which is determined by the groundwater level at a depth of 1.25-2.2 m, mineral contents more than 1g/l and presence of soils salinated in the 0-1 m layer to moderate and severe extents. The ecological descriptions are based on Glazovsky et al. (1990). Satisfactory conditions were typical for areas with less than 10% of the irrigated soils; unsatisfactory ameliorative state, 10-20%; conflicting, 21-30%; crisis, 31-50%; and catastrophic, more than 50%. For assessment of ameliorative conditions of irrigated soils, cadastre data were used (Cadastr, 1993).

Kalmykia and Dagestan Republics are in catastrophic ecological conditions, where 56 and 74% of irrigated areas have been subjected to salinization and over-humidity. In Khakassya Republic, Astrakhan, and Rostov regions, a conflicting ecological situation is marked. Ural, West-Siberian, and non-Chernozemic regions are characterized by satisfactory ecological conditions. With irrigated soils of Russia, 19% are over irrigated, 6% are salinized, which, on large areas, erosion and loss of humus and carbonates, compaction (rarely slitization), and deterioration of physical properties and structure are noted.

The Asian parts of Russia with an increase of irrigation pose these problems more acute than the European one. Asian soils have lesser profile thickness, humus reserve, humicness, and higher cracking. Besides irrigation leads to a decrease of the root-layer temperature, both due to a cooling influence of irrigation waters and an increase of soil cold capacity.

In the absence of landscape approach under projection of irrigation systems, great losses of irrigation

water promote salt movement from deep horizons, where main salt reserves concentrate. The increasing drainage leads to leaching of salts, nitrates, pesticides into the rivers, in this case a disturbance of balance and contamination are observed.

Remediation of Irrigated Degraded Soils

1. Rational water use (up to 300 m³/ha), watering of the layer which contains 85% of plant roots in accordance with plant development; realization of refreshing irrigation by the rate of 50-70 m³ /ha.
2. Measures preventing or decreasing the compaction effect of machinery: designing new units with low pressure on soils and application of accessories to existing technique which reduce soil consolidation (expansion and doubling of tractor wheels decreasing pressure on soil, less use of farm machinery, combined units with extension-type appliances, technological gauges and application of higher application fertilizer rate).
3. Erosion-preventive measures, e.g., reduction of erosivity of irrigation water, decrease of water flows, increase of soil stability with trash conservation on the surface with straw (2 t/ha), avoiding destruction of surface crust, bedding (on slopes with up to 6°), accommodation of plants in bands (on slopes with 6-12°).
4. Applications of different agrotechnical methods, and, whenever possible, postponement to autumn of a part of early spring processes causing compaction.
5. Application of gypsum, conditioners, lignin and other materials to improve structural stability and water penetration.
6. Measures for maintenance of positive humus balance: application of organic and mineral fertilizers, straw, peat, keeping of maximum plant residues on fields, sowing of perennial grasses and stubble crops. Remediation measures at irrigation by mineral waters or saline soils and at the rise of saline ground waters.
7. Other measures include: drainage, leaching, chemical amelioration, and growing of salt-resistant plant crops and complete removal of their biomass from fields.

New Irrigation Strategy

Now, under conditions of economical difficulties, a new irrigation strategy is proposed:

- Decrease of irrigation water rate by 20-25%.
- Leveling of soil surface for decreasing of water filtration through micro-depressions.
- Reducing of irrigation area, avoiding saline, over-wetting, eroded soils.
- Concentration of fertilizers on valuable soils, which give higher increase of crop yield with irrigation.

- Reduction of drainage runoff and area irrigated by saline waters.
- Decrease of irrigated Chernozem area where possible. Non-irrigated agriculture is used insufficiently. In hydromorphic regime, the resistance of these soils is less than of the other ones.
- Material incentive for people to benefit from their work.

REFERENCES

- Cadastr. Emeliorated cadast of Russia. 1993. Glavvodstroy, Moscow.
- Chizhikova, N.P., and B.P. Gradusov 1972. Effect of local waters irrigation on chemical and mineralogical composition of dispersed Chernozems *Baraba Bulletin*. V.V. Dokuchaev. Soil Science Inst. Moscow. 117-125.
- Dobrovol'sky, G.V., and Y.D. Nikitin. 1990. Ecological functions of soils. Moscow Univ., Moscow.
- Zimovetz, B.A., and N.B. Khitrov (Ed.). 1996. Ecological requirement to soil irrigation in Russia: Recommendation. V.V. Dokuchaev. Soil Science Inst. Moscow.
- Glazovsky, N.F., N.I. Koronkevich, and B.I. Kochurov. 1991. Critical ecological regions: geographical approaches and research principles. *Izvestiay of Vseros. Geograf. Obshchestva*. 123 (1): 9-17.
- Khitrov, N.B. 1995. Slitozems of Northern Caukaz: Avtoreferat Diss. Dokt. Nauka. Moscow.
- Khokhlenko, T.N. 1988. Estimation of irrigation water on thermodynamic indices. *Melioratziay i Vodnoe Khozaystvo*. 2: 38-40.
- Kovda, V.A. 1981. Soil cover, their improvement, utilization, and remediation. Nauka, Moscow.
- Kozlovsky, T.I. 1991. Modern natural and anthropogenic processes of soil evolution. Nauka, Moscow.
- Krechetov, P.P., and S.A. Nikolaeva. 1995. Estimation of carbonate calcium system condition of chernozems under irrigation. *Vestnik Moscow University. Pochvovedenie*. 2: 42-51.
- Kuznetsov, M.S., V.A. Grigor'ev, and K.U. Khan. 1990. Erosion of soil and under-sprinkler irrigation. Nauka, Moscow.
- Medvedev, V.V. 1988. Optimization of agrophysical properties of chernozems. Agropromizdat, Moscow.
- Orlov, D.S., E.M. Anikanova, and V.A. Markin. 1980. Peculiarities of organic matter in irrigated soils. Problems of soil irrigation in south Chernozemic zone. Nauka, Moscow. p. 35-61.
- Oster, J.D., M.J. Singer, A. Fulton, W. Richardson, and T. Prichard. 1992. Water penetration problems in California soils. Univ. California, Davis.
- Prikhod'ko, V. Ye. 1996. Irrigated steppe soils: functioning, ecology, and productivity. Intellect, Moscow.
- Rozanov, A.B., and B.G. Rozanov. 1990. Ecological of consequences of anthropogenic soil changes. *Itogi Nauki i Tekhniki*. 7. VINITI. Moscow.
- Scheptukhov B.N., T.V. Reshetina, P.N. Berezin, I.I. Karmanov, B.V. Vinogradov, and B.A. Zimovetz. 1997. Improvement of estimation of soil degradation processes. *Pochvovedenie*. 7: 799-805.
- Snakin, V.V., P.P. Krechetov, and T.A. Kuzonikova. 1992. System of estimation of soil degradation degree. Preprint. Pushchino.
- Sozinov, A.A., V.V. Medvedev, S.U. Buligin, N.A. Lapa, T.N. Laktionova, and N.B. Kozlov. 1994. Agroecological mapping of agricultural area of Ukraine. p. 8-13. *Proc. Congress of Soil Scientists and Agrochemists of Ukraine*. Kharkov.
- Val'kov V.F. 1992. Soils and agricultural plants. Rostov-on Don, Russia.

Towards Sustainable Agriculture on Central and Marginal Slopes of Wadi El Natrun Depression, Egypt

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ABSTRACT

Wadi El Natrun community is situated in a relatively fragile ecosystem, and is under environmental pressures that are already limiting or affecting its development. It is characterized by geologically complex soils formed on deposits belonging to the Quaternary and late Tertiary periods. Quaternary lake deposits and old alluvial deposits of sands and gravel cover the area. The total precipitation in Wadi El Natrun is very low, and mostly occurs in winter; it is not sufficient for irrigation.

Groundwater is the only source of water for irrigation on its old gravelly plains and slopes. As a result of the intensive cultivation, a steady rise in the salinity of groundwater has created serious problems.

In central and marginal areas of Wadi El Natrun that are not used for intensive agriculture, some farmers still use the land to grow watermelon. These areas are cultivated in a traditional way of bringing the crop into contact with water. Such cultivation is known as "non-irrigated" cultivation. In order to cultivate the area, huge amounts of sand must be removed until the loamy sand to sandy loam layers, wherein seeds are sown, are reached. The plant roots follow the thin fresh water layer, which rises up by capillarity.

Four locations representing different geomorphologic units identified by digital image processing of image from Landsat satellite have been studied and the mechanisms of the plant's fresh water uptake have been described.

INTRODUCTION

Wadi El Natrun area has been considered as a possible area for reclamation and utilization. The presence of irrigation water from an underground source on the outer parts of the depression, and the availability of some moisture contained in the very fine and fine sandy layers at the central of the western part of the depression serve the needs for agricultural purposes. In the central and the marginal areas of Wadi El Natrun that are not used for intensive agriculture, some farmers still use the land to grow watermelon. These areas are cultivated in a traditional way by bringing the crop into contact with water. Such cultivation is known as *non-irrigated cultivation*. In order to cultivate the area, huge amounts of sand must be removed until the loamy sand to sandy loam layers are reached. After seeds are sown, the plant roots follow the thin fresh water layer, which rises up by capillary.

Some plants grow well in salty water, others do not; some plants grow fairly well in salty water in coarse-textured soils, but do not grow well in fine-textured soils. In the first example, the salt tolerance of plants is not yet well understood. In the second example, the phenomenon at work may be that of distillation (vaporization) and condensation (forming liquid) processes. When coarse materials (sands and gravels) are wet with salty water, the plant roots may not remain submerged in salt water.

After normal drainage, the roots extending into large soil pores may be mostly in soil air and not submerged in salty water. The soil air is near 100% relative humidity, whether the soil is dry or moist. Slight temperature fluctuations allow water vapor to condense in cool periods on the exposed root surface. This condensed water is distilled; thus, it contains no salts and can be absorbed easily by plants. Thin salt-water films continue to supply a source of evaporating water and some nutrients.

Water-use calculations by French scientists caused them to estimate that common plants such as peas, tomatoes, corn, and cabbage have the capacity to absorb in their hair roots more than 55 times the maximum water plants actually need for transpiration. A single small crop plant may accumulate one to two liters of "dew" on its roots each morning. The main objective of the study is to determine the different areas of the central and marginal areas of Wadi El Natrun that could be preserved under a non-irrigated cultivation system.

General Description of Wadi El Natrun Depression

Wadi El Natrun depression lies 40 km west of the Nile Delta parallel to the Cairo - Alexandria desert road, in the stretch from 84 to 130 km. It is bounded between longitudes 30° 20' and 30° 30' east, and latitudes 30° 17' and 30° 38' north. It is about 50 km long its width ranges between 7 km at both ends and 13 km in the middle.

The lowest point in the depression is about 23 m below sea level and about 50 m at the level of the lands surrounding the rim of the depression. A series of salt-water lakes occupy the central low-lying part of the Wadi. The soils of Wadi El Natrun are situated in the torric moisture regime (Erian, 1989). Some soils in the margins of Wadi El Natrun lakes, where the soils are continuously saturated with water, have an aquic moisture regime. Soil temperature regime is hypothermic.

Pliocene formations exposed on the bottom of the Wadi are different from the major Pliocene formation in Egypt; it includes fossils of fish, crocodiles, etc., and some land animals (Abu El Ezz, 1974). Eolian forces are the sole agents responsible for eroding and excavating a wide gap within the soft materials covering the bottom of Wadi El Natrun.

The geomorphology of Wadi El Natrun area could be subdivided into three main units (La Moreaux, 1962; El Fayoumy, 1964; Abou Khadrah, 1973).

- A. *Gravel Plain Areas:* Most of Wadi El Natrun depression east and west direction covered by gravel plains. The surface is covered by pebbles of different sizes interspersed with sand, silt, and clay.
- B. *Table Upland in Marginal Slopes:* This is formed from a few scarps of low topographic relief. They occur in the form of elongated ridges bordering the two main depressions Wadi El Natrun and Wadi El Farigh. Hard siliceous beds with gypsum cap most of the ridges; conglomerate sandstone and gravel cap other ridges.
- C. *Lowland Areas:* The study area is considered as part of the lowland areas. The main topography is the most permanent. They are extending in a NW - SE direction for about 50 km. A series of isolated saline lakes occupy the axis of the depression.

The Natrun Depression obtains its water from two sources, one is the springs found in the bottom of the Depression, the other is seepage into the lakes from the side; the direction of this lateral seepage is generally from the northeast.

MATERIALS AND METHODS

The Landsat Thematic Mapper (TM) Computer Compatible Tape (CCT) of August 18, 1997 of Path No. 177, Row No. 39 was acquired. The images on the CCT's were already geometrically corrected at the Function Receiving Station, Telespazio, Italy. The thermal image has been used for detecting soil moisture conditions about the area. The data extraction from the thermal band generates a preliminary soil moisture condition map, which must be checked and completed

through field observations. The fieldwork was planned to include the following:

- Soil profiles representing different depths of fresh water (5).
- Testing undisturbed samples for physical and chemical analyses (22).
- Watertable samples (5).
- Observation points - 24 (soil augers).

The different analyses, which were carried out according to the standard methods, included particle-size distribution, following the dry-sieving method and classified according to Trask (1950). Undisturbed samples (18) were collected from the same locations in cores with the dimensions of 2.5-cm length and 5-cm diameter. These were meant for studying the moisture retention at field capacity, permanent-wilting percentage, and interval points as measured by the pressure membrane apparatus (Klute, 1986).

Calcium carbonate content was determined using a Collins Calcimeter (Nelson, 1982). Organic matter content was determined according to Nelson (1982). The electrical conductivity of the saturated soil extracts was carried out according to Rhoades (1982). Soil reaction (pH) was determined in soil extract (1:2.5) using a Beckman pH meter.

The topographic maps of the area sheets, NH36Ic "Jabal Hadid" and NH36Id "Wadi El Natrun" at scale of 1:50000, were produced by the Egyptian General Survey Authority. The integrated land and watershed management system (ILWIS) developed in ITC (Version 2.2) has been used as the main software for this study.

RESULTS

The slicing operation capability of ILWIS has been used by for classifying the thermal band into six different classes as presented in Table 1. The soil studies of the area are based on the soil moisture condition map combined with the non-irrigated cultivation. The soil profiles represent the different soil moisture classes.

Table 1. Areas calculated for each moisture classes.

<u>No.</u>	<u>Classes</u>	<u>Slicing TM Band 6</u>	<u>Area</u>
		<u>Value Intervals</u>	
			-feddan- -%-
1	Lakes	0 - 30	2963 4.46
2	Waterlogging/ very poorly drained	31 - 130	4022 6.06
3	Poorly drained	131 - 172	10,483 15.79
4	Imperfectly drained	173 - 186	14,077 21.20
5	Moderately well drained	187 - 227	23,986 36.12
6	Well drained		10,879 16.38
Total			66,411 100

CONCLUSIONS

The results explained that 36% of the area studied, mainly of Class 5, is suitable for the non-irrigated cultivation. In this area, the initial volumetric moisture content falls between the two extremes of the available water content. It means that the soils under investigation do not need artificial irrigation and the available water, which remains inside the soil profiles proceed from vaporization and condensations of the watertable during the soil temperature fluctuate.

The result of correlation between the initial volumetric moisture content and soils characteristics have shown that the linear correlation is more significant than the log, exponential, and power types of correlation. The data explains that there are positive significant correlations between volumetric moisture percentage and all organic matter, silt + clay, slow drainage pores, and non-useful pores. Otherwise, there are negative significant correlations between volumetric moisture percentage and all coarse and quick-draining pores.

REFERENCES

- Abou El Ezz, M.S. 1974. Land forms of Egypt. The American University in Cairo, Egypt.
- Abou-Khadrah, A.M. 1973. Geological and sedimentological Studies of Wadi El Natrun District, Western Desert, Egypt. Ph. D. Thesis, Faculty of Science, Cairo University.
- Erian, W.F. 1989. Soil climate and balance diagram of some horizontal extension areas in Egypt. *Egyptian J. Soil Sci.*, p. 45-74.
- Jackson, M.L. 1967. Soil chemical analysis, Prentice Hall of India Ltd., New Delhi.
- Klute, A. 1982. Water retention, laboratory method: *In: Methods of soil analysis, Part 1* (A.L. Page, Ed.). Amer. Soc. Agron. Madison, Wisconsin, USA.
- Moreaux, L.A. 1962. Reconnaissance report and recommendations for groundwater investigations, Wadi El Natrun, Western Desert of Egypt. General Desert Development Organization, Desert Inst., 81:12-25.
- Nelson, R.E. 1982. Carbonates and gypsum. p. 181-198. *In: Methods of soil analysis, Agron. 9, Part 2*, (A.L. Page, Ed.). Amer. Soc. Agron. Madison, Wisconsin, USA.
- Rhoades, R. 1982. Soluble salts. p. 167-180. *In: Methods of soil analysis, Agron. 9 Part 2*, (A.L. Page, Ed.) Amer. Soc. Agron, Inc. soil science. Society of America, Inc., Madison, Wisconsin, USA.
- Donahue, L., R.W. Miller, and J.C. Shickluna. 1983. Soils and an introduction to soils and plant growth. Fifth Edition. Prentice Hall, Inc., Englewood Cliffs, New Jersey, USA.
- Shate, A. 1955. An introductory note on the geology of the northern portion of Western Desert of Egypt. *Bull. Desert Inst.*, No. 2: 87-98.
- Shate, M. 1962. Preliminary report on the geology, hydrology and ground water hydrology of Wadi El Natrun and adjacent areas. Desert Inst. Mimeo.
- Trask, P.D. 1950. Applied sedimentation. John Wiley & Sons., Inc., New York.

Climatic and Agroecological Desertification in Jordan

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ABSTRACT

Desertification has attracted the attention of scientists concerned about the sustainability of the resources' productivity in the arid and semi-arid regions. Understanding the causes of degradation processes leading to desertification in these ecosystems is essential since actions to combat desertification depend on the nature of these processes. Scientists have not reached an agreement concerning the role of climate as a natural factor inducing desertification. Many scientists argue that since climate had not changed during the last 5,000-10,000 years, degradation in these regions should therefore be attributed primarily to human activities.

This investigation was conducted over a period of two decades and included the findings of several studies which covered the different ecosystems in Jordan. The objectives of this study were to: 1) investigate the climatic changes that affect the different ecological systems in Jordan; 2) relate climatic changes to degradation processes affecting the soils of the different ecosystems; and 3) assess the role of climate and human activities in causing desertification within each of these ecosystems.

Long and short-term climatic changes had affected, to a great extent, the land resources in Jordan. Research has indicated that climate within the different ecosystems have been more humid prior to the prevailing one. Information suggested that the latest climatic changes have occurred 5,000-10,000 years ago. Long-term climatic changes had resulted in the formation of soils highly vulnerable to degradation processes. The prevailing climate within the different ecosystems is characterized by high annual and seasonal variability. Climatic fluctuation, as indicated by the analysis of precipitation records, indicated a substantial reduction in the annual rainfall during the last 30 years. The reduction in precipitation has influenced the density of plant cover, and ability of various plant species to withstand arid conditions, thus accelerated erosion by wind and water.

A model that describes the possible pattern of climatic changes and variations within the different ecosystem was proposed on the basis of actual and computed rainfall pattern. The model suggested that, even under the current climate, a substantial reduction in the rainfall has occurred and is responsible for the development of either fragile ecosystem or ecosystems that are prone to degradation. According to this model, the influence of human interference would be effective only in ecosystems of

high fragility. The examination of long-term changes, as extrapolated from different types of soils occurring in different ecosystems, suggested a regional pattern of gradual changes in climate characterized by cyclic rainfall. Furthermore, the analyses indicated that edaphic aridity is gradually increasing along the southeast-northwest direction.

The risk of degradation varied from one system to another. The influence of climate and climatic fluctuation were found to be leading factors contributing to desertification in most ecosystems. The impact of human activities also varied from one ecosystem to another, but was found to be inferior to climate in most of the ecosystems. Maximum impact of human interference occurred when equilibrium between the ecosystem components was weak. Such impact was best demonstrated in the semi-arid to arid ecosystem (steppe region).

INTRODUCTION

Desertification is a multiple process that occurs in semi-arid to arid ecosystem. Processes contributing to desertification can be *natural* or *artificially* (anthropogenic) *induced*. This process attracted the attention of policy-makers, planners, and researchers in many countries because of its impacts on the natural resources and their sustainability. Globally, it had also attracted the attention of many international organizations because of its impacts on other equally important processes such as *global warming*, *displacement of inhabitants*, and *the degradation of biodiversity*.

The distinction between those natural and human-induced processes causing desertification has, for a long time, generated worldwide discussion between scientists interested in this subject as well as in related fields. Accepting either the natural or the human-induced processes, as the primary contributor responsible for the occurrence of desertification, has significant implication. If desertification was artificially induced, then measures to combat desertification must be directed towards changing the behavior of society, while if desertification was naturally induced, measures to combat desertification must focus on adapting to the prevailing conditions.

Distinguishing between those naturally or artificially induced processes presents real obstacles to scientists working in ecological investigations. Research had dealt in most cases with a single ecological process. Attempts were also made to correlate between various processes and a single component of an ecosystem. In many cases, it has been forgotten that desertification represents a specific ecosystem status characterized by poor soil productivity caused by degradation.

Therefore, in order to understand the mechanism of degradation associated with a specific ecosystem, efforts should be exerted to understand the role played by many of the ecosystem components and the interactions with each of the degradation processes since both types of factors influence any natural system, but with varying magnitude.

Soil properties and their distribution in any area are the product of several types of processes, which are related to factors such as climate and living organisms. Soil, as a major component of any ecosystem, is affected directly by the type of climate and indirectly by type of plants. It is very well known and accepted by soil scientists (Jenny, 1940) that it is possible to differentiate between soils at different locations based on the differences in climate, if other factors were equal, even though specific patterns of soil property distribution develop in soils under certain climates. For example, under a humid climate, soils have low soluble salt content, the oxide content is high, and pH is low. While generally under an arid climate, the soils are high in salt content, have high pH values, and have low oxides content.

Therefore, a model of soil property distribution, which reflects the type of climate that influenced the soil, can be established. If more than one type of climate has influenced a soil at a certain location, a specific distribution of properties develops in that soil which reflects the type of climate. If more than one pattern of soil property distribution were detected, then more than one climate could have influenced that soil. If these changes in soil properties were detected, the climatic sequence can be established. If not, no climatic sequence can be established and a gap in the climatic sequence will exist.

When a new type of climate prevails in a certain area, a series of ecological changes are initiated. The first groups of ecosystem components which interact with such changes are the plants and the microorganisms. The reduction in plant density and types triggers soil degradation processes such as erosion by wind and water. Such changes are indirectly related to the influence of climate on soil. Furthermore, there are numerous soil degradation processes that are directly related to climatic changes.

The pattern of soil property distribution can also provide very valuable information regarding climatic changes. Interest should be directed to changes of soil properties within the upper surface layers, which represent the climate-soil interaction to the most recent climatic changes. For example, the accumulation of calcareous silt in the topsoil layers indicates active sedimentation process by wind. If such sediments were salty or rich in gypsum, then it is clear that such sedimentation is the product of weathering processes under effect of arid climate. If the accumulation process were not continuous, no such accumulation would be detected in the soil. Thus, it can be ascertained whether the prevailing climate is permanent or not.

Accordingly, establishing the sequence of soil development, including the associated climate, can be considered a good record which can be correlated with the climatic sequence that prevailed in a certain area. In some cases, the occurrence of a certain sequence can be used to generalize about the present and future climate, assuming the continuation of existing conditions.

Understanding the relationships between the type of climate and extent of climatic changes, and the status of a specific ecosystem element, is very important to understand the mechanisms of ecological changes. In this regard, two issues are to be considered:

First: How long is the transitional period that elapses before a change from one type of climate to another takes place? Generally, this period may last for hundreds or thousands of years during which every element of the ecosystem will pass through a sequence of changes that characterize the degree and intensity of climatic changes.

Second: What is the nature of ecological changes that occur under the most recent climate? Usually some of these changes may continue or may be superimposed by the products of new processes triggered by the new climate. For example, when the climate is arid, physical weathering dominates, and silt and salt accumulate at the soil surface. Consequently, erosion by wind characterizes the ecosystem. On the other hand, if the climate was humid, chemical weathering would dominate and more clay would accumulate, and the salt content would be very low. Consequently, erosion by water would characterize the ecosystem.

Accordingly, changes in the components of an ecological system (soil and plant) will occur during the transitional period and after the prevalence of the new climate. The sequence of these changes would be completed when a new state of equilibrium between the climate and the other components of the ecosystem is reached.

Generally, there are no rules as to the time needed to reach or complete any stage. The previous principle represents the mechanism under which changes occur during and after climatic changes. Generally, climatic changes from humid to arid are responsible for processes that causes natural degradation because they are usually associated with lowering soil productivity. *The combined effect of different degradation processes is called desertification.* The rate of degradation does, however, increase until a state of equilibrium is reached. Under such equilibrium, the rate of degradation is minimum and steady.

The objectives of this study were to investigate the climatic changes that occurred within the different ecological systems in Jordan, relate climatic changes to degradation processes affecting the soils of those ecosystems, and assess the role of climate and human activities in causing desertification within each ecosystem.

MATERIALS AND METHODS

Jordan's Ecosystems: Distribution and Characteristics

For the purpose of this investigation, four main ecosystems are recognized and investigated.

Sub-Tropical Semi-Arid and Arid

Semi-arid areas dominate in Jordan Valley north of Deir Alla; high summer and winter temperature characterize this ecosystem, while annual rainfall varies from 250-400 mm. Arid areas dominate south of Deir Alla to the Dead Sea. Temperature is high during summer and winter. Annual rainfall varies from 250 mm at Deir Alla, at the upper north, to 100 mm near the Dead Sea south.

Mediterranean Sub-Humid to Semi-Arid

This dominates in the Highlands east of the Jordan Valley. The winter has a cool temperature, while the summer is mild. Relative humidity is maximum during winter and very low during summer. Rainfall varies from 250 mm at the eastern part to 500 mm towards the northwestern portion. The rainy season starts in November until March. Thunderstorms or scattered showers occur during March and May. Annual and seasonal rainfall variation is very high. The area is dominated by steep topography toward the western and the northwestern part, and gradually becomes less steep towards the east. Areas covered with forest are found in this ecosystem. The area is influenced mainly by water erosion and airborne sediments carried from the east and southeast parts of the country. This ecosystem occupies about 9% of country.

Mediterranean Semi-Arid (Steppe)

This ecosystem occupies the region east of the Highlands. Temperature level and variation is similar to the previous ecosystem, except that of lower minimum night temperature and higher frost occurrence due to the influence of cold desert air, especially during winter. Annual rainfall varies from 100-250 mm and is characterized by very high seasonal and annual variation. The rainy season extends from late November to the end of February. Scattered showers and thunderstorms occur afterwards. Flat topography dominates the area, causing strong wind activity. Strong wind erosion is very noticeable especially in the Khamaseen (April-May) period during which sediment is carried by easterly and southeasterly wind to this region and to western regions. The dominant vegetation is short grass with some sporadic small shrubs. This ecosystem occupies about 11% of Jordan.

Mediterranean Arid

This ecosystem, locally called the *Badiyah* of Jordan, it covers about 80% of Jordan. Temperature is high during the summer and cool during the winter, with high

frost re-occurrence. Relative humidity is very low during the summer season. Gusty wind occurs during all seasons, accentuated by open flat topography of the whole area. Annual rainfall is 50-100 mm, with extreme annual and seasonal variation. Most of the rain occurs as scattered, but intensive showers. Vegetation is sporadic short grass. The young landscape surfaces are dominated by gravely or silty soils, while well-developed soils which are protected by either basalt (north, northeast) or limestone desert pavement occupy the old surfaces. Soils of very sandy texture occur towards the east, where strong wind causes the formation of sand sheets. The formation of sand dunes is found in areas that originated from sandstone (Wadi Araba, Disi-Mudawara area) at the south and southeastern regions of this ecosystem. These ecosystems were used as the primary units for all subsequent soil and climatic analyses

Soil Investigation

Soil investigations were carried over many years; several soil profiles were described and analyzed. A large number of profiles were sampled from each of the four ecosystems. Only some examples of the highly relevant soil data were presented in this paper. The rest of the data can be found in cited references or in unpublished data collected by the author over the last two decades.

Climatic Data

Daily rainfall data for several meteorological stations (Ministry of Transportation, Ministry of Water and Irrigation) were collected and computerized for analysis. The data represent all the readings recorded at these stations. Most of the selected stations had good records, which started since 1942 or 1937. Regression equations that describe the relationship between time and the annual rainfall were computed for representative stations within each ecosystem. Annual rainfall averages that represent two periods were computed.

The first period covered the records for 30 years from the first year of collecting data, while the second period covered the second subsequent 30 years. In some cases, the second period covered 28 or 29 years. The long-term average, which represents the whole record period, was also computed. The purpose of this calculation was to assess any change in the average rainfall during the last 30 years, and to compare between the actual rainfalls in comparison with the rainfall quantity obtained from the computed equations. Five years moving-averages were also calculated to investigate the presence of any specific rainfall distribution.

Paleoclimate

Paleoclimate changes that took place within the different ecosystems were investigated using an extensive database, including detailed field and laboratory analyses. These investigations were carried out over two

decades. The results of some of these investigations were published in local, or international journals or graduate theses, while others are not published yet.

RESULTS AND DISCUSSION

Thrusts of the Analyses

Attempts were made to use available soil and climatic data to evaluate the status of ecosystem elements during different time sequences. Climate and climatic changes, as well as the risk inflicted by climatic changes on soil properties as important elements of the ecosystem, were given special attention. Furthermore, distinction between natural and artificially induced processes was attempted in order to evaluate any possible evidences which might allow forecasting any future climatic trends. This was done assuming that naturally occurring degradation would continue in the future and a continuation of the current pattern of climate prevailing within each of the ecosystems.

These principles and concepts were utilized to assess climatic changes and to evaluate the role of climate and climatic changes on soil degradation within the different ecosystems in Jordan. The characteristics of the past and present climatic changes and prevailing climate were used to identify the most important degradation processes associated with desertification. Evidence that could be utilized to extrapolate any future climatic trend with potential influence on degradation processes was also investigated.

The first step of the main thrust of the analyses was to characterize the rainfall pattern that prevails within each of the four ecosystems, and to investigate any indications of climatic changes expressed by rainfall distribution or possible changes over the time covered by the records. The crucial question to be answered was whether the obtained changes in the rainfall pattern reflected permanent or cyclic changes in the rainfall distribution. It is understood that the period covered by the rainfall records was not long enough to draw any concrete conclusion regarding climatic change. Therefore, changes in those soil properties, which could be linked to a certain type of climate or those known to be associated with climatic changes, were investigated.

The hypothesis used was that the trends of changes exhibited by soil properties reflect very well the trend of climatic changes. Since a long time is needed to detect the influence of climate on the soil properties, the trend expressed by soil property changes can be considered as a good means to predict long-term climatic changes. Attempts were also made to draw conclusions from trends exhibited by the occurrence of specific distribution of soil properties, or other changes which could support either a hypothesis of permanent climatic changes or a short-term variation.

Climatic Variation and Changes

Analyses of precipitation data for several stations indicated a high degree of annual rainfall variation. Coefficient of variation (CV) for stations with rainfall less than 200 mm varied from 40-70%, while CV was 30-45% for stations with 200-350 mm annual rainfall, and 25-35% for stations with higher rainfall (Hadidi, 1996). The value of 5-year moving-average suggested a cyclic pattern of annual rainfall variation. The length of the cycle seemed to endure for 20-25 years. Moreover, the average rainfall was always lower for the most recent cycle. This pattern appeared to apply for all stations with annual rainfall higher than 200 mm.

The analyses of short-term rainfall changes indicated a systematic reduction in the rainfall amount, except for the fourth ecosystem (Badiyah). The computed regression equations for different stations within the four ecosystems suggested that, except for the fourth ecosystem, a clear trend of decreasing rainfall pattern. The average rainfall computed for the two periods of 30 years is given in Table 1. The difference between the annual average for the two periods indicated a substantial reduction in the annual rainfall. The magnitude of reduction was highest for the ecosystem with higher rainfall, while areas with lower rainfall had less rainfall reduction. The most significant reduction was noted in the area which receives 200-350 mm of annual rainfall.

Comparing the differences between the computed and actual average rainfall indicated about 20-30% reduction in the annual averages during the last 30 years. The data also suggested that maximum reduction occurred towards the northwestern regions, with no reduction within the areas with annual rainfall less than 200 mm. A question of great concern is whether such pattern represents a permanent change or a cyclic fluctuation. Unfortunately, concrete conclusions cannot be extrapolated from a 60-year long climatic record. Therefore, other ecosystem elements closely associated with climate should be used.

The distinction between a pattern of cyclic rainfall fluctuation and no reduction in annual average rainfall, and another pattern, but associated with a reduction of annual rainfall average, cannot be based on short climatic records. A model of climatic changes, which represents a pattern of rainfall changes during transitional stage of climatic changes, was proposed. The model assumed a cyclic pattern of rainfall fluctuation, which is a part of long-term gradual changes and characterized by occurrence of new rainfall cycles of lower annual rainfall averages. This model was based on regression analyses, which clearly suggested a reduction in annual rainfall, and from the short-term analyses, which indicated the occurrence of rainfall cycles associated with lower annual rainfall.

According to this model, one should expect rainfall variation. However, the change from one type of climate to another, which will be discussed in the next section, does not occur over a short period of time, but rather gradually over a period of time during which the

transitional system dominates the region. This model will be a very valuable means to answer important questions such as "Is there any climatic change, although gradual, occurring during the past period, and could it continue in the future?". This is supported by the regression analyses and the actual reduction of annual rainfall over a cycle of 30 years.

If the answer to this question is yes, then the different ecosystems are heading toward a higher level of aridity. Accordingly, the claim suggested by many that the characteristics of the climate had not changed over the last 5000 years is not accurate, unless it is proven that catastrophic changes in the climate had occurred in the region, which nobody had ever reported. Furthermore, the idea that human activities as the sole factor responsible for the desertification had to be re-considered again since the soil properties are continuously changing in response to the climatic changes. However, this is not to claim that human activities have no role in causing desertification, but one should weigh and identify the role of the leading factors which depend on the fragility of the system in the first place.

(sub-tropical arid, first ecosystem) and southeastern part of Jordan (Mediterranean arid, fourth ecosystem).

Investigations carried within the arid ecosystem (Irani and Taimeh, 1992) confirmed the occurrence of climatic changes from humid to semi-arid within the areas currently under the influence of semi-arid climate (Mediterranean semi-arid, third ecosystem) and an arid climate within areas with rainfall less than 250 mm of annual rainfall (fourth ecosystem). Paleosoils with properties reflecting such sequence were found everywhere in Jordan (Taimeh, 1996, unpublished). Regarding the time during which the latest climatic changes had taken place, evidences indicated that climate in the southern part of Jordan Valley (sub-tropical arid ecosystem) was arid since the evolution of the Dead Sea 11,000 years ago (Taimeh, 1988).

Evidence of climatic changes was also documented in the north-northeastern (second ecosystem) region (Taimeh, 1996, unpublished). This area is covered with physically weathered basalt rocks, which clearly reflected the dominance of weathering under the influence of arid climate. Highly weathered, clayey soils

Table 1. Thirty years rainfall average and average reduction of annual rainfall.

Station	Last 30 years 1969 - '99	Before 1969	Reduction % year
		100 - 200 mm	
Muwaqar	152	153	...
Qatrana	88	103	0.5
Mufraq	149	165	0.5
		200 - 350 mm	
Shoubak	273	382	3.6
Mazar	284	336	1.7
Busseria	244	260	0.5
Ramtha	273	296	0.8
		350 - 500 mm	
Hawara	326	374	1.6
Irbid	370	450	2.7
Al-Taiyiba	456	513	1.9
Kufr Awan	432	524	3.0
		> 500 mm	
Salt	555	1045	3.0
Kitta	478	583	3.5
Kufrinija	582	646	2.1

Paleoclimates Changes

Several studies had indicated that all the ecosystems in Jordan were affected by more than one type of climate during the Quaternary. A climatic sequence of humid-arid-humid and arid-semi-arid-sub-humid was established for Irbid region - second ecosystem (Taimeh, 1984). A semi-arid, sub-humid climate prevails currently in this region. The sequence of climatic changes from humid to arid was also established (Taimeh, 1992b) in the southern part of Jordan Valley

that can only be formed under humid climate were observed under the physically weathered basalt-originated soils. Age determination of the basalt flow (NRA, 1966) indicated that most recent basalt deposition occurred 5000 years ago.

The presence of the well-developed soils below the basalt flow can be correlated with the paleosoils of Irbid, which were developed under humid climate. (Current climate is sub-humid at Irbid and arid at the areas covered with basalt flow towards the east).

Comparing the current climate with the one dominated before the deposition of the basalt suggested that the change in the climate had covered a substantial part of the northern areas of Jordan. Furthermore, evidences gathered from various areas suggested that a sequence of climatic changes had taken place along the southeast northwestern direction. This becomes obvious if one observes the rainfall distribution in the southern region of Syria, north of Irbid, which regresses towards a central point, as if the arid climate is spreading and the humid climate is shrinking.

The latest climatic changes at the Dead Sea (first ecosystem) area, which occurred 11,000 years ago, was marked the evolution of the Dead Sea (Neev and Emery, 1967), and was followed by the current sub-tropical arid climate (Taimeh, 1984; Abed, 1985). Accordingly, it could be proposed that climatic changes had started 11,000 years ago at the southeast corner and gradually changed towards the northwest. This was marked by the prevalence of the current climate 5000 years ago. Systematic changes reflected by soil properties supported such climatic changes along that direction. Such changes can be expressed by the dominance of physically weathered soils overlaying chemically weathered soils at the south and southeastern corner, with increasing chemically weathered soils reflecting more humid conditions towards the northwest corner.

Therefore, the latest climate changes in Jordan had gradually started 11,000 years ago along the SE-NW direction, and that drier conditions prevailed along the NW-SE. Apparently, changes in the climate from semi-arid to arid was completed in regions with rainfall less than 200 mm about 5000 years ago, which coincided with the deposition of the most recent basalt flow at the upper part of the north region. This was also substantiated by the occurrence of well-developed soils (second ecosystem) in Karak region, south of Jordan, which could not develop under the current climate. The general pattern of current rainfall distribution, too, seems to increase along this direction. Furthermore, landscape systems and soil properties exhibited, in a gradual manner, features highly correlated with prevailing climate-type along that direction.

Topography Configuration

It is well known that, based on the hydrological characteristics of arid land system, mountains are denuded and eventually flat topography dominates (Garner, 1934). The topography along the NW-SE and W-E directions reflected features highly correlated with the current climate pattern. Moreover, evidence related to alteration from humid to arid climate existed within arid as well as other regions. The extent of topographic maturity associated with the endured arid climate increased towards the east and southeast, indicating that aridity had prevailed earlier along this direction, and that a higher state of equilibrium between climate and the landscape had been attained. The development of strong desert pavement that expresses a high degree

of landscape maturity also increased towards the east and southeastern regions. The occurrence of the pavement was noticed to cover soils that originated from different types of parent material. Field studies revealed that well-developed soils associated with humid conditions existed below the desert pavement without any exception, which confirms the occurrence of humid-arid climatic alternation in that region too.

Vegetation Cover

The composition and the density of the vegetation cover interact relatively quickly with climatic changes or fluctuation. Plant species are also sensitive to such fluctuation and changes. The existence of certain isolated forest plant species in regions where no forest trees are present is strong evidence as to the degradation of the forest system. Abundant examples concerning the existence of forest cover within the area now designated as a steppe zone has been cited. It has been reported that this zone was covered with forest trees for the last 300-400 years (Taimeh, 1996). The presence of certain forest species extended this period to 800 years ago (semi-arid ecosystem) (Tillawi, 1989). Observations documented by historians described some locations as being forest areas 1200 years ago (Zidan, 1950). The most recent record, which described the occurrence of degraded forest, was dated 100-150 years ago (Musa and Trestram, 1872).

Patterns of Soil Properties Distribution

The distribution of some soil properties (calcareous silt, soluble salts, and gypsum) was used to establish possible regional climatic changes or trends. According to the regional distribution of these properties, three regions were investigated: Arid (Badiah), Steppe, and Highlands. (Note: The distribution of the above properties was investigated within the four ecosystems, but correlation with climatic changes was established with the above ecosystems).

The distribution of the silt content revealed a strong pattern of calcareous silt accumulation in the top surface layers within Region 2 and 3. In this regard, the following patterns were observed:

Arid region

The silt content at the surface of soils occupying younger geomorphic locations was lower than subsurface. This suggested losses of silt by wind. The silt content of the soil surface increased slightly towards the west.

Steppe

Maximum silt accumulation was found at the surface of the soils in this zone. The extent of the accumulation increased towards the west.

Highland

Accumulation of silt at the surface layers was very clear throughout this region. The magnitude of the difference between surface and subsurface was relatively less than the soils of the Steppe zone.

This criterion is not based on the total amount of silt content at the surface, but rather on the difference between the surface and subsurface content, because the soil parent material may be rich in silt. Thus, the difference between the surface and subsurface represented the magnitude of processes responsible for the silt accumulation.

The distribution of salt content in the soil profiles of the arid region was the highest, which clearly indicated that this area had been affected by arid climate for long period of time. Lower salt content was found in the soils of the Steppe zone and minimum content was recorded in the soils of the highland region. Gypsum accumulation was observed only in the eastern part of the Steppe and arid region (Badiah); it was never detected in area with a rainfall higher than 200 mm (Taimeh, 1992a). It is clear that such rain quantity is enough to remove the gypsum from the soil, even though calcium sulfate, which was considered responsible for the formation of certain gypsum formation in low rainfall area, was detected in the rainwater within the highland region (Salameh et al., 1991).

The regional distribution of the silt, soluble salt, and gypsum content suggested the following:

- Aridity had prevailed for a longer time toward the east and southeast of the arid region. As indicated earlier, climate had changed 5000 years ago at the northern part of this region and 11000 years at the Dead Sea area. Thus, increasing aridity prevailed at earlier ages along the east and southeastern directions.
- Maximum silt accumulation occurred within the Steppe region.
- Calcareous silt is currently accumulating at the surface of the soils within the Highlands and the Steppe. The accumulation within the Highlands can be considered the initial stage before converting the soil medium to be vulnerable or more prone to degradation.
- The wide occurrence of strong surface crust responsible for lower rainfall infiltration was observed within the Steppe zone. This property was correlated with very high silt accumulation and is responsible for reducing the amount of rain that could be stored in the soil profile. Thus, the plant receives less moisture than indicated by the annual average. This is responsible for what is called "Edaphic aridity." The clear accumulation of calcareous silt in the Steppe reached a high level causing strong edaphic aridity, which was responsible for the collapse of the vegetation cover and accelerating wind and water erosion. If the present pattern of silt accumulation in the Highlands endures, the water stor-

age capacity of the soils will also be further reduced, and a stronger surface crust will develop, thus accentuating edaphic aridity. The sedimentation of the calcareous silt can best be recognized during the Khamaseen period during which southeasterly wind blows continuously for 50 days, carrying with it the silty dust from the eastern arid regions.

- The strong correlation between the distribution of the various soil properties and the type of climate substantiated the occurrence of climatic changes along the west-east and southeast-northwestern directions. Such changes can only develop in soils as a result of enduring aridic conditions. Moreover, if such changes were cyclic in nature, the silt accumulation at the topsoil layers within the semi-arid to sub-humid, the semi-arid to arid ecosystems, and the semi-arid Sub-tropical ecosystems, can only occur under sustained or increasing level of aridity.
- Consequently, the current reduction in the amount of annual rainfall is a part of general trend of gradual climatic changes toward increasing aridity along the southeast-northwestern directions. This general pattern of increasing aridity toward the northwest is confirmed by other studies, which supported the regional nature of the climatic changes (Commission of the European Community, 1996).

Factors Responsible for Degradation

Many researchers raised questions regarding the present-day degradation processes. In most cases, the occurrence of degradation was indiscriminately attributed to human activities. It is true that degradation processes related to nature do occur almost at any places where human activities might be found. The vital question to be answered is whether the degradation observed at any place was primarily caused by human or by natural factors such as climate or associated with climatic changes. The decision as to the supremacy of either of the natural or human factor cannot be answered without considering the status of the environment and the stage of equilibrium between its various components.

The advocate of the first opinion claims that no climatic changes had occurred during the last 5000 years. Thus, the changes in the agro-ecological characteristics leading to the occurrence of desertification had occurred as a direct effect of human activities. While the advocates of the second opinion suggest that, although climatic changes had not occurred during the last 5000 years or so, evidence indicated that natural degradation leading to agro-ecological changes does also occur under the same type of climate and cause changes in the agro-ecological characteristics of that system. Furthermore, distinction between the natural or anthropogenic factors should take into consideration the indigenous characteristics of that system and whether human activities can alter its equilibrium.

This is not to state that there is no cases where humans could do just that, but there are abundant examples where the interference was very localized and the impact was negligible.

For example, very fragile sandy soils reflected by the presence of sand dunes; with almost no detectable human activities, occurred widely at some parts of the arid regions. Moreover, soils in many parts of the arid region formed from non-sandy parent materials had reached a state where very little changes in their properties would be expected with or without human interference. The nature of the characteristics of the ecosystem in that region reflected a sequence of changes with negligible human influences.

For example, the extreme soil degradation by deflation, which resulted in the formation of desert pavement, flat surface configuration, accumulation of soluble salts, and many others, all signified the role of processes directly related to the influence of climate. However, many people had indicated that the region previously showed better plant cover than the present one. Nevertheless, it is the indigenous characteristics which determine the plant density that could be supported by the ecosystem. For example, how can we explain the absence of plant cover in some areas even during the rainy season? and still attribute this to the influence of human, while the soil salinity is so high where very few plant species can tolerate such level of soil salinity.

Furthermore, the existence of some relic forest areas in the semi-arid Steppe region ecosystem raises the following questions:

First: Could the degradation of the forest cover be attributed to the conversion to arid climate?

Second: Could the degradation be attributed to the changes in the agro-ecological properties caused by processes such as erosion of soil triggered by a gradual change in the climate, thus making the soil unsuitable for the growth of forest trees? Or:

Third: Could the degradation be attributed to human activities, which increased by the turn of this century, which was marked by increasing human settlement?

Processes that could occur under the hypothesis assumed in the first two questions are interrelated. Also, changes implied by the first hypotheses could be responsible for intensive degradation.

The implication of accepting the hypothesis assumed by the first or second question will determine whether the area has suffered less rainfall during the last 1200 years, or that ecological changes, which do not favor a forest system, had intensified during the last 5000 years. Accepting the second hypothesis implies that the ecological system is at a stage closer to equilibrium with the prevailing climate and the existing ecosystem does not support forest system. Therefore, aridity stress attributed to climate is not expected to increase to a higher level. However, evidences

provided earlier suggested that edaphic aridity would intensify, thus causing a higher rate of degradation. On the other hand, if a gradual climatic change was initiated 5000 years ago, and is still continuing, such a trend means that the ecological system is at a stage marked by disappearance of forest cover and that higher rate of degradation processes should be expected (See section on climatic model).

Evidence as to which hypothesis to support can be provided from trends exhibited by some climate parameters, changes in soil properties, and some regional features. Changes in climatic parameters (annual rainfall average) expressing reduction in the rainfall amount was indicated earlier (Table 1). The magnitude of the annual reduction increased along the southeast-northwestern direction. If such a pattern represented a permanent change, not a cyclic climatic fluctuation, then the area with rainfall less than 200 mm rainfall, which suffers the least from rainfall reduction, could be designated as the region with least expected climatic changes in the future. This was also substantiated by a higher degree of landscape maturity towards the southeast and eastern directions. Furthermore, soil properties also exhibited a more advanced state of equilibrium with aridic climate along the same directions.

According to the analyses of rainfall records, the reduction in the annual average in the Steppe zones was higher than the arid region and less than the Highlands (> 350 mm). The characteristics of landscape in these two regions also exhibited geomorphic features such as more angular and steeper topography, which are associated with more humid conditions towards the northwest direction.

Degradation Related to Climatic Changes

Degradation processes, related to the most recent climate influencing an ecosystem, are restricted to the upper soil layers. The thickness of the soil layers that reflects such influence depends on the nature of the processes and the length of the period during which this processes have been operating. For example, if the degradation was due to erosion by water, the thickness of the upper layer will be inversely related to intensity and time. Other features that could be related to climatic changes are landscape and plant cover characteristics. However, these processes could also be attributed to human activities. Nevertheless, in many cases, evidence to distinguish between the natural or artificial induced changes does exist.

Degradation is initiated during the transitional period of climatic changes. Initially, the rate of degradation will increase until climatic changes are completed and a state of equilibrium is reached. The initial changes introduced during the transitional period could be of little influence on the ecosystem. This stage is called "incipient" stage. As time progresses, a higher rate of degradation occurs, where a threshold point is crossed, beyond which the influence of the degradation cannot be halted or reversed. Afterwards, the rate of

degradation reaches a low but steady level. This represents a state of equilibrium between the components of the ecosystem. The different stages from the pre-incipient, incipient, to the equilibrium stages are characterized by a specific combination of climate, water balance, evolution of soil properties, the existence of a specific combination of plant species, and landscape features that interact actively with the components of these systems.

The change in the degradation rate, as described, is attributed to natural factors. Time needed to cross from one stage to another depends on the original status of the ecosystem, its ability to withstand new factors, and on the rate of climatic changes. At a given stage, any ecosystem possesses the capability to withstand external forces, whether natural or anthropogenic. The ability of the anthropogenic factors to alter this equilibrium, at any stage, depends on that stage itself. For example, at the pre-incipient or incipient stage, the equilibrium between the elements of the ecosystem is strong. If human interference takes place at a stage when the ecosystem is suffering from high rates of changes, or is characterized by a state of ecosystem fragility and of low recovery capability, the influence of the human activities will be effective, and would increase the rate of degradation. At the advanced stage, when a state of equilibrium is maintained, the rates of changes are low, and the recovery rate is poor, and the impacts of human activities will be negligible.

Changes caused by human activities are usually localized and could be completed in a short period of time, while natural changes require a longer period of time, operate on a regional scale, and are associated with landscape changes, which cannot be produced by any human activities. In some cases, it is difficult to differentiate between the influences of natural and the human-induced factors. This is especially true when equilibrium of the ecosystem is at its weakest status and when degradation occurs at a maximum rate. This stage is marked by poor recovery capability, and the ecosystem will be highly vulnerable to the influence of human activities.

The differentiation between the two types can, however, be achieved sometime with certainty. For example, a high salinity level within a certain area could be reached within a few years in semi-arid to arid region, if the land was irrigated with poor quality water. That is a clear example of specific ecosystem changes by an anthropogenic influence. On the other hand, such rapid soil salinization could not take place, if the climate was humid. The difference is specifically related to the capability of the ecosystem to cope with external forces.

Attempts were made to differentiate between degradation processes related either the type of climate, or climatic changes (natural), or human activities. Criteria such as status, and characteristics of the ecosystem, and the capability of the ecosystem to withstand external forces, were used. Regional rainfall distribution and the

level of rainfall reduction were also correlated with other ecosystem characteristic. Attempts were made to deal with an important hypothesis, "Does the detected reduction in precipitation reflects a real permanent change, or is it only a cyclic fluctuation in climate?". In order to facilitate the correlation, which might reveal any possible trend, characteristics of the ecosystem, and the nature of the on-going degradation processes were also investigated. Attempts were made to associate changes with past climate within each ecosystem. As a result, the following summarized such evaluation conducted within each of the four ecosystems:

Sub-Tropical, Semi-Arid Ecosystem

This system exists in Jordan Valley north of Deir Alla. Erosion by water, and slight accumulation of calcareous silt carried from the eastern region are among the degradation processes that characterize this ecosystem. High evaporation demand, thus poor water balance, imposes great risk on this ecosystem and paves the way for effective human influence. The use of water with marginal quality for irrigation could cause soil salinization under prevailing conditions. If the reduction of precipitation was permanent, the risk of higher negative water balance would increase, and the deterioration of soil properties such as organic matter content would reduce soil productivity. Salinization hazard would also increase.

Sub-Tropical, Arid Ecosystem

This ecosystem is found in Jordan Valley south of Deir Alla and north of the Dead Sea. The current climate prevailed since the evolution of the Dead Sea 11,000 years ago. Ecosystem components such as gravely soils, extensive distribution of saline soils towards the south, and low organic matter content characterized the soil of this region. Soil properties were identical to those properties produced under arid ecosystem. The soil properties were not very much different from the original sediment. Very little changes associated with prevailing climate were detected, except for water erosion during flood events, and accumulation of soluble salts at the upper soil layers. The risk imposed by climate could be related soil salinization if further deterioration of the irrigation water quality occurred.

Mediterranean, Sub-Humid Semi-Arid

This ecosystem occupies the Highland areas east of the Jordan Valley. This system supports forest trees in areas with annual rainfall higher than 300 mm. This region had been affected by more than three episodes of climatic changes. The last episode is less humid than the previous one. Thus, if changes should occur, it is expected to cause further degradation. It is obvious that a state of equilibrium between climate and other ecosystem elements has not been reached.

Erosion by water is the dominant degradation process in this region. The exposure of rock surfaces associated with evidence that such surfaces were

covered with soil material, the occurrence of very deep soil adjacent to rocky surfaces, and the occurrence of red soil relics over steep surfaces substantiate the hypothesis that degradation processes are rather recent. If no climatic changes had taken place for the last 5000 years, the occurrence of isolated forest trees at various locations with ages varying from 400-1000 years suggested that these degradation processes are recent and are continuing under the present climate.

Nevertheless, the poor natural forest regeneration in areas with isolated forest trees suggested that the system recovery had been extensively weakened. Such poor recovery was ascertained by the repeated failure to grow forest trees without irrigation in this area. Moreover, if no climatic changes had taken place during the last 5000 years, why has the forest ecosystem failed to regenerate during the last 400-1000 years? The answer to such a question can only be explained if we accept the fact that soil properties had degraded to a great extent and cannot support forest trees anymore. The strong correlation between the slope and depth of soil reflected the influence of erosion by water, which is considered the most important degradation process related to climate in this region.

Some concerns were voiced that degradation of forest ecosystems was caused by human activities and not by natural processes. It is true that forest in many areas have disappeared as a result of cutting, as some areas described as being thick forest 100 years ago (Trestam, 1872; Musa, 1875) are barren land today. Nevertheless, forest destruction occurred by the turn of century when the population of this region, estimated in the thousands, was at most localized, while the influence of extensive erosion by water dominated the whole region.

Deep soils adjacent to barren steep slope, and the presence of soil relics, characterized the whole area. The dominance of landscape with rounded-edge mountains, which signified the product of weathering under drier conditions, cannot by any means be attributed to human activities. This, however, does not, underestimate the accelerated erosion by water here and there. Nevertheless, *the overwhelming fact remains that climate-induced erosion is the primary factor responsible for detected changes in soil properties, vegetation, and landscape characteristics.* Such changes are considered responsible for the current degradation of the ecosystem.

The other issue to be considered is whether further climatic changes and more intensive degradation processes are expected to occur in this region. Confirming such hypothesis requires data at a regional scale and evidence associated with long-term changes. Such evidence is provided by soil properties of this region, as expressed by the accumulation of calcareous silt at the soil surface layers of the whole area. Strong correlation between desertification processes and the accumulation of calcareous silt in the upper soil layers was also observed. Edaphic aridity, as a regional prop-

erty causing desertification, would be aggravated if silt accumulation continued. Many plant species, less resistant to arid conditions, would disappear and the soil surface becomes more vulnerable to erosion by water, which further aggravates the soil conditions.

Currently, it appears that silt accumulation is at a level which did not cause a significant change in the ecological system. Consequently, it could be considered at the incipient stage. The significance of such a process is that it points towards increasing aridity and the development of harsher conditions for the plant if the present climate prevails in the future. These changes occurred at a regional scale, and are attributed to processes strongly associated with the type of climate.

Semi-Arid Ecosystem (Steppe)

This ecosystem occupies the area east of the Highland region. The prevailing climate exerts maximum risk of degradation. Low and highly variable rainfall, high evaporation demands, strong wind, and low relative humidity characterize this ecosystem and are responsible for the development of an environment hostile to plants. This region had apparently suffered during the last 5000 years from continuous accumulation of calcareous silt transported from the east and southeastern regions. The accumulation had reached a level whereby it can be classified as loess sediment. Consequently, the soil water-holding capacity for the upper 40 cm, most important for perennial plants, was substantially reduced, thus aridity stress.

Moreover, the high silt content coupled with very low organic matter helped the development of strong surface crust with a low infiltration rate. Such a property accelerated runoff and reduced water storage in the soil for plant use. The value of infiltration rate varied between 8-2 mm/hr (Ziadat and Taimeh, 1995). Thus, if rainfall intensity exceeds this value, rain would be lost as runoff. Strong evidence was gathered indicating that such features have been developing in the soils of this region following an episode of more humid conditions (Taimeh, 1996).

The very open and level topography, especially towards the eastern part, explains why wind activity is very effective active. The flat topography at the eastern side, the dominance of rounded edge-mountains and hills stripped from soil, suggested active weathering under arid conditions. The observed strong correlation between slope and soil depth also supported the hypothesis of active geologic erosion by water.

Therefore, it can be concluded that the prevailing ecosystem is characterized by a climate which exerts high risk as indicated by high rate of wind and water erosion, and by the occurrence of a soil media that is very hostile to many plant species. Variable human activities, such as plowing, overgrazing, and heavy traffic movements were effective in destroying what is left of the adapted vegetation cover. The damage seemed to be extensive up to the extent where plant

cover was totally absent in some areas, while in some other areas plants were found only along waterways.

Less rainfall reduction was detected in this area in comparison with the Highland region. Nevertheless, prevailing conditions, expressed by wind and water erosion and less effective rainfall, strongly suggested an increasing climatic risk in this region. Furthermore, it is expected that human activities would be very effective and capable of causing further degradation due to ecosystem fragility. Such degradation will not only affect this region, but will be extended to the Highland region, since this area serves as a source of calcareous silt whose accumulation at the topsoil layers was found to occur in the whole Highland region. The continuation of such a pattern means increasing edaphic aridity, less favorable plant growth conditions, and thus higher rate of ecosystem degradation.

Arid Ecosystem (Badiah)

This ecosystem occupies about 81% of Jordan. More than 70% of the land has a slope less than 8% (Hariz, 1988). Evaporation demand is among the highest in Jordan (2300 mm/ year), especially toward the east and southeast. Vegetation cover is mainly short sporadic grass, or absent at many locations. Aridic weathering had been operating for long time and resulted in the production of silty or gravelly soils with low potential productivity and very distinct salt distribution which increased towards the east and southeastern areas. Extensive areas are covered with basalt or limestone desert pavement, which reflected endured aridic conditions.

The occurrence of the gravelly soils and the desert pavement was more imminent toward the east and southeastern regions, which substantiated the hypothesis that aridity prevailed along this direction. Therefore, changes in the ecosystem as a result of such a climate had substantially advanced along this direction. The occurrence of sand dune east of Azarq, at the southeastern regions, and the southern part of the panhandle, indicated very advanced stage of system degradation. Moreover, the filling of old *wadi* systems with gravel, and the development of soils with very poor potential in areas with well developed soils, which could only develop as a result of weathering under humid climate, supported the hypothesis that the status of poor vegetation cover was not due to human influence.

Examples of such conditions were found in areas such as Wadi Araba, Desi, and Mudawara areas, where the development of sand dunes which originated from the weathering of sandstone and granite is responsible for the dominance of an unstable surface. As a result, desertification in these areas has reached an advanced stage. The development of sand dunes on limestone-originated soils, within the northern part of the Panhandle area, suggested that desertification had also reached an advanced stage in these parts too. The occurrence of a gravelly surface also indicated that finer

particles were lost by wind (Irani and Taimeh, 1992). Such material was detected in other ecosystems occurring westwards.

As a result, desertification processes had reached an advanced stage that reflects a state very close to equilibrium. Expected changes might be restricted to the loss of finer particles from the soil surface towards the east. As a result, gravel content increases in the soil. The water balance in this area indicated that evaporation demand could accommodate twenty times the existing rainfall quantity. The dominance of gravelly or silty soil with poor water-holding capacity add additional stress to that currently inflicted on plant cover. Pressure by human activities under such conditions was very subordinate in its magnitude and impact.

Furthermore, desertification processes in this region occurred as a result of processes attributed to climate only. Among evidence which supported this conclusion was the presence of an extensive area covered with desert pavement, the occurrence of an area with no plant seed stock, the extent of areas covered with gravelly soils, and the dominance of flat topography occupied with soils that were formed by natural weathering processes.

Future trends concerning degradation processes indicated the continuation of wind activities, which would be responsible for the development of more sandy landforms, and the spreading of gravelly soils. Further extensive soil degradation is not expected, since the characteristics of ecosystem components was substantially altered. In other words, the rates of degradation processes are low in this ecosystem. Under such a system, the influence of human activity is expected to be negligible.

SUMMARY AND CONCLUSIONS

Available information indicated that different climatic episodes have prevailed in Jordan. The present climate was preceded by a humid climate in most regions. Climate and climatic changes is responsible for the existence of four different ecosystems, and is the most important factor contributing to degradation in these zones.

The analyses of precipitation trend suggested rainfall reduction in the semi-arid-sub humid zones that could be translated to a higher climatic risk. Nevertheless, confirming such trends must be based on evidence associated with long-term records. However, the following can be stated: (1) On the basis of climatic pattern, less rainfall during the last 30 years might be enough to reduce plant density in many areas and cause a higher rate of erosion. (2) Analyzing the components of the ecosystem, and using those highly associated with climatic changes, the analyses showed that, in many areas, soil properties reflected increasing aridity along the southeast to northwestern direction.

The analysis of rainfall records indicated the occurrence of climatic cycles of 20-25 years long, and a pattern of rainfall reduction was detected within the

Highland and the Steppe regions. The analyses also suggested that the reduction in the amount of rainfall could be a part of cyclic fluctuation of annual averages, but resulting in lower annual rainfall averages. This pattern was assumed to be a long-term reduction rather than a cyclic distribution since evidence gathered from soils within these two regions strongly supported the hypothesis of sustained aridic conditions and not the occurrence of wet-dry-wet rainfall cycles. According to this model, it is expected that the rate of some types of degradation in these regions would accelerate in the future.

Changes in the agro-ecological system, namely soils' properties, indicated that a higher level of aridity should be expected within the sub-humid to semi-arid ecosystems. The Badiah region is expected to suffer the least from these changes since a near state of equilibrium with climate had apparently been maintained. Maximum increase in edaphic aridity is expected to accelerate in the Steppe zone followed by the Highlands.

Risk inflicted by the type of climate or climatic changes indicated that present climate is responsible for several active degradation processes. In areas where maximum climatic influence was found to be maximum, human interference was subordinate. The apparent impact of human activities in the Steppe zone was primarily attributed to the fragility of the ecosystem in this the first place. *Such a conclusion doesn't by any means underestimate degradation associated with human activities in this region.* Nevertheless, accepting such a conclusion will help in formulating appropriate plans to combat degradation in this vital region for Jordan.

The advanced stage of desertification observed within the Mediterranean arid region (Badiah) was attributed to the nature of the prevailing and paleoclimates, with a very minor or no human influence. The system potential productivity had already reached a poor status and the existing soils of that region cannot support better plant cover under the prevailing climate. Such a conclusion was clearly demonstrated by the poor plant cover within some protected area in this region, which practically had not improved even after a long period of protection.

REFERENCES

- Taimeh, A.Y. 1984. Paleoclimatic changes during the quaternary in Irbid region. *Dirasat* 11 (7): 131-149.
- Taimeh, A.Y. 1988. Genesis of some salt affected soils in southern Jordan Valley. *Dirasat* 15 (11): 79-103.
- Taimeh, A.Y. 1989a. Desertification in Jordan: environmental disasters and desertification. Inter. Conf. on "Desertification and Sand Dune Fixation". University of Trieste, Italy.
- Taimeh, A.Y. 1989b. Desertification and potential sand dune formation in Jordan: Inter. Conf. on "Desertification and Sand Dune Fixation". University of Trieste, Italy.
- Taimeh, A.Y. 1992a. Classification, distribution, and properties of gypsiferous soils in Jordan. Workshop on "Management of Gypsiferous Soils", ICARDA.
- Taimeh, A.Y. 1992b. Formation of gypsic horizon in some arid soils of Jordan. *Soil Science*. 135: 79-103.
- Taimeh, A.Y. 1995. Desertification in Jordan: problems and solutions. The Second Scientific Week: "Land Resources Towards Better Uses". Higher Council for Science and Technology, 26-31 August.
- Abedulkader, A.M. 1985. Geology of dam formation. *Dirasat*. 12 (22): 99-105.
- Dadoush, H.B. 1988. Potential utilization of water and land in Jordan. (*Unpublished Thesis*, University of Jordan).
- Bender, F. 1994. Geology of Jordan. Gebruder Borntraeger, Berlin.
- Commission of The European Communities, 1996. Environment and Climate Program. Mediterranean Desertification and Land Use. *MEDALUS II*.
- Salameh, E., O. Remanie, and Abumoghli, 1991. Precipitation water quality in Jordan. *Res. Bull.*, Vol. 16. The Water Research and Study Center. University of Jordan.
- Garner, H.F. 1994. The origin of landscape: A synthesis of geomorphology. *Oxford University Press*. p. 310-381.
- Jenny, H. 1941. *Factors of soil formation. A system of quantitative pedology*. Mc Graw-Hill Book Co. Inc. 104-197.
- Irani, K., and A.Y. Taimeh. 1992. Properties and formation of some aridisols in Jordan. *M. Sc. Thesis*, University of Jordan.
- Al Hadidi, L.M., and A.Y. Taimeh. 1996. Evaluation of desertification risk in Jordan using some climatic parameter. *M. Sc. Thesis*, University of Jordan.
- Ministry of Transportation, Meteorological Dept., Rainfall records for many years. Amman, Jordan.
- Ministry of Water and Irrigation. Daily rainfall records database, Records for many years. Amman, Jordan.
- Musa, S. Travelers' observation in Jordan. 1875-1905. Culture and Art Dept., Amman, Jordan.
- Natural Resources Authority. 1966. A report on geological and petrological studies of the plateau basalt in N.E. Jordan. German Geologic Mission in Jordan.
- Neev, D., and K.O. Emery. 1967. The Dead Sea: depositional processes and environment of evaporates *Geo I. Sur. Israel. Bull.* 41: 144.
- Tillawi, A. 1989. Forest of Jordan. Published by Dar Al Basheer. 91-95.
- Trestram, H.B. 1872. Trips in TransJordan. (in Arabic, published by Arab Press, Amman).
- Zidan, G., 1950. Fatat Ghassan. *Stories in Islamic history*. Lebanese Printing and Publ. Co. p. 91.
- Ziadat, F., and A. Taimeh. 1995. Effect of management practices on soil losses in arid to semi-arid areas in Jordan (*Unpublished Thesis*, University of Jordan).

Aeolian Sedimentation in Irrigated Lands of the Arid and Hyper-arid Zones in the Sudan

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ABSTRACT

Aeolian action is a major land degradation process spreading widely in the arid and hyper-arid zones of the Sudan. The irrigated land along the River Nile, White Nile Schemes and northwestern Gezira Agricultural Scheme are seriously affected by sand encroachment. This paper describes causes and impacts of sand encroachment in the irrigated agricultural land, on soils and irrigation system. Aerial photographs and Landsat imageries were used to explore the spread and magnitude of sand encroachment. The major causes for aeolian erosion are the bare sandy lands (as source) and the prevailing winds from the northeast during the winter season and from the southwest during the summer season. Field data, coupled with physical and chemical data, were used to assess the adverse effects of wind sand deposits on the agricultural land.

The data show that there are adverse changes in the morphological and physical soil properties that affected the soil internal infiltration rate, water storage capacity and soil tilth. Soil fertility decreased, especially in nitrogen, phosphorus, organic carbon and soil pH. The wind-blown sand blocked the canalization system in many irrigated schemes and made it inaccessible for farming. The adverse effects of sand encroachment on the soil physical properties coupled with the degraded fertility are threatening the sustainability of irrigated agriculture.

Accelerated soil erosion, land degradation and consequent desertification, are considered as one of the most critical environmental hazards. These hazards are brought together in the arid, semi-arid, and dry subhumid ecosystems, where they have been caused by various factors, including physical (environmental) and human activities (UNEP, 1994). These ecosystems are defined by locality depending on their features of aridity, drought, soils, and vegetation.

Any form of land development in the dry ecosystems should pay attention to the degradation of soils by aeolian erosion and, as a rule, great care should be taken to prevent potential damage induced by wind. Mainguet (1999) citing FAO, stated that of the total area of the African drylands some 16% were affected by water erosion, 25% suffered from salinization and 45%, by far the greatest proportion, were subjected to traumatic aeolian activity. In many parts of the Sahelian zone, shifting sands,

mobile barachans, and elongating seif dunes are the agents through which the gardens, the palm tree plantations, the wells, and the villages are being invaded by sand (Mainguet, 1999). Communication lines, irrigation systems, and pipelines built in an area of shifting sands, migrating dunes, or blowouts are vulnerable to deep burial by sand or to being undermined by deflation (Cooke et al., 1982; Mainguet, 1991).

In the Sudan, aeolian action is a major land degradation process spreading widely in the arid and hyper-arid zones. In the west of the country, especially in the northern Sahel zone, aeolian accumulation is taking place, many *wadis* are buried under wind-blown sand-sheets (Ibrahim, 1982). Ayoub (1998) reported that the total area affected by wind erosion, in the Sudan, is 27 M ha, most of it in arid and semi-arid zones (21.2 M ha), while in the hyper-arid zone, it is about 5.8 M ha. Before the last three decades, the irrigated agriculture in the arid zone did not suffer from sand encroachment.

Since the establishment of the irrigated agriculture in the Gezira and the White Nile schemes, the trend of rainfall of the period 1920-1965 had generally records above average rainfall with relatively minor year-to-year fluctuations. During this period, the population was low and the natural resources were traditionally and wisely utilized. The droughts of 1968-1984 in the Sahel, accompanied by mismanagement of natural resources, led to severe wind erosion in the arid zone. The Nile alluvial terraces and the basins in the hyper-arid zone are being steadily invaded by the aeolian sedimentation. The blown sand has endangered the River Nile itself (Lamprey, 1975; Hassan, 1985; Laki, 1994; Ayoub, 1998).

The aim of this paper is to highlight the Aeolian sedimentation in the irrigated lands along the River Nile and its tributaries in the Sudan. The causes and impacts of sand encroachment on soils and irrigation system are discussed.

Location, Climate, and Soils

The Sudan, Africa's largest country with flat topography, lies between latitudes 3° and 22°N and longitudes 22° and 38°E, and covers 2.5 M km² (Fig. 1). Sudan has a hot, tropical, continental climate, with the exception of areas at higher altitude and in proximity to the Red Sea. The country can be divided into five aridity zones which form a consecutive series from north to

south (Ayoub, 1998). The zones condition is affected by the seasonal movement of the *Intertropical Convergence zone*. The flat topography produces a gradual transition from one climatic zone to another, and both humidity and rainfall decrease as one moves northwards, while daily and seasonal temperature variations increase steadily from south to north (Table 1).

The rainfall and the distribution of various climatic types are closely related to the seasonal migration of the *Intertropical Discontinuity* and the rain belt to the south of its northernmost position of 17°N in August. The duration of the wet season increases southwards; as a result, there is a progression from north to south from hyper-arid, through arid, semi-arid, dry subhumid, and moist sub-humid. In the summer season (April-

October), the humid southwesterly trade wind blows in the country, while in the winter season (November-March) the dry northeasterly trade wind blows.

The soils of the Sudan are very variable due to the differences in climate conditions, topography, and origin. In the moist sub-humid area in the south the iron-stone (Oxisols) soils are dominant. The most extensive soils in the central Sudan are cracking clay soils (Vertisols). In the western Sudan (Sahel), the sandy soils exist with variable degree of development (Entisols, Inceptisols, and Alfisols). In the north, the narrow alluvial strips (Fluvents and Aridisols) exist along the Nile, and bounded on both sides by shallow and deep desert soils (Psamments and Aridisols).

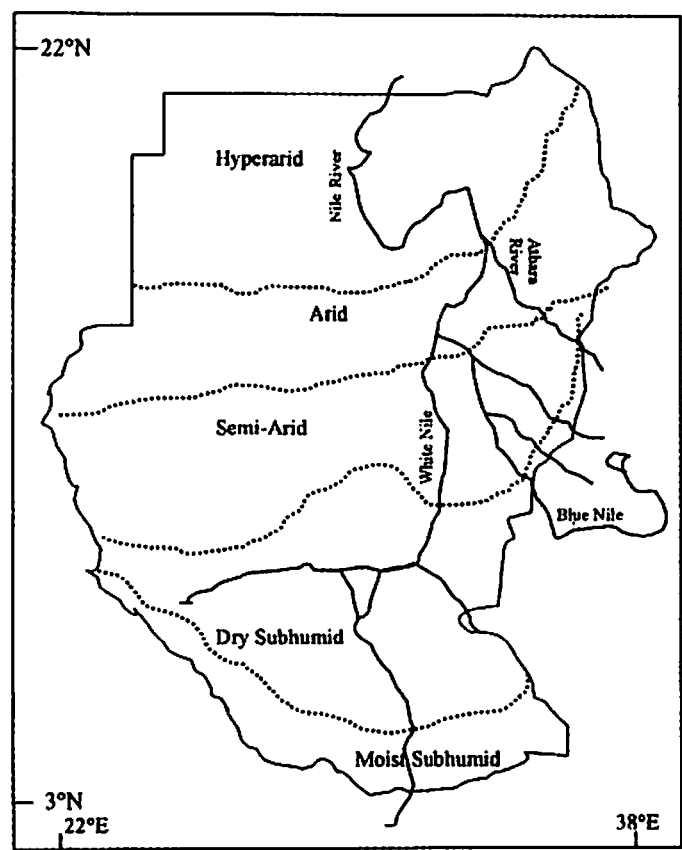


Fig. 1. The aridity zones of the Sudan.

Table 1. Climatic conditions of different zones in the Sudan.

Zone	Maximum Temperature -----°C-----	Minimum Temperature -----°C-----	Average Annual Rainfall -----mm-----
Hyper-arid	42 - 44	8 - 13	0 - 75
Arid	40 - 42	13 - 16	100 - 250
Semi-arid	38 - 40	13 - 20	250 - 400
Dry Sub-humid	36 - 38	18 - 21	600 - 800
Moist Sub-humid	33 - 35	14 - 19	1200 - 1600

Irrigation in Sudan

The River Nile and its main tributaries (White Nile and Blue Nile) bisect the Sudan from the south to the north. Undoubtedly, irrigation is not new to the Sudan; it has begun since human settlements along the Nile River. Traditional gravity-irrigation has been practised in the flood Plains of the Nile, while in the eastern regions flush irrigation from the seasonal rivers exists. The British introduced modern irrigation methods to the country in the early 1900s by installing pumps to irrigate experimental cotton farms along the main Nile and the Blue Nile.

Large-scale gravity irrigation began in the Gezira Scheme with completion of Sennar Dam on the Blue Nile in 1925. The Gezira Scheme is situated between the White and Blue Niles in the northern part of the central clay plain. Development of livelihood medium-scale irrigated pump schemes along the White Nile and the River Nile followed the development of the Gezira Scheme (Table 2).

Sand Encroachment in Irrigated Agriculture

Irrigated agriculture is the main activity of the population and the backbone of the Sudan economy. Most of the irrigated schemes are allocated in the dry region. These are mainly hyper-arid, arid- and semi-arid, with annual rainfall less than 400 mm, and remain dry for 8 to 12 months. Wind erosion and sand encroachment on farms and irrigation system are becoming serious problems, since the occurrence of the drought of 1968 to 1972. This is especially the case of the Nile Valley from Khartoum northwards; Toker, and El Gash pump schemes on both banks of the White Nile from Dueim town northwards, and recently the northwestern part of the Gezira and Managil Schemes.

Recently, the main environmental problems threatening agricultural production in the irrigated farming are shortage of water supply (drought) and salinity, which are aggravated by sand encroachment. Sand encroachment has blocked the canal system and buried the fields, thus rendering most of the irrigated land

Table 2. Existing irrigation developments in the Sudan and their climatic zones.

Water Source	Supply Method	Area (1000 ha)	Climatic Zone
Blue Nile	Gravity	924	Semi-arid/Arid
Blue Nile	Pump	391	Semi-arid/Arid
White Nile	Pump	247	Semi-arid/Arid
Atbara River	Gravity	193	Arid
Main Nile	Pump	125	Arid/Hyper-arid
Main Nile	Basin	34	Arid/Hyper-arid
Gash and Baraka	Flush	59	Arid/Hyper-arid

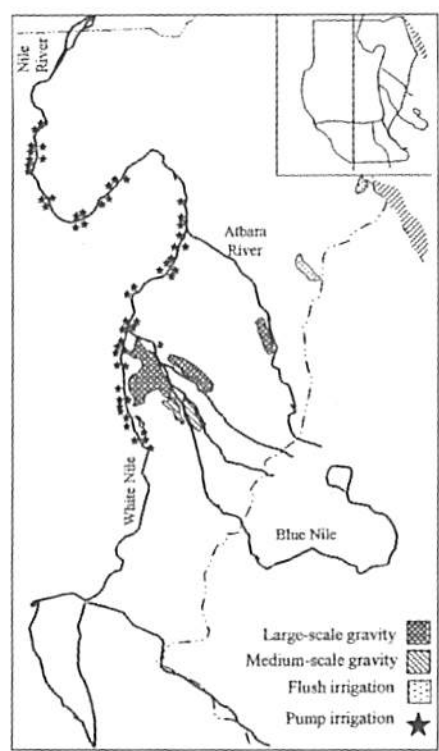


Fig. 2. Irrigated agriculture in Sudan.

inaccessible to farming. The problems of sand encroachment for the irrigated land in the hyper-arid and arid zones will be highlighted and discussed.

Sand Encroachment in Nile Valley

The northern part of the Sudan is an absolute desert, with extremely low organic matter, and is devoid of vegetation cover. The Nile River bisect the desert, forming a discontinuous narrow strip of productive alluvial land. It consists mainly of basins, which were former courses of the Nile (Wadi El Khowi, Kerma, Wad Hamid, etc.), recent and old higher terraces, and islands. The basins are flooded by water from the Nile during the flood period, and in the past the *wadis* (seasonal watercourses), e.g., Howar, El Mugadum, El Milk etc., were providing water to the Nile, and hence increasing the area of basin irrigation. After the occurrence of the drought in the Sahelian region, sands have buried these *wadis*, which are no longer providing the Nile with water. Thus, the Nile could not flood its basins as it used to.

(bank sliding). Therefore, the irrigation pump sites have been remarkably affected either eroded by the River Nile (bank erosion) or the river diverting its course leaving these sites without water to irrigate the agricultural land.

These resulted in abandoned canals, which have been filled with aeolian sands. Similarly, the fields were left without cultivation and aeolian deposition took place. The accumulated sand on the topsoil has changed the physical and chemical properties of the original alluvial soil. The physical data in Table 3 reveal great differences in the soil properties between the top aeolian deposition and the heavy textured alluvial soil underneath. This abrupt change in texture has adverse effects on water-holding capacity and the hydraulic conductivity of the subsurface horizon, where the cracks and pores were filled with sand particles coupled with high exchangeable sodium. On the other hand, the fertility of the aeolian horizon is very low compared to that of the alluvial horizon in the subsoil.

Table 3. Physical and chemical properties of soil profiles, including aeolian and alluvial deposits in the hyper-arid region of the Sudan.

the hyper-arid region of the Sudan.								
<u>Soil</u>	<u>Particle Size Distribution</u>			<u>Water</u>	<u>Hydraulic</u>	<u>Available</u>		
<u>Depth</u>	<u>Sand</u>	<u>Silt</u>	<u>Clay</u>	<u>Saturation</u>	<u>Conductivity</u>	<u>Water</u>		
						<u>Content</u>		
-cm-	-----g kg ⁻¹ -----			--g kg ⁻¹ --	----cm ha ⁻¹ ----	--g kg ⁻¹ --		
	Physical							
0-30	700	230	70	210	5.15	28.0		
30-60	150	500	350	420	1.09	81.1		
60-95	180	330	490	500	0.46	196.5		
95-110	620	230	150	340	0.91	87.8		

	<u>Exchangeable Bases</u>		<u>CEC</u> ²	<u>Nitrogen</u>	<u>Organic Carbon</u>	<u>Available P</u>	<u>pH</u>	<u>ESP</u> ³
	<u>Sodium</u>	<u>Potassium</u>						
--cm--	-----meq. 100g ⁻¹ -----		meq.g ⁻¹		---g kg ⁻¹ ---	---mg kg ⁻¹ ----	--%--	
	Chemical							
0-30	1.1	0.3	9	0.12	0.59	1	7.2	5
30-60	20.5	0.6	30	0.28	2.73	7	8.9	40
60-95	17.2	0.7	51	0.39	2.34	6	8.8	35
95-110	8.6	0.3	49	0.21	2.73	5	8.9	48

0-30cm aeolian deposits and 30-110 cm alluvial deposits. ²Cation Exchangeable capacity. ³Exchangeable sodium percentage.

In the last three decades, the cultivated basins have been encroached by mobile barachan dunes, and sand sheets in some parts have invaded even the Nile itself. This is due to the relatively favorable conditions; exposed loose sandy soils with negligible organic matter content, strongly dry northeasterly wind as a transporting agent, and the Nile basins as the depositional area. The accumulated sand on the basins is well manifested in aerial photographs as mobile barachan dunes along the Nile.

The sand encroachment towards the Nile in some parts resulted in the formation of sand islands, which changed the course of the Nile causing bank erosion

It is clear from the preceding facts that the irrigated agricultural development along the Nile River is hyper-arid, is challenged by the desertification in the form of aeolian sand deposition at higher rates than in the arid and semi-arid zones. This is due to many factors: the very low rainfall, exposed loose sand surface and strong northeasterly wind during the winter season causing dust storms. Mainguet (1999) stated that when wind blows through dry bare soil surface can remove substantial amounts of soil; the annual removal of 1 mm at the soil surface is equivalent to a loss of 10 to 15 t/ha. The drier the area, the more wind sand storms incidents. This phenomenon is well expressed in Toker

Agricultural Scheme, which is located in the hyper-arid and occupies an alluvial delta (fan) between the Eritrean highlands and the Red Sea. The delta has a fertile silty materials renewed annually by the flush of Baraka seasonal river. Toker meteorological station has the driest weather conditions and has the greatest frequency of dust storms known as El Etabeit, caused by the dry summer winds (Middleton, 1985).

Sand Encroachment in Western Gezira Scheme and White Nile Pump Schemes

The irrigated agriculture in the arid region is mainly located in the northwestern Gezira and the White Nile terraces. The soils in these locations are cracking clays (Vertisols). The area between the Gezira Scheme and the White Nile terraces is known as natural fringes that protect the Gezira scheme. The climate is characterized by fluctuating rainfall, and high temperature in the summer with high evaporation rate.

In addition to these climatic parameters, the region is exposed to southwesterly wind in summer, especially in May, June, and July. As wind speed with average threshold of 15 km/h may start to lift soil particles of different sizes to different heights (Mainguet, 1999), the strong southwesterly wind in the Gezira during May to July (14-18 km/h) causes dust storms (*Haboub*).

These conditions are coupled with low rainfall (<200 mm) during this period, enhancing the initiation of dust storms. The relationship of rainfall data and dust storms of the world have shown that the deflation of dusts is maximum in areas with annual rainfall rang-

ing from 100 to 200 mm (Goudie, 1978).

In the last three decades, the Sahelian zone was characterized by very severe droughts and decreasing rainfall below average. Hence, the stabilized dunes of Kordofan have become an area prone to drought, facing the challenges of wind erosion. The decrease of rainfall and the increase of human activities, which had major impacts on the natural vegetation cover, reactivated the stabilized dunes to be deflated by the strong southwesterly wind. Simultaneously and in the same manner, the natural vegetation and grass cover of the Gezira fringe areas have been invaded by dry mechanized farming, deforestation, and over grazing.

All these physical and human factors together exposed the western parts of the Gezira Scheme for aeolian sedimentation. Comparably, in drought-prone regions, such as in Kazakhstan, the introduction of advanced technology of cultivation methods to virgin lands, has led to severe land damage by wind erosion (Middleton, 1985).

The problems associated with wind erosion in the White Nile terraces and western Gezira can be classified and examined to three fundamental processes; *deflation, transport, and deposition*. These processes are portrayed by satellite image (MSS) of the region. The sand source is the reactivated dunes of Kordofan, where the deflation process is taking place. It can be seen in the image on the western side of the White Nile. The wind passes through a corridor crossing the White Nile transporting sands to the eastern side of the White Nile. The sands have been deposited on the terraces of the White Nile and the Gezira Scheme and its fringes. The deflation process also is taking place in the

Table 4. Soil physical and chemical properties in sand encroached and not-encroached sites in the Gezira Scheme and its western fringes.

<u>Site</u>	<u>Texture</u>	<u>Particle Distribution</u>			<u>Infiltration</u>	<u>Wetting</u>	<u>Sand Encroachment</u>
		<u>Sand</u>	<u>Silt</u>	<u>Clay</u>	<u>Rate</u>	<u>Front Rate</u>	
		-----g.kg ⁻¹ -----			---cm h ⁻¹ ---	---cm---	
Gezira	Sandy	730	100	170	8.0	58	Affected
	Loam						
Gezira	Clay	320	210	470	4.0	40	Not-affected
Gezira	Clay	290	240	470	4.3	38	Not-affected
Fringe							
Gezira	Loamy	800	30	70	14.5	60	Affected
Fringe	Sand						
<u>Chemical Properties</u>							
	<u>pH</u>	<u>N</u>	<u>Organic Carbon</u>	<u>Available P</u>	<u>CaCO₃</u>		<u>Sand Encroachment</u>
	1:1	-----g kg ⁻¹ -----		---mg kg ⁻¹ ---	---g kg ⁻¹ ---		
Gezira	7.2	0.2	3.2	3	20		Affected
Gezira	8.1	0.4	5.4	7	30		Not-affected
Gezira Fringe	8.3	0.4	5.2	6	40		Not-affected
Gezira Fringe	6.5	0.1	2.0	1	00		Affected

fringes as indicated by the disappearance of A horizon bringing the B horizon on the surface and the appearance of ripples on sand sheets.

The evidence of the desertification is well expressed, in the fringe areas, in different forms of indicators such as mobile barachan dunes, partially fixed dunes along the drainage ways, sand sheets and hummocks with deflated areas. The effect of blown sand deposited on the Gezira Scheme is quite evident in burying the irrigation canals and the fields. The Aeolian sedimentation in the Gezira has adverse consequences on the textural class of the Gezira clay soils (Table 4).

The physical properties of the Gezira soil were affected by the Aeolian deposition, which have drastically changed the infiltration rate and wetting front. Certainly, the changes in the physical properties of the Gezira clay soils have its impacts on the gravity irrigation system, which has been designed for the unique flat cracking clays of the Gezira. Furthermore, the deposition of sand on the Gezira fields decreased the soil fertility. This can be well demonstrated by the lower pH values and the content of macro-elements in the affected soils.

CONCLUSIONS

Aeolian sedimentation in irrigated agriculture in the hyper-arid and arid zones in Sudan is evident. In the hyper-arid region, the source of the sand is from the eastern desert bordering Wadi El-Khowi and transported by the northeasterly wind in the wintertime. The most effective conservation measure to protect the agricultural land in this region is to establish shelterbelts of mixture drought-tolerance fast growing, and long-living tall trees in the direction of the winds. In the arid region, the sand source is the bare deflated sand dunes west of the White Nile and transported by the summer southwesterly winds through a corridor crossing the

White Nile. The suggestions for conservation measures in this arid region can be as follows: (a) establishment of shelterbelts with different rows of mixed indigenous trees and (b) stabilizing the mobile dunes in the fringes of the Gezira and west of the White Nile by reseeding of the adapted natural grasses and afforestation.

REFERENCES

- Ayoub, A.T. 1998. Extent, severity and causative factors of land degradation in the Sudan. *J. Arid Environ.*, 38: 397-400.
- Cooke, R.V., and A. Warner. 1973. Geomorphology on desert. University of California Press, Berkeley. 374 pp.
- Goudie, A.S. 1978. Duststorms and their geomorphological Implications. *J. Arid Environ.*, 1: 297-310.
- Hassan, M.H.A. 1990. Report of the international workshop on soil transport and desertification in arid land. p. 3-8. In: Elbaz, F., I.A. El Tayeb, and M.H.A. Hassan (Ed.), *Proc. Inter. Workshop on Sand Transport and Desertification in Arid Lands*, World Scientific Publishing Co, London. 469 pp.
- Ibrahim, F.N. 1982. Monitoring and controlling ecological degradation in semi-arid zone of the Sudan. In: Mann, H.S. (Ed.), *Scientific Reviews on Arid Zone Research*, 1: 53-85. Scientific Publ., Jodhpur, India.
- Laki, S.L. 1994. Desertification in Sudan: causes, effects and policy options. *Inter. J. Sustainable Develop. World Ecology*, 1: 198-205.
- Mainguet, M. 1991. Desertification natural background and human mismanagement. Springer Verlag. 306 pp.
- Mainguet, M. 1999. Aridity droughts and human development. Springer Verlag. 302 pp.
- Middleton, N.J. 1985. Effect of drought on dust production in the Sahel. *Nature*, 316: 431-434.
- UNEP. 1994. United Nations Convention to Combat Desertification, Nairobi, Kenya. 35 pp.

Soil and Water Conservation and Dryland Farming for Sustainable Agricultural Production in Iran

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ABSTRACT

The Islamic Republic of Iran, with an area of 1,648,000 km², is the sixteenth largest country in the world. Iran is a high-plateau (90%) mountainous country with an arid to semi-arid climate. Out of a total area of 160 million (M) hectares, 20.7% is desert, 54.9% natural pasture, 7.6% forest, and only 11.6 M hectares are annually under cultivation out of the cultivable area. Due to limited water resources, two-thirds of the cultivated area is rain-fed. The major farming system in the dryland areas is cereal-pastoralism. In view of the great importance of dryland areas in the economy of Iran, research is geared to develop improved production technology (crop varieties and package of production practices), while conserving the resource base. New crop varieties with very high yield potential have been developed and released for the farmer's general cultivation. With the adoption of these varieties and a package of production technologies, it is expected that the yield of wheat and barley will increase to 1.5 t/ha from the present very low yields of less than a ton. This increased production will not only help to overcome the food shortage at the country, but will also provide additional feed for almost 11 M sheep and goats and reduce the pressure on over-grazed pastures/rangelands. This will help in sustainable production of agriculture by conserving the environment and checking soil degradation.

INTRODUCTION

The Islamic Republic of Iran, with an area of 1,648,000 km², is a vast country in southwest Asia. Anciently known as Persia, Iran is the sixteenth largest country in the world. The geographical environment of Iran has great variety. It is located between 25° to 40° degrees north (latitude and 44 to 64 degrees east longitude. Generally speaking, Iran is a mountainous region with a dry climate; a dry belt of the globe accounts for its mountainous terrain and arid climate. Iran has only limited regions for agricultural exploitation. Of total area (160 M ha), about 20.7% is desert, 54.9% natural pastures, 7.6% forest land, and only 16.8% is potentially arable, of which 11.6 M ha is annually under cultivation and the rest is kept fallow. The overall average annual rainfall in the country is about 240-300 mm.

Since about 90% of Iranian land is situated on a plateau, more than half of the country is covered by mountains. These mountains are divided into the northern, western, and eastern mountain ranges. These mountains surround the saline sandy and rocky desert

of the central Iranian plateau, making a closed basin containing many kinds of accumulations.

Main Geological Units

From south to north, the country can be divided into the following main geological units: Khuzistan Plain, Flooded zone, Iranides, Central Plateau, Elburz Mountains, Turkemen-Khurasan Mountain, and Caspian littoral. The high elevation areas (<1300 m.a.s.l) are commonly snow-capped. Vegetation varies according to the climatic zone. The original vegetation consisted of oak and beech in the more humid sections of the north and a thin cover of grasses and or scattered shrubs in the semi-arid and arid regions. Because of misuse and destruction by people, the vegetation of many areas, especially the arid and semi-arid ones, now bear little resemblance to the original cover. Different environmental factors such as climate, topography, rock and vegetation formed several types of soils, and man, with a long history, has effected changes in soil nature by irrigation, plowing and different cropping systems. Though Iran is a predominantly arid to semi-arid country, it has one million hectares of inland lakes and water bodies. The central plateau of Iran has a limited agricultural activity on account of its climatic conditions.

The well-known deserts of Iran, are the Dast-e-Kavir, with an area of over 200,000 km², and Dasht-e-Lut with over 166,000 km². Both have a very wide expanse, and are still considered to posses, after some improvement practices, vast resources for future generations. The area of different soil types are: soils of the Plain and valleys (30.5 M ha); plateau (47 M ha); Caspian pediment (0.35 M ha); dissected slopes and mountains (86.15 M ha); and lakes (1 M ha). The total area of Iran is 165 M ha.

Based on Keoppens system, as adapted by Sanji, there are three climate types:

1. *Dry climate* (B climate): the dominant type (2/3) on the climatic map of Iran. There are two kinds of B climates in the country: Desert type of climate (BW), and semi-arid steppe climate (BS).
2. *Mesothermal* (C climate): one quarter or about 40 M ha of total land surface of Iran is dominated by the C group of climates. Most of the Iranian population is located in this climatic zone; there are two kinds of C climates in Iran: Highland type (SC), and Caspian type (CC)
3. *D and E climate*: about 40 M ha have a D-type climate in which coldest month is below 3°C degree and the warmest month is above 10°C. The E type of climate's warmest month is below 10°C.

According to the precipitation map of Iran, issued in 1959, there are five different soil moisture regimes: *Arid*, annual precipitation less than 100 mm; *Semi-arid*, from 100 to 250 mm; *Dry subhumid*, 250 to 500 mm; *Moist subhumid*, 500 to 1000 mm; and *Humid*: 1000 to 2000 mm.

According to the latest general census taken in 1996, the population of Iran is about 60 M; 41% lives in rural areas, and 26.6% are engaged in agriculture, which has an important role in people's employment and national income. Livestock and fisheries are the other major sources of income (Sadeghi, 1998).

The main agricultural products in Iran are wheat, barley and rice, and also potatoes, cotton, tea, citrus, dates, maize, sugarbeet, pistachio, almond and other fruits, and summer crops and vegetables. In agricultural research centers, great efforts were made for the improvement of cultivation methods and mechanized agriculture.

About 8.7% of the total lands of Iran are arable (14.4 M ha), and 46.5% of arable (7 M ha) is irrigated and 53.5% (7.7 M ha) is rainfed. In 1996, from total agricultural products (43.3 M tons), 86.1% (39 M tons) was from irrigated lands and 13.8% (6 M tons) from rainfed areas. Presently, the contribution of rainfed

1. **Tillage** judicious use of appropriate implements such as moldboard, chisel plow and sweep. During the dry period, plowing is avoided.
2. **Water harvesting** through bund system, contour leveling, increase infiltration rate, and storage of water (construction of dams, etc.).
3. **Weed control** during summer to control water loss.
4. **Zoning of agricultural areas** and restricting grazing in fragile ecosystems, such as moisture-stressed rangelands and cropped areas. Restrict grazing to rehabilitate soil cover through increased feed availability from other sources.
5. Studies on **water-use efficiency** to make judicious use of supplemental irrigation water to increase crop productivity as well as conserve precious water.
6. **Crop rotation** to control biological degradation of soil nutrients; leguminous crops such as chickpea, forage legumes, etc. has been introduced in the cropping system to replenish soil fertility

IMPROVEMENT OF DRYLAND PRODUCTION

Two thirds of the agricultural areas in Iran are rainfed,

Table 1. Area and production of major crops in Iran.

<u>Crop</u>	<u>Condition</u>	<u>Area</u> ---ha × 10 ³ ---	<u>Production</u> ---ton × 10 ³ ---	<u>Yield</u> --tons/ha--
Wheat	Irrigated	2249	6870	3.27
	Rainfed	4051	3241	0.8
Barley	Irrigated	696	1782	2.89
	Rainfed	1054	954	0.9
Chickpea	Irrigated	52	52	1.02
	Rainfed	854	298	0.35
Lentil	Irrigated	20	19	0.94
	Rainfed	251	101	0.4
Oilseeds	Irrigated	135	150	1.11
	Rainfed	60	60	0.96

areas toward national production is very low (Table 1).

As described above, the environmental conditions are such that the soils are constantly under threat of degradation. Similarly, the water is a scarce resource. Therefore, the conservation of these natural resources for sustainable agricultural production is essential. The Government of Iran has launched several projects for conserving soil and water. Some of which are mentioned below.

SOIL AND WATER CONSERVATION ACTIVITIES

Soil degradation in Iran is primarily caused by water, wind, and biological factors. These factors and the steps taken to conserve soils and water are:

which makes a major contribution to her economy. The predominant farming system practised in the dryland areas of Iran is cereals (wheat and barley) and pastoralism (livestock), indicating the interdependence of crops and livestock production in these areas in a balanced way. Presently, yields of major rainfed crops (wheat, barley and food legumes) are very low, but studies carried out in various regions indicate that there is a great potential for increasing productivity in these areas. Any increase in crop production will have positive effect on livestock production.

These areas are also prone to environmental degradation and, if not properly managed, they can cause irreversible damages to our natural resource base. Therefore, to exploit the agricultural potential of these areas in a sustainable manner without damaging the

natural resource base and to improve the economic conditions of the resource poor-farmers in dryland areas, the Dryland Agricultural Research Institute (DARI), established in 1991, is striving to develop appropriate production technology for each region of the country through its research centers located in different areas to increase the yields of wheat and barley from the present very low yields of 800 and 903 kg/ha, respectively.

Crop Varietal Improvements

The accelerated research program on varietal improvement has resulted in the release of three bread wheat varieties with a yield-potential of 3.5-4 t/ha, i.e., *Zagros* (=Tan's/Vee's//Opata), a yellow rust-resistant, high-yielding variety suitable for warm spring wheat-growing areas of Iran; *Gahar* (named after an Iranian river) has been derived from a multiple cross (Nd/Vg 9144/Kal/3/Bb/4/Yaco's/5/Vee's'). This line is also suitable for warm, spring wheat-growing areas, but carries a different genetic make-up for yellow rust resistance. The third cultivar released is *NikNijad*, derived from a cross. This variety is very versatile and carries a lot of plasticity for adaption to different climatic situations. Therefore, it can be successfully grown under both moisture stress and irrigated conditions (Roozitalab et al., 1998). One durum wheat (*T. turgidum* var *durum*) line, *Om-Rabi 5*, developed at ICARDA, and extensively tested and evaluated under Iranian conditions, with a yield potential of 4-5 t/ha has also been released under the name "*Seimereh*" for general cultivation.

The release of these four genetically diverse wheat varieties is very strategic to minimize the risk of yellow rust (YR) epidemic on a large scale, due to their different genetic make-up for YR-resistance, which is very important to realize a sustainable increase in wheat production. A breakthrough has also been made through successful selection and release of a winter barley variety, "*Sahand*", in the cold dryland areas of the country, with a yield potential of 3.5 t/ha.

Considering the present yield level of 0.8t/ha and 0.903 t/ha for wheat and barley, the new varieties with very high yield potential; when adopted by the farmers on a large scale, they will substantially increase the food and feed production from the dryland areas.

Major factors adversely affecting the productivity of cereals in dryland areas have been identified through diagnostic surveys, and a research plan has been devel-

oped to find quick answers to some of those constraints and livestock production for sustainable agricultural production and environment conservation.

Livestock Production

The livestock sector plays an important role in the national export economy (7%), mainly from carpet exports. The livestock contribution to agricultural GDP is by far the most significant (34%). It is estimated that about 10% of the total population is involved with livestock production. The main systems of livestock husbandry are nomadic and transhuman, involving 70% of the total livestock population. Sheep are the most dominant type of livestock, estimated at over 45.4 M, followed by goats at 23.5 M (FAO Yearbook, 1994).

Despite the importance of livestock in the national economy, the growth rate in livestock products is low (less than 1% per annum). It is believed that nutrition is the main limiting factor for improving livestock production. At present, rangelands are the main source of animal feed (80%). However, out of the 105 M ha of rangeland available for grazing, only 10 to 12 M provide good grazing.

Crops and Livestock Integration

Availability of feed is a major livestock production constraint. Due to increasing demand for livestock products, the pressure on rangelands is causing environmental degradation, which can result in irreversible environmental degradation. The crop residues, as well as some of the crops such as barley, forage legumes, etc., provide substantial amounts of feed for livestock

Therefore, it is of paramount importance to integrate crops and livestock production. This is even more important in the dryland areas of Iran where cereal-livestock (pastoralism) is the main farming system. Therefore, DARI scientists are working to improve crop productivity that is sustainable, serves the existing farming system, and at the same time is environment-friendly. The synergistic effect of increased crop productivity on livestock production has been calculated on the basis of harvest index of 33% (grain 33.3% and straw 66.6%) and using the existing area and production of wheat and barley as well as expected increases due to adoption of new varieties and production technology (Table 2).

Increased straw and grain (barley only) production will be 8.39 and 1.91 M tons, respectively. This

Table 2. Present and expected dryland cereal production with adoption of new technologies.

Crop	Area ---M.ha---	Present Production		Expected Production	
		Grain	Straw	Grain	Straw
		-----M tons-----			
Wheat	4.05	3.24	6.48	6.48	12.96
Barley	1.1	0.954	1.91	1.91	3.82

increased availability of 10.3 M tons of feed will be sufficient to support or raise 11 M sheep/goats in the country. This extra feed will be helpful in different ways. It can be used to feed existing livestock and reduce the pressure from the over-grazed pastures in the rangelands; this will help not only in rehabilitating the degraded rangelands and restoring their productivity, but will also help in conserving the environment. This additional feed can also be used to produce more livestock to meet the increasing demand of livestock products.

I would like to conclude with the statement that the dryland areas have paramount importance in the Iranian agriculture to meet the future food requirements. Therefore, top priority has been accorded to research and development of dryland areas in Iran.

CONCLUSIONS

1. The dryland areas are playing an important role in Iran's economy and hold considerable potential for increasing agricultural production.
2. With the adoption of new technologies, the production of wheat and barley can be doubled.

3. Increased production will provide additional feed for 11 M sheep and goats.
4. Appropriate production technologies will help in sustainable agricultural production and restrict environmental degradation.

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REFERENCES

- FAO. 1994. FAO Production Yearbook, Rome, Italy.
- Sadeghi, E. 1998. Soil and water conservation and dryland farming in Iran. Country Report presented in China, p. 1-5.
- Roostitalab, M.H., P. Karbasi, and M. Tahir. 1998. Research highlights. Ministry of Agriculture, Tehran, Iran. p. 1-84.

Data Integration for Assessing Agricultural Soil Degradation in South-Central Iran

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ABSTRACT

In the Marvdasht Plain of Iran as in other arid and semi-arid areas, the imbalance between precipitation and evaporation requires water supply through irrigation to secure agricultural production. The sustainability of the soil resources suffers mostly from mismanagement under intensive agriculture, which directly or indirectly affects management-dependent soil properties.

Soil degradation is a widespread issue in the Marvdasht Plain, but its geographical distribution and the total area affected are not known. Chemical deterioration includes soil nutrient loss and salinization. Soil physical deterioration mainly occurs through compaction by agricultural machinery and transportation vehicles, and through sealing and crusting of the topsoil, resulting partly from mismanagement and partly from natural processes. Waterlogging is also an important soil degradation factor, which has a close relationship with potential salinity hazards that may occur under mismanagement.

This research investigates the changes in soil quality under the long-term effect of irrigated winter-wheat monoculture. Soil degradation types are investigated through the application of statistical quality control charts and geostatistics to management-dependent soil properties. The research findings are integrated through spatial analysis, using geographic information systems (GIS) facilities to map the degree and extent of soil degradation at regional level, and the causative factors of soil degradation are summarized.

INTRODUCTION

This research concerns the Marvdasht Plain, in the upper part of the Kor Valley, a large inter-mountain valley in Fars Province, located between 29° 45' to 30° 14' N and 52° 24' to 52° 48' E, about 50 km northeast of the provincial capital, Shiraz. The average elevation of the Valley is 1,500 to 1,600 meters above mean sea level. Soon after leaving the Drudzan Dam, the Kor River enters the Marvdasht Plain, through which it pursues a meandering course prior to emptying into Lake Bakhtegan, a land-locked complex of saline open water and marshes, 120 km downstream from Drudzan Dam. Along its course through the Valley, the Kor River is joined by two small tributaries, the Maeen and Sivand Rivers, both at the left bank. The study area covers about 183,000 ha.

The selected area has a semi-arid climate, with mild winters and dry, relatively hot summers. All significant precipitation falls from November to May, while the other five months are very dry. In an average year, about 330 mm of rain falls on the area. The mean monthly temperature ranges from 3.4°C in January to 28.8°C in July. The mean annual air temperature is about 17°C, the mean maximum is 39.5°C, and the mean minimum is -5.5°C. Absolute maximum and minimum values of 42.5°C and -14.5°C have been recorded in July 1977 and February 1968, respectively. The relative humidity varies from 23 to 68%, with an average of 58% in winter (48 to 68%) and 27% in summer (23 to 36%). The total yearly evaporation, measured from a Class "A" pan at Marvdasht pilot project area (Soil Institute of Iran, 1968), is 2,326 mm. The average evaporation loss is 3.3 mm/day during winter (November to April) and 9.3 mm/day during summer (May to October).

The Marvdasht Plain, one of the most productive in Iran, is very susceptible to land degradation. The sustainability of the soil resources in the study area stems mostly from mismanagement under intensive agriculture, which directly or indirectly affects management-dependent soil properties. Soil *compaction*, *salinization*, *waterlogging*, and *fertility depletion* are the main area-specific factors controlling soil quality and, hence, the sustainability of crop production in the area. This research investigates the changes in soil quality under the long-term effect of irrigated, winter wheat monoculture. Data on management-dependent soil properties were analyzed to determine if land management practices and land use have been successful or detrimental to soil quality. The results obtained through GIS-assisted integration of information are presented.

MATERIALS AND METHODS

Data layers were derived from several primary data sources, including (1) a soil map produced by conventional soil survey techniques, (2) land use and soil degradation maps prepared by digital processing and visual interpretation of remotely sensed data, and (3) maps of management-dependent soil properties generated by applying geostatistics to past and recent soil data. The GIS configuration used (ILWIS) supports functions for manipulating both raster and vector data.

The data types and the research techniques shows the way different sets of information about soil conditions, obtained through the implementation of various research techniques, are integrated to contribute to the

decision-making phase. Temporal analysis of remotely sensed data provided qualitative information on land use and soil degradation. Quantified information was obtained through the application of descriptive statistics and geostatistics to past and current soil data. The results of descriptive statistics were used as inputs to statistical quality control (SQC) charts for structural analysis and to geostatistics for spatial analysis (Moameni and Zinck, 1997, 1998).

In spite of a huge literature on the application of geostatistical modeling to soil properties, knowledge about soil variability is not yet organized in such a way that allows the user of soil information, unskilled in geostatistics and modeling, to make the best possible decisions under conditions of uncertainty (McBratney et al., 1991). Most geostatistical publications use arbitrary coordinates for the output maps.

Few geostatistical applications to environmental issues integrate geostatistics with GIS (e.g., Liebhold et al., 1993). This lessens the usefulness of mapping soil quality changes because it is not easy to locate landscape features and, hence, adapting management practices to the variation of soil properties becomes impractical.

Moreover, geostatistically produced maps with arbitrary coordinates cannot be integrated with other data layers because an obvious prerequisite to any spatial analysis is the acquisition of spatially referenced data. Integration of geostatistical studies with a GIS can help create maps with real coordinates that facilitate locating the problem-areas so that measures can be taken to ameliorate soil deficiencies at a regional level.

The aims of using GIS were threefold: *Firstly*, it was used to geo-reference map data to ensure the creation of error-free input data with the same real-world coordinates. *Secondly*, it served as a database for all the qualitative and quantitative data layers, produced through different stages of the research. Finally, it allowed linkage between the geo-referenced, multi-source information to build a decision tree, based on which the sustainability of the land use and management was assessed.

Several variables were used to assess soil compaction, including bulk density, resistance to penetration (measured in terms of California Bearing Ratio or CBR), total porosity, soil hydraulic properties, and aggregate stability.

The spatio-temporal changes in soil quality controlled by salinization and waterlogging were modeled using geostatistical techniques. Critical zones of salt-affected and waterlogged soils were established from the contour maps representing soil electrical conductivity (EC) and depth to the groundwater-table, obtained through kriging techniques.

Soil quality indicated by the soil fertility status was assessed in two ways: (1) by describing the mean and determining the variability of soil nutrients within map units, using SQC charts, and (2) by modeling the spatial variations in soil nutrients using geostatistics. The

research mobilized a large dataset that allowed both approaches to be implemented.

Sample statistics, such as the *mean*, *range*, and *standard deviation*, were calculated from a large data set made available by the Agricultural Research Center of the Fars Province, Division of Soils. These statistics were used as input to SQC charts to assess the variability of management-dependent soil properties within map units. Geostatistical analysis was applied both to data collected in the sample areas and to the large data set. Sample variograms were computed to analyze the spatial behavior of selected soil properties.

The large data set was collected during the period of 1991-1995 in cultivated areas. The area was divided into regularly spaced squares of 500 by 500 m, and the sampling points were located at grid nodes. The sampling grid was aligned with a topographic map at the scale of 1: 50,000. This was helpful for adjusting the direction and tracking the sampling points. A level was used to give the direction and the sampling points were located by pacing. Composite samples were taken from the topsoil (0-25 cm) to obtain average values and minimize the deviations due to factors such as sheet erosion, animal droppings, and burning.

The dataset included about 6,600 measured values for organic carbon (OC), total nitrogen (N), available phosphorus (P), and available potassium (K), determined on 2,000 composite soil samples (0-25 cm). Some 500 samples were also analyzed for EC. Soil bulk density (BD) was determined on undisturbed ring samples (16 samples) from sites where also water infiltration rates were determined. Available water content (AWC) was determined on 16 samples from some representative soil profiles in the piedmont and Valley landscapes as well as in a lacustrine depression.

The laboratory determinations were carried out at the Soil and Water Research Institute of Iran in Kerman and Shiraz, following standard laboratory methods. After air-drying, the soil samples were sieved at 2 mm and analyzed for different properties. Soil samples collected in sample areas (305 samples) were analyzed for pH, EC, OC, total N, available P, and K. Samples from representative soil profiles (95 samples) were analyzed for pH, EC, calcium carbonate equivalent, OC, total N, available P, available K, sand, silt, and clay.

SOIL NUTRIENT LOSSES

The contour maps depicting the spatial variability of soil fertility properties, obtained through geostatistical analysis, were spatially referenced to the soil map. This allowed for aggregating the degree of soil nutrient losses within soil map units and for mapping the regional extent of soil nutrient losses. The soil nutrient variability features were related to geo-referenced units in the UTM projection system (WGS-84 ellipsoid) using the ILWIS software package (ITC, 1997).

A decision-tree was applied to generate information about the degree and extent of soil nutrient losses in each map unit. Four levels of soil degradation were

considered, following Oldeman et al. (1991). A query syntax in the form of IF, THEN and ELSE statements was used to aggregate the degree of occurrence and the extent of nutrient losses within each soil map unit.

When a soil map unit is affected by more than one degradation type, production of an aggregate severity map (Oldeman et al., 1991) can help determine the degree and extent of each degradation type. However, the presence of a large imbalance between soil nutrients in the Marvdasht Plain lessens the usefulness of such a map.

Available K showed no deficiency over the whole area. In contrast, total N deficiencies occur everywhere. Total N loss is so widespread that, if this data layer is combined with data layers on the other degradation types, it will complicate the interpretation of the aggregate severity map. Therefore, the data layer on available K was excluded from spatial data analysis and total N was mapped individually.

Table 2 shows the statistics for soil nutrient losses in the Marvdasht Plain. Loss of total N is the most severe sub-type of chemical soil degradation, strongly affecting 53,000 ha, corresponding to about 88% of the cultivated land (63% of the total area studied). Zones where strong OC and P deficiencies occur in the topsoil, cover about 43,500 ha, corresponding to 72% of the cultivated areas (52% of the total area). The areas affected by moderate OC and moderate P losses, covering about 32,500 ha corresponding to 54% of the cultivated areas (39% of the total area). Moderate OC and available P losses overlap only in about 3,800 ha (6% of the cultivated land).

Strong variations in nutrient deficiency levels over the major part of the cultivated area indicate a large fertility imbalance between soil nutrients that results from over-utilization of the soil resources and can seriously constrain economic crop production in the Marvdasht Plain. The need to improve the management of soil fertility in a way that balances the productive capacity of the soils is an important challenge for sustainable crop production in the area.

SOIL COMPACTION: REGIONAL

For mapping the degree and extent of soil compaction at a regional level, the soil map was rasterized and used as a base map. The decision-tree applied was constructed from soil bulk density values measured at representative sites, supplemented by CBR values measured in soil map units.

Soil compaction, caused by agricultural machinery and transport vehicles, is a serious problem in the Marvdasht Plain. Soils are affected by compaction at various degrees of severity over the entire cultivated area. Strongly affected soils account for about 31,000 ha of land, corresponding to 24% of the total cultivated areas.

Surface crusting is also a form of compaction that can adversely affect crop production. Unfortunately, there is no standard method for measuring surface crusting. On the other hand, it is not clear whether the figures apply to human-induced crusting, resulting from tillage operations, or naturally occurring crusts developed, for example, by rain splash. Crusting is spread over the whole area, but there is no information available on the type and degree of crusting.

Table 1. Loss of topsoil (0-25 cm) nutrients with crop intensification in the Marvdasht Plain

Degree of Loss	Soil Nutrient Sources								
	N			OC			P		
	Area ha×10 ³	Cultivated ¹ -----%-----	Total ²	Area ha×10 ³	Cultivated -----%-----	Total	Area ha×10 ³	Cultivated -----%-----	Total
Cultivated Areas									
Negligible	-	-		-	-		36	60.0	43.0
Light	0.5	0.8	0.5	-	-		8	13.3	9.5
Moderate	6.5	11.0	8.0	21.5	35.8	25.5	11	18.3	13.0
Strong	53.0	88.2	63.0	38.5	64.2	46.0	5	8.4	6.0
Subtotal	60.0	100		60.0	100		60	100	
Non-cultivated Areas									
Mountain Regions	24.0	28.5		24.0	28.5		24	28.5	
Total	84.0	100		84.0	100		84	100	

¹percentage of the cultivated area covered by the contour maps of soil nutrient variables obtained through kriging techniques (i.e., 60,000 ha), ²total area studied.

Table 2. Soil compaction status in the Marvdasht Plain.

Cultivated Areas	Degree of Compaction	Extent of Areas Affected by Compaction		
		Area ---ha---	Cultivated Area ---%---	Total Area ---%---
	Light	55,155	43.5	30.2
	Moderate	40,515	32.0	22.2
	Strong	31,398	24.5	17.2
Mountain Regions and Rangelands	-	52,790	-	28.9
Dam Reservoirs	-	2,748	-	1.5
Total		182,606	100	100

SOIL SALINITY SUSCEPTIBILITY

In irrigated areas water can move upward by capillary forces during irrigation intervals or during fallow periods when there is no downward flow of percolating water. The capillary upward flux varies with soil type, depth of watertable, and soil water gradient (Ritzema, 1994). In the Marvdasht Plain, the groundwater is continuously fed by seepage from many springs and from the flooded rice fields. Therefore, the high watertable causes capillary ascent, especially during summer, when land is not irrigated. The climatic harshness and the flat topography aggravate the situation, breaking the potential resistance of soils to salinization. Mapping salinity-prone zones helps improve the management of soils potentially at risk of salinization and, hence, contributes to sustained crop production.

To produce a salinity-hazard map, the soil salinity map was crossed with the map of the depth to the groundwater-table. Severity levels were formulated in a decision-tree and translated into a decision matrix (a two-dimensional table in ILWIS terminology) to allow integration of the two maps.

The decision matrix was used to aggregate the degrees of soil degradation associated with the two degradation sub-types considered, soil salinity and depth to the watertable. The rule of the most limiting factor was applied to determine the aggregate level of degradation severity. For example, when the degree of salinity was moderate and that of the watertable was strong, the overall degradation severity was assessed as strong. Of the 98,100 ha of the Marvdasht Plain, about

42,000 ha (43% of the total cultivated area and rangeland) are at strong to extreme risk of salinization and need careful soil and water management.

Compaction and Salinization Risk

Aggregate degradation severity maps are very useful because the aggregate severity may be higher than the severity of the individual degradation types and may need a combination of control actions (Oldeman et al., 1991). For mapping the aggregate degradation severity, all data layers must be geo-referenced. Therefore, to produce a map aggregating the present soil compaction status and the potential of the soils to salinization, the compaction map and the salinity-risk map were first referenced to the soil map and then integrated through cross operation, using a decision matrix.

Compaction and salinity are the two main soil factors constraining the agricultural productivity in the Marvdasht Plain. About 74,000 ha (75% of the total cultivated area and rangeland) are exposed to strong or extreme aggregate severity degradation, taking into account the combined effect of compaction and the risk of salinization (Table 3). This indicates the seriousness of the soil degradation problem in the area and calls for an integrated approach to secure sustainable crop production. Because of the strong imbalance between soil nutrients, it was not possible to create an aggregate severity map for fertility depletion. Therefore, soil nutrient losses were assessed from individual nutrient types.

Table 3. Areas affected by compaction and at risk of salinization in the Marvdasht Plain.

<u>Degree of Degradation</u>	<u>Extent of Degradation Area</u>	<u>Relative</u>
	<u>---ha---</u>	<u>---%---</u>
Light	9,850	10.0
Moderate	14,140	14.5
Strong	33,590	34.0
Extreme	40,520	41.5
Total	98,100	100

CAUSATIVE FACTORS OF SOIL DEGRADATION

The Marvdasht Plain is one of the important agricultural zones in the country and has a high potential for wheat production, which is the staple food. During the past three decades, attempts have been made to ease the problem of feeding the increasing population by intensifying agriculture and bringing marginal lands under cultivation, without considering soil conservation measures. The result of such practices has been to lower soil productive capacity.

Some of the important factors involved in soil degradation in the Marvdasht Plain are given in Fig. 1. The immediate cause of soil degradation is mis-management. Besides inappropriate tillage, poor animal husbandry, lack of fallow period and burning of crop residues are the main factors responsible for the deterioration of the soil physical conditions and fertility decline. In general, over-exploitation and mismanagement lead to declining soil productivity. The over-exploitation is partly because of accelerated investments that seek profit maximization with little or no efforts for maintaining soil productivity.

CONCLUSIONS

Nutrient deficiencies, salinity, waterlogging, and compaction affect a large percentage of irrigated land in the Marvdasht Plain. Soil nutrient loss and salinization are the most active subtypes of chemical degradation. Soil compaction caused by using heavy agricultural machinery deteriorates soil physical conditions.

Mapping the regional extent of soil degradation can help raise public awareness about the loss of soil productivity and establish a priority of actions to be taken by the decision-makers and policy-makers.

Using spatial analysis techniques, the critical zones of soil degradation (such as zones of *compaction*, *salinity*, *waterlogging*, and *nutrient deficiencies*) can be established by analyzing the area-specific soil variables which are most susceptible to deterioration under long-term farming.

These zones can help estimate soil quality changes and changes in the management levels required for maintaining soil productivity and monitor the degradation or improvement of the soil quality at regional level.

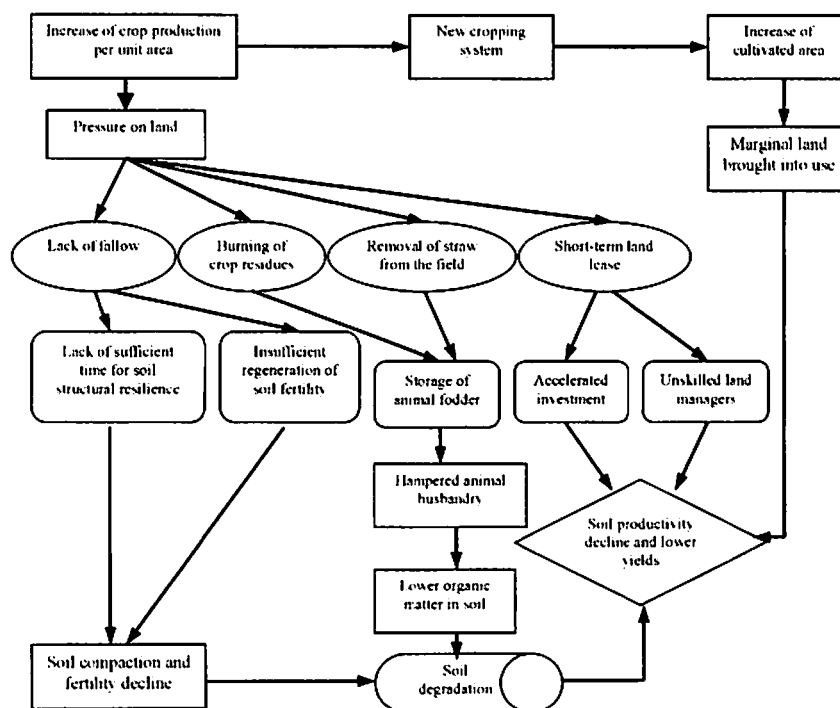


Fig. 1. The causative factors of soil degradation under the new cropping systems in the Marvdasht Plain.

Public awareness is a key factor in relation to soil quality resilience and renewal of soil fertility. This can be achieved by raising farmers' knowledge about the magnitude of the damages. In recent years, much has been said about the potential of increasing crop yields and re-using degraded soils, but little has been done to assess and monitor soil quality deterioration. Food increase through intensification of agriculture, without considering soil conservation measures, has been bought at the price of potentially less food production in the future.

Deterioration of soil physical properties and depletion of the soil nutrient pool requires the current land use and land management practices to be either changed or improved, if the land is to be used in a sustainable manner.

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REFERENCES

- ITC. 1997. The integrated land and water information system (ILWIS): version 2.1 for windows. International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands.
- Liebholt, A.M., R.E. Rossi, and W.P. Kemp. 1993. Geostatistics and geographic information systems in applied insect ecology. *Ann. Rev. Entomol.* 38: 303-327.
- McBratney, A.B., G.A. Hart, and D. McGarry. 1991. The use of region partitioning to improve the representation of geostatistically mapped soil attributes. *J. Soil Sci.* 42: 513-532.
- Moameni, A., and J.A. Zinck. 1997. Application of statistical quality control charts and geostatistics to soil quality assessment in a semi-arid environment of south-central Iran. *ITC J.* 1997-3/4: CD-Rom.
- Moameni, A., and J.A. Zinck. 1998. Application of geostatistics and remote sensing to soil quality assessment in a semi-arid environment of Iran. 16th World Congress of Soil Science. Montpellier, France, August 20-26: CD-Rom.
- Moameni, A., and A. Farshad. 1998. Evaluation of prevailing irrigation practices and their relation to soil properties: a case study of Hamadan-Bahar area of western Iran. *Annal Arid Zone*, Jodhpur, India, 37: 119-131.
- Oldeman, L. R. 1988. Global assessment of soil degradation (GLASOD): guidelines for general assessment of the status of human-induced soil degradation. ISRIC, Wageningen, The Netherlands.
- Oldeman, L.R., R.T.A. Hakkeling, and W.G. Sombroek. 1991. World map of the status of human-induced soil degradation: an explanatory note. ISRIC, Wageningen, The Netherlands.
- Ritzema, H.P., and H.M.H. Braun. 1994. Environmental aspects of drainage. 16: p. 1041-1065. In: H.P. Ritzema (ed.). Drainage principles and applications. International Institute for Land Reclamation and Improvement (ILRI), Wageningen, the Netherlands, ILRI pub.
- Soil Institute of Iran, 1968. Annual report of Marvdasht pilot project in Drudzan area. Publ. No. 213. Soil Institute of Iran, Tehran, Iran.

Crop Rotations for Sustainability of Rainfed Barley Production in Egypt's North-West Coast

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ABSTRACT

Absence of a well-established crop rotation system, combined with poor soil nutrients content is one of major problems confronting barley production under rainfed conditions in the north-west coast (NWC) of Egypt. On-farm trials were conducted for four seasons (95/96, 96/97, 97/98 and 98/99) in two sites (Zone 2 of East and West Barrani) with a seasonal average rainfall a little greater, and a little less, than 150 mm, respectively. The objective of the study was to investigate the effect of crop rotation on sustainability of barley production while maintaining natural resources and diversity of crop production through the optimum use of land and water resources, and to determine the suitable economic crop rotation. Rotations were barley-fallow, barley-pulses, barley-wheat, barley-fertilized barley, and barley-native legume fodder compared to continuous cultivation of non-fertilized barley.

The results showed that the barley-fallow rotation produced the highest barley grain yield and its attributes, whereas the barley-wheat and barley-barley rotations produced the lowest yield in the two sites for three years. Barley-pulse rotations (barley-pea and barley-lentil) performed better under the higher rainfall conditions, while barley-vetch showed a higher performance than rotation with pulse crops under lower precipitation. The results and observations indicated that local vetch (*Vicia monantha*) is most adapted to the NWC environment, whereas other leguminous fodder (medic and lathyrus) performed poorly and were dropped from the study in the second season.

Recommendations obtained from this study were demonstrated in the past two years (97/98, 98/99) in many locations in cooperation with extension and farmers. Targeted Bedouin farmers (sheep owners) at the two sites (East and West Barrani) were particularly interested and impressed by the barley-vetch rotation, which also has comparative economic advantages over the other rotations.

INTRODUCTION

Barley is the main crop cultivated in the north west coast of Egypt, being well adapted to adverse conditions, and is a key element in the feeding regime of small ruminants. Water resource availability is the key limiting factor. The long-term average rainfall is about 145 mm. The area cultivated to barley is about 300,000 feddans (4200 m²), but it varies between good and poor rainfall years and with land availability under the traditional rights.

Poor soil nitrogen content was a major problem confronting barley production improvement under rainfed conditions. The agronomic practices are *conventional, without chemical fertilizers and a planned crop rotation system*. Barley is usually grown after summer fallow. Sheep manure is the only available source of organic matter; it cannot provide enough nutrients to sustain barley production, particularly under the conventional mono cropping system.

Many workers concluded that crop rotations, especially cereal-legume rotations and biological N fertilizers were effective in rainfed areas to safeguard production, reduce chemical use and production costs, help to protect the environment, and attain sustainability (Karaca et al., 1991). Leguminous crops provide N for subsequent cereal crops in the crop rotation (Reeves, 1991; Papastylianou and Panayiotou, 1993).

Wheat grain and straw yields differed significantly among rotations (chickpea-wheat, lentil-wheat, and summer crops-wheat). The highest wheat grain and straw yields were obtained from rotation of summer crops-wheat (Pala and Matar, 1988).

Grain yield of wheat sown after leguminous fodder crops was superior to that after fallow (Loizides, 1980). In the NWC of Egypt, Abdel Aleem and Sabry (1994) found that the highest grain yield and spike number/m² of wheat were obtained by inoculating seeds with bacteria, when compared to wheat-wheat and wheat-lentil rotations.

Under rainfed conditions at ICARDA, Pala (1994) reported that total production of biomass and protein was only marginally reduced if the vetch in barley-vetch rotation is grazed instead of being allowed to grow to maturity. Also, he found that comparison of barley-leguminous fodder rotations with barley-fallow showed a large advantage in favor of the legume rotations.

Livestock grazes almost all land, but forage production and quality are low and well below potential. The main sources of forage in the semi-arid region are cereal residues, including straw and stubble (Watts and El Mourid, 1988). In a survey conducted in the semi-arid region, 25% of the arable land was weedy fallow (Derkaoui, 1989).

Ley farming is a system where self-regenerating annual legumes are grazed in rotation with cereal crops. Sufficient seed reserves of hard-seeded legumes are built up in the soil after sowing the first year, so that there is no need to sow the legume again in subsequent years. This technology has been practiced in southern Australia since 1930 (Puckridge and French, 1983). The objective of this work was to study the

effect of different crop rotations on barley grain yield and yield components, and also to evaluate this economically.

MATERIALS AND METHODS

The study was conducted in two sites (East and West Barrani, 135 and 150 km west Marsa Matrouh, respectively) in Agroecological Zone 2 under rainfed conditions during the period from 1995/96 to 1998/99 seasons.

This on-farm trial aimed to study the effect of eight crop rotations on barley productivity and economics. The treatments involved ten rotations in the beginning, but two rotations were canceled from the second year (barley-medic and barley-lathyrus), while the remaining rotations were: A. Barley - barley (B/B); B. Barley - wheat (B/W); C. Barley -fertilized barley (B/fert. B); D. Barley - broad bean (B/bb); E. Barley - lentil (B/L); F. Barley - pea (B/P); G. Barley - vetch (B/V); and H. Barley - fallow (B/F).

The experimental design was randomized complete block with three replicates at the two sites. The strip plot area was 500 m² (10 × 50 m), and each was divided into two sections for sowing the alternate crops in a two-course rotation every winter season.

The participant farmers in each site were involved in conducting all agronomic practices. The seeding rate (kg/feddan) for barley (G126 cv.) varied from 25 to 30 between both sites, while the seeding rate for food legumes was 45 for broad bean (G. 461 cv), 30 kg/feddan for lentil (G. 370 cv) and 35 for pea (Master cv). The seeding rate for vetch (*Vicia monantha*) was 25 food legume seeds were inoculated with *Rhizobium* bacteria and vetch seeds were treated by commercial sulfuric acid 70%. Seeds were broadcast after an effective rainfall.

In B/fert. B rotation, 15 kg P₂O₅ and 10 kg N/feddan were applied to plots of preceding barley only. In B/V rotation, the vetch seeds were sown in the 1995/96 and 1996/97 seasons only and in the last two seasons, 7.5 kg P₂O₅ /feddan was applied with one plowing pass. Also, vetch was grazed at the 50% pods maturing phase (50% shattered pods).

The soil texture was loamy sand (40-60 cm deep) and sandy loam (> 60 cm deep) in the first and second sites, respectively. However, both sites were poor in soluble N (0.02-0.03 ppm) and P (22-27 ppm), with high Ca CO₃ content.

Rainfall was below the average (145 mm) in 1995/96 and 1998/99 season, the 3rd year (97/98) had a record high rainfall, but the 4th year had very poor rainfall distribution. The second year (1996/97) was below or about average, but with the good distribution (Table 1).

Data on barley yield and its attributes affected by different preceding crops in all rotations were statistically analyzed according to Snedecor and Cochran (1967). Also, variable costs and output values were recorded for each two-course rotation.

Interviews or meetings were conducted for the involved local communities at East and West Barrani to determine priorities according to the Marsa Matrouh Resource Management Program (MRMP) approach and WB recommendations. Also, field days were carried out to obtain the opinions of participant farmers. Farmers were interviewed to record field operation costs, total sales (returns from grain, straw and residues-grazed for cereal and legume crops involved in each two-course rotation under study).

Also direct costs (seed, plowing, fertilizer, *Rhizobium* bacteria, cultivation, labor, harvesting and threshing were recorded and variable costs were derived. Economic analysis using partial budget analysis was conducted for the different crop rotations according to Perrin et al. (1983).

RESULTS AND DISCUSSION

Barley Yield and Attributes

The barley following the different preceding crops in the different crop rotations under study showed significant differences in yield and yield attributes in favor of B/V and B/F rotations when compared to B/B in the two sites. There were no significant differences between the different crop rotations in plant height at the two sites for all trial years, except the 1998/99 season, where the rainfall was less than the average

Table 1. Monthly rainfall data during four growing seasons.

Month	95/96	96/97	97/98	98/99	Mean
			-----mm-----		
Oct.	12.0	10.7	46.5	2.0	17.8
Nov.	16.5	17.5	17.0	37.2	22.0
Dec.	3.0	16.5	2.0	4.5	6.5
Jan.	67.0	46.5	42.2	17.0	43.2
Feb.	5.5	25.6	32.5	18.5	20.5
Mar.	8.5	21.5	26.0	15.0	17.8
Apr.	11.6	5.0	6.5	-	5.8
May	-	-	-	-	-
Total	124.0	143.3	172.7	94.2	133.6

(145 mm). There were significant differences in number of spikes/m² and 1000-grain weight in the two sites for all trial years. Average over all years, B/F and B/V rotations provided about 13-14% higher spikes/m² and about 5-6% higher 1000-grain weight than B/B in the two sites.

As shown in Table 2, grain, and straw yields of barley differed significantly between the different crop rotations in the two sites for all trial years. It is interesting to note that B/V rotation was superior to all rotations at the two sites in 1997/98 (a good rainfall year, above 145 mm). However, in the average or poor rainfall years (1996/97 and 1998/99, respectively) the B/F rotation was superior to the others in both barley grain and straw yields.

Over all years, average grain yield obtained from barley following vetch in B/V produced 1.3 and 0.8% less than that obtained from B/F in the two sites, respectively. However, B/V rotation provided 44.8 and 63.5% higher grain yield than B/B and B/W, respectively, in the first site, while in the second site the percent increases were 46.4 and 60.9% in the same order. For barley grain and straw, B/L in the first site and B/P in the second site produced yields greater than other rotations with food legumes, wheat, and fertilized or continuous barley. Mostly barley after legume did better than after wheat or continuous barley at the two sites in the different rainfall years.

These results agree with those obtained by Christiansen et al. (1994) and Pala (1994) under rainfed conditions in Syria. Also, Loizides (1980) reported that wheat grain yield after leguminous forages was superior to that after fallow.

The preceding crop resulted in significant differences in harvest index for all rotations in the two sites for all trial years. Similarly, barley with legume rotations in the first site and barley after fallow in the second one produced higher average harvest index means than those obtained from B/B or B/W rotations. For this reason, the farmer's decisions are towards grazing barley plants which gave the least harvest index. Generally, the performance of different crop rotations for barley yield and its attributes was different depending on rainfall years and the preceding crop in two different soil types. Superiority of barley productivity after vetch or food legumes over continuous barley or B/W rotation may be due to the fact that N fixed by legumes as a preceding crop was used by subsequent barley plants, particularly when legume seeds are inoculated by *Rhizobium* bacteria and a good distribution of rainfall occurred until flowering stage.

This may result in the accumulation of fixed N and improvement of organic matter by legumes, as reported by White et al. (1994). Leguminous crops also provide N for subsequent cereal crops in the crop rotation (Reeves, 1991; Papastylianou and Panayiotou, 1993).

Table 2. Barley yield as affected by preceding crop in the rotations.

Preceding Crop	East Barrani				West Barrani			
	96/97	97/98	98/99	Mean	96/97	97/98	98/99	Mean
Grain								
-----ton/feddan-----								
Barley	0.284	0.420	0.164	0.289	0.222	0.382	0.149	0.251
Wheat	0.159	0.292	0.123	0.191	0.150	0.277	0.122	0.183
Fert. barley	0.292	0.472	0.199	0.321	0.250	0.404	0.190	0.281
Broad bean	0.507	0.573	0.355	0.478	0.402	0.556	0.280	0.413
Lentil	0.518	0.651	0.368	0.512	0.407	0.587	0.303	0.432
Pea	0.515	0.573	0.361	0.483	0.410	0.607	0.303	0.440
Vetch	0.508	0.682	0.383	0.524	0.412	0.655	0.338	0.468
Fallow	0.520	0.679	0.393	0.534	0.440	0.636	0.341	0.472
F. test	**	**	**		**	**	**	
L.S.D	0.032	0.047	0.014		0.014	0.027	0.024	
Straw								
-----ton/feddan-----								
Barley	0.627	0.907	0.298	0.611	0.405	0.832	0.280	0.506
Wheat	0.460	0.861	0.213	0.511	0.395	0.609	0.198	0.401
Fert. barley	0.693	0.886	0.325	0.635	0.587	0.836	0.301	0.575
Broad bean	1.123	1.073	0.575	0.924	0.885	1.007	0.482	0.791
Lentil	1.142	1.145	0.610	0.966	0.880	1.007	0.495	0.794
Pea	1.137	1.119	0.610	0.955	0.882	1.040	0.520	0.814
Vetch	1.160	1.477	0.685	1.107	0.888	1.095	0.598	0.860
Fallow	1.222	1.401	0.698	1.107	0.893	1.000	0.602	0.832
F. test	**	**	**		**	**	**	
L.S.D	0.039	0.064	0.044		0.014	0.060	0.032	

* **: Significant at 5% and 1% level of probabilities. Fed*: 4200 m².

Differences in the B/V rotation may be due to green-grazed vetch that conserves a small amount of soil-stored water for the subsequent barley.

Pala (1994), investigating water use by barley in rotation with common vetch and fallow under rainfed conditions in Syria, found that barley following green-grazed vetch was able to utilize 11 mm more water than barley following mature-harvested vetch and about 70% of any such benefit may be available to barley following green-grazed vetch. In this respect, Harris (1989) reported that soils store very little water from a winter fallow over the summer for the next crop.

Economic Evaluation

Data in Table 3 show averages of net benefit - analysis for eight crop rotations in the two sites at east and west Barrani, respectively. From partial-budget analysis, the average of variable costs from two sections of each rotation were different, with differences in preceding crops and depending on the variable cost of field operations in relation to crop species, soil type and precipitation timing. There were differences between the different crop rotations under study in average gross returns for all products of both phases of each rotation. These differences were due to grain, straw, and field residue by-products and their prices during the two phases of each rotation that related to differences in rainfall.

comparison between B/V and check rotation (B/B), the former provided 52 and 64.8% higher NB than the latter in the first and second sites, with a consequent higher average rate of return (157.4 and 129.6%, respectively). There were differences between B/V and B/F in average rate of return. Nevertheless, B/F in average gave less NB than B/V, but had lower variable costs. According to NB, some rotations such as B/W, B/bb and B/P gave less NB than the check rotation in the first site, whereas in the second site, B/W, B/bb, B/L and B/P were dominated by the check rotation.

A partial-budget analysis for all crop rotations indicated that those five crop rotations in the first site and four in the second site were profitable under the existing price and cost conditions. Mostly, B/V, B/L, B/F, and B/fertilized barley rotations in the first site and B/V, B/F and B/fert. B rotations in the second site were dominant alternatives over B/B rotation.

As reported by Pala et al. (1994), barley-vetch rotation showed a large advantage over barley-fallow rotation under Breda conditions in Syria. Also, under dry farming conditions in Syria, Christiansen et al. (1994) reported that in mean values for 7 years, the barley-vetch was the most productive rotation biologically, compared with barley-fallow and continuous barley.

These results led to the choice of the B/V rotation as the best recommendation for farmers, where it attained a 157.4 and 129.6% increase in average rate of

Table 3. Averages of net benefit analysis for different crop rotations in the two sites.

<u>Crop Rotation</u> ²	<u>Variable Costs</u> ¹	<u>Gross Returns</u> ¹	<u>Net Benefits</u> ¹	<u>Average Rate of Return</u>
----- Egyptian pounds (LE) -----				
East Barrani				
B/B	247	419	172	70
B/W	273	380	107	39
B/fert. B	284	486	201	71
B/bb	315	452	137	44
B/L	306	533	227	74
B/P	313	455	141	45
B/V	228	588	359	157
B/F	140	346	206	147
West Barrani				
B/B	240	345	105	44
B/W	268	308	40	15
B/fert. B	277	419	142	51
B/bb	309	217	-92	-30
B/L	300	395	95	32
B/P	307	347	41	13
B/V	230	528	298	130
B/F	140	310	170	121

¹LE / feddan for the two phases of each rotation. ²See text for abbreviations.

Data from partial-budget analysis showed that there were wide differences between crop rotations in net benefits (NB) in favor of B/V rotation, which gave the highest gross returns with moderate variable costs. In

return in the two sites, respectively. This recommendation has more importance for extension and farmers, particularly those who are sheep owners in similar areas to the two sites in this study.

CONCLUSIONS

The present study was carried out under rainfed conditions in northwestern coast area, of Egypt during the period from 1995/'96 to 1998/'99 to determine the effect of eight crop rotations on barley production sustainability and economics in the two sites (East and West Barrani) in collaboration with extension and farmers.

The averages for all trial years showed that B/V and B/F rotations produced the highest grain and straw yields of barley compared to continuous barley and other rotations with wheat or food legumes in the two sites. Also, comparison between rotations with pulse crops, wheat and continuous barley showed clear distinction in favor of the legume rotations, particularly B/L rotation in the two sites.

It is evident that B/V rotation was superior to other rotations in 1997/'98 seasons as a good rainfall year (above 145 mm). However, in the average or poor rainfall years (1996/'97, and 1998/'99, respectively), the distinction was in favor of B/F in the two sites for grain and straw yields of barley.

The B/F rotation showed an advantage over B/B rotation. Nevertheless, a crop yield obtained from rotation with fallow was only once every two years and the advantage may be due to storage of soil water from a winter fallow over the summer for the next barley, particularly when the fallow phase corresponds to good rainfall years.

On the other hand, superiority of B/V to B/B, B/W or B/pulse rotations may be attributed to better adaptability to drought stress of the native vetch (*Vicia monantha*), as well as its high straw palatability compared to barley or wheat straw. Also, it has high ability for nodulation due to the fact that specialized bacteria for native vetch (unknown) is more adapted to stress conditions than those of other food legumes.

This may help to increase the fixed N to improve soil fertility. Likewise, native vetch is a shattering species with regenerated seeds and hence N fixation occurs every year. Also, barley following vetch in crop rotations will be mixed and subsequently barley straw quality will be improved.

A partial-budget analysis showed that barley-vetch rotation was economically the best. It attained 157.4 and 129.6% increases in the average rate of return in the first and second sites, respectively. This recommendation is more profitable for farmers, particularly sheep owners, who expressed their opinions that growing barley after vetch will become widespread without high costs because it did not require seeding every year. This recommended crop rotation might assure increased sustainability of barley production under such dry farming conditions.

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REFERENCES

- Abdel Aleem, M.M., and S.R.S. Sabry. 1994. Effect of crop rotation, chemical and biological nitrogen fertilizers on sustainability of wheat production in the northwest coast of Egypt. *Proc. 6th Conf. Agron.*, Al Azhar Univ., Cairo, Vol. 1: 351-363.
- Christiansen, S., F. Bahhady, E. Thomson, M. Singh, and A. Ferdawi, 1994. On-farm trials comparing forage legume/barley rotation to fallow/barley rotation and continuous barley in northwest Syria. *Pasture, Forage and Livestock Program Annual Report*, p. 53-67. ICARDA, Aleppo, Syria.
- Derkaoui, M. 1989. Plant-animal associations in the cereal semi-arid zones of Morocco. p. 1311-1312. In: *Proc. XVI Inter. Grassland. Congr.*, Assoc. Française Pour La Production Fourragère. Nice, France. Institut National de la Recherche Agronomique, Route de Saint-Cyr, 78026 Versailles, Cédex, France.
- Harris, H. 1989. Crop-water use and water-use efficiency in contrasting barley rotation, p. 36-54. *FRMP Report for 1988*. ICARDA, Aleppo, Syria.
- Karaca, M., M. Guler, N. Durutan, K. Meyveci, M. Avci, H. Eyuboglu, and A. Avcin. 1991. Effect of rotation system on wheat yield and water-use efficiency in dryland areas of central Anatolia. *Soil and Crop Management for Improved Water-Use Efficiency in Rainfed Areas. Proc. International Workshop*, Ankara, Turkey, May 15-19, 1989.
- Loizides, P. 1980. Crop rotations under rainfed conditions in a Mediterranean climate in relation to soil moisture and fertilizer requirements. In: *Proc. Regional Seminar on Rainfed Agriculture in the Near East and North Africa*. Amman, Jordan May 5-10, 1979.
- Pala, M., and A. Matar. 1988. Soil test calibration with N and P for wheat under dryland conditions in Syria. *Soil Test Calibration in West Asia and North Africa. Proc. Second Regional Workshop*, Ankara, Turkey, Sep. 1-6, 1987.
- Pala, M. 1994. Effect of type and harvest time of forage legumes on yields in barley-forage legume rotations. *FRMP Annual Report*, 31-44, ICARDA, Aleppo, Syria.
- Papastylianou, I. and G.S. Panayiotou. 1993. Productivity and economic and financial profitability of three rainfed rotation systems in Cyprus.

- Agric. Res. Inst., Mini. Agric. and Natural Resources, Nicosia, Cyprus, *Tech. Bull.* No. 148.
- Perrin, R. K, D.L. Winkelmann, E.R. Moscardi, and J.R. Anderson. 1983. From agronomic data to farmer recommendations: an economics training manual, CIMMYT, *Info. Bull.* 27, 5th Printing.
- Puckridge, D.W., and R.J. French. 1983. The annual pasture in cereal-ley farming systems of Southern Australia: A review. *Agr., Ecosystems Environ.* 9: 229-242.
- Reeves, T.G. 1991. The introduction, development, management and impact of legumes in cereal rotation in Southern Australia. Soil and Crop Management for Improved Water-Use Efficiency in Rainfed Areas. *Proc. International Workshop*, Ankara, Turkey, May 15-19, 1989.
- Snedecor, G.W., and W.G. Cochran. 1967. Statistical methods. 15th ed. Iowa State, Univ., Press, Iowa, USA.
- Watts, D., and M. El Mourid. 1988. Rainfall patterns and probabilities in the semi-arid cereal production region of Morocco. Institut National de la Recherche Agronomique, Settat, Morocco.
- White, P.F., N.K. Nersoyan, and S. Christiansen. 1994. Nitrogen cycling in dry Mediterranean zones: changes in soil N and organic matter under several crop/livestock production systems. *Aust. J. Agric. Res.* 45: 1293-1307.

Arab Center for the Studies of Arid Zones and Dry Lands' Strategy for Development and Improvement of Arid and Semi-Arid Areas

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INTRODUCTION

The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) was established in 1971 within the framework of the League of Arab States. The Arab state's decision to establish ACSAD was based on the importance of the arid and semi-arid lands, which encompass most of the natural and agricultural resources available to the Arab world, e.g., *water, soils, rangelands, and livestock wealth*. These lands, which face some grave problems such as the spread of desertification, deterioration and pollution of the water resources, and the loss or extinction of some forms of biodiversity continue to produce most of the cereals (wheat and barley) and livestock in the Arab World and are considered as an important store of animal and plant genetic resources.

All the studies and research indicate that these lands have great potential capacities, which can be conserved and increased if sound practices are adopted and appropriate measure are taken to ensure the development and proper exploitation of the natural and agricultural resources in these lands and help in the realization of the objectives of the Arab food security.

Taking into consideration the great importance of the arid and semi-arid areas in the Arab World, it appears that the Arab countries have assigned ACSAD with a great and sensitive task, which is closely related to the question of the development of the Arab agriculture, i.e., the finding of scientific and practical solutions for the problems and constraints which impede the development and improvement of the arid and semi-arid areas in the Arab World.

STRATEGY

ACSAD's strategy aims to make its activities more dynamic and flexible vis-à-vis the new developments in the fields of technology and the agricultural policies on the one hand and the transfer of the results of the research and studies to the farmers in the Arab countries on the other hand. It also aims to give ACSAD a special and distinctive role in the specific fields relating to the Arab water security, the use of non-traditional resources to support the agricultural traditional resources, the conservation of the environment and biodiversity, and combating desertification, in addition to its traditional duties in the fields of the survey, evaluation and development of the natural resources in the arid and semi-arid areas, and the improvement of the knowledge and expertise of the personnel working in these areas.

Objectives

The main objectives in the field of the development of the Arab arid and semi-arid areas can be summarized as follows:

1. The optimum and rational exploitation of the available and potential agricultural resources in the arid and semi-arid areas to get the maximum economic return from the unit area and unit water within the framework of the sustainable development so as to help achieve the objectives of the Arab food security.
2. Changing the arid and semi-arid areas with their available and potential natural and agricultural resources and social and population frameworks from marginal areas for agricultural production and rural and nomadic life into integrated productive areas, taking into consideration that such change will allow the arid and semi-arid areas to provide better life conditions for the Arab people and protect the wet and semi-wet areas from desert encroachment.

The strategy depends on integrated pivots which can be identified as follows:

- Survey and evaluation of the renewable natural resources in the Arab World.
- Conservation of the natural and agricultural resources and rehabilitation of those subject to deterioration.
- Benefiting from the non-traditional resources in supporting the agricultural resources.
- The use of the socio-economic criteria in developing the arid and semi-arid areas.
- Transfer and introduction of the technologies which are suitable for the Arab conditions.
- Documentation and dissemination of the results of the research programs and scientific studies.

RESEARCH AND DEVELOPMENT PROGRAM

Water Resources

Taking part in the realization of the objectives of the Arab water security is one of ACSAD's main tasks and as the coming period will be characterized by the increase of the demand for water.

With aggravation of the problem of water shortage is therefore important to diversify the water resources and improve their management. The secondary objectives in this field are as follows:

- Developing the surface water resources and concentrating in this respect on the management and harvesting of rainwater and increase the integrated use of the surface water and the groundwater resources.
- Protecting the water resources from pollution and maintaining the water-environmental balance, noting that environmental deterioration of the water resources is one of the main causes of water shortage.
- Expanding the use of the non-traditional water resources, especially the desalinization of seawater and the saline and slightly saline groundwater and purification of wastewater.
- Improving the management of drinking water and wastewater networks and increasing the efficiency of the use of these water resources.
- Assessing the common groundwater resources.

Soils and Water Uses

Arab agriculture suffers from a number of problems pertaining to soils and water uses, such as the lack of the optimum use of the soils, problem of desertification, environmental pollution, and the use of out-dated and traditional practices. The secondary objectives in this field can be summarized as follows:

- Making the optimum use of the lands according to soil survey and classification data.
- Arresting the spread of desertification and rehabilitating desertified lands with the use of modern techniques.
- Increasing land productivity through diversifying and increasing the non-traditional water resources and increasing the efficiency of irrigation water use.
- Improving the rural environment and spreading the use of the biogas technique in rural societies.

Plant Wealth

Agriculture in the arid and semi-arid areas suffers from the decrease of productivity despite the potential capacities in these areas; this is due to the use of the inappropriate practices in the exploitation of the resources in these areas. The secondary objectives in this field are as follows:

- Providing development programs in Arab countries with reliable genetic resources that are suitable for the Arab environments.
- Providing a base of suitable technology for the optimum use of Arab arid and semi-arid areas.
- Evaluating the environmental situation in the arid and semi-arid areas and protecting them from deterioration.
- Conservation the Arab plant biodiversity, and benefiting from genetic variation to increase production and productivity.
- Evaluating and maintaining genetic resources, including plants threatened with extinction so as to

make use of them in the Arab development programs.

Animal Wealth

Animal production in the Arab countries is facing some major constraints, including natural constraints pertaining to the climate and the availability of feed resources and institutional constraints pertaining to the multitude of parties responsible for the animal wealth and the weak relationship existing between the scientific agricultural research and the agricultural extension services and the breeders. There are social constraints pertaining to the food pattern of the people and the increase of the population growth average. The secondary objectives in this field can be summarized as follows:

- Making available improved lines of small ruminants and assisting the Arab countries in drawing up programs for the multiplication and spreading of highly efficient animals.
- Preserving the Arab environment and the Arab animal biodiversity and coordinating with Arab and international organizations in this field.
- Improving the efficiency of feed use, benefiting from the non-traditional resources to feed the animals and supporting the feed research and development network and the research pertaining to feed resources in the Arab countries.
- Improving camel production through strengthening the technical capabilities, transferring the appropriate techniques, and supporting the research activities on camels in the national institutions.
- Developing the animal production through nutrition studies, suitable breeds, and improved animal health.
- Improving the efficiency of the Arab cadres and disseminating the results of the research and studies.

Social and Economic

The economic factor has become an important criterion for testing the technical solutions for the different developmental and environmental problems and it is now necessary that the scientific studies should include socioeconomic analyses and feasibility studies which help in taking sound and effective decisions. The secondary objectives in this field are as follows:

- Identifying the socioeconomic and structural capabilities and constraints vis-à-vis the adoption of the new techniques that help in increasing production.
- Studying the economic feasibility of results obtained from ACSAD's research.
- Evaluating and developing the social characteristics and productive capacities of the human resources.
- The economic and social evaluation of the technical constraints facing the different agricultural production sectors.

Increasing and improving the capabilities of technical personnel working in the different fields of scientific research and agricultural development.

Achievements

Since its inception in 1971, ACSAD has carried out many important programs and activities in the Arab countries, concentrating on scientific, technological and organizational aspects, which helps in the development of the Arab arid and semi-arid areas. It also played an important and vital role in solving many of the problems that impede the development of these areas. It is worth mentioning that ACSAD work has not been restricted to conducting research and studies and providing technical services; it expanded to serve as a link between the findings of the research and studies and the large-scale practical application on the farmers' fields. It has carried out many research and development projects in cooperation with the concerned parties in the Arab countries and with many Arab and international organizations, and has gained an excellent reputation at the Arab and international levels as an Arab center for research and studies. Its achievements can be summarized as follows:

- Considered as the main source in the region for providing the national programs for the development of rangelands with the seeds of range plants which are tolerant to drought, ACSAD collects hundreds of varieties of these plants with the aim to select those that are suitable for the Arab environments, and then it multiplies them and send them to the Arab countries.
- ACSAD has produced, within its breeding programs, a number of high-yielding wheat and barley varieties which are tolerant to drought; these varieties, which are now grown in many Arab countries, outyielded, on average, the local varieties by 27% for wheat and 42% for barley. A number of other new wheat and barley varieties have been produced and will be sent to the Arab countries after the confirmation of their superiority and their tolerance of drought.
- ACSAD has established a field genebank that contains 430 varieties of fruit trees which are tolerant to drought (olive, pistachio, almond, fig, and grape). This genebank provides the national programs with excellent and reliable genetic resources in the form of seedlings, seeds, and scions; it also gave special attention in its research and studies to the identification of the best agricultural practices and techniques which can help in increasing the production and improving its quality.

ACSAD has established the Date Palm Research and Development Network with the aim to stop further decline in date production and improve date yield and fruit quality of this important tree. This Network is financed by the Arab Fund for Economic and Social Development and the Islamic Development Bank.

In the field of conservation and exploitation of the plant biodiversity to ensure the sustainable development of the Arab environments, ACSAD has established protected areas and genebanks for forage plants and introduced the superior varieties with the aim to increase the genetic variation and select and breed of the promising varieties of these plants.

ACSAD has acquired many improved varieties and hundreds of promising lines, which are included in the breeding programs. More than 15000 plant representing over 1000 plant species have been documented and these constitute the Arab Database for Arid Plants (ADAP). The wild stocks of almond tree in Syria were surveyed within a regional project as a first step to reach to a comprehensive survey of the various wild stocks of the fruit trees.

- ACSAD has given attention also to the conservation of the animal biodiversity in the Arab countries and it established a bank for the animal genetic resources; it has been assigned by the Arab Council of Ministers responsible for the environment with the task of following-up and coordination among the Arab countries as regards the implementation of the International Convention on Biodiversity.
- ACSAD has prepared studies about the natural plants in the Arabian Peninsula, Syria, Iraq, and North Africa, and also about techniques used in the conservation and exploitation of the biodiversity.
- ACSAD has provided the "green belt" establishment and desertification combating projects with seedlings which are adapted to local conditions, especially the multi-purpose species (forage, firewood, timber, fruits, and medicinal and industrial materials); 15 tree species were tested under different environmental conditions (tolerance to drought and cold and resistance to salinity). Also, 30 forest tree species were identified to be suitable for afforestation in the arid areas.
- ACSAD has given special attention to small ruminants (sheep and goats) and its activities in the field concentrated on improving the production capacity of the lines which are widespread in the Arab countries through the genetic improvement, improvement the feeding systems, proper management of the herds, the development of the production systems, and the marketing of products. It has produced improved lines of the Awassi sheep that give higher yields (78% in milk, 14% in meat and 29% in wool). Attention is also given to the improvement of other lines of sheep in some Arab countries and the distribution of the improved males to the Arab countries is under way with the aim to improve the indigenous lines.
- Because of the importance of goats and their role in developing the arid and semi-arid areas in a number of Arab countries ACSAD has given attention to the development of this animal through research and studies that aim to increase its productivity.

It established a station in order to improve and multiply the excellent breeds such as the Shami goats. A program is being carried out in a number of Arab countries to crossbreed the indigenous goat breeds with the Damascus goats or the Syrian mountain goats.

ACSAD has studied carrying capacities which are suitable for the natural rangelands and the adverse effects of the excessive carrying capacities on the vegetative cover; it has established a network for feed development and research with aim to coordinate between the national organizations and support the research pertaining to feed sources.

- Special attention has been given to camels, and it established the Camel Applied Research and Development Network, which is financed by the International Fund for Agricultural Development (IFAD), and other agencies with the aim to devise and transfer the techniques which are suitable for camel breeding, and the processing and marketing of camel products.
- Great attention has been given to the soil and water resources in the Arab arid regions because of the vast agricultural areas in the regions and the great potential capacities that can play an important role in satisfying the populations' food needs and improving their standard of living. ACSAD has established data banks for soils, water and climate in the Arab countries.
- ACSAD has concentrated on a number of vital projects which deal with the soil resources and water uses in the arid and semi-arid areas through research studies under varying conditions in the Arab world. The desertification has been studied in terms of the constraints and also the methods of controlling it through the use of the modern techniques, including the remote sensing systems.

It has carried out many studies and pilot projects in the field of desertification control and sand dune fixation, and as a result of its experience, it has been assigned by the Council of Arab Ministers Responsible for the Environment with the task of coordinating between the Arab countries and the Arab regional and international organizations in connection with the implementation of the International Convention for Combating Desertification.

It has concentrated its attention also on dealing with the irrational exploitation of fresh, saline, slightly saline, and treated wastewaters so as to devise sound methods for their use and determine their suitability for irrigation for crops, depending on the characteristics of the soil and climate and plants.

ACSAD has established the infrastructures required for monitoring desertification and has conducted research and studies aiming to rehabilitate desertified lands. The results of its activities in this field will be distributed to the other Arab countries that

are suffering from desertification, through the implementation of pilot projects.

- It has completed a number of soil maps in several Arab countries and has prepared an atlas of desertification.
- ACSAD has identified a package of practices and techniques suitable for rainfed agriculture within integrated farming systems, which include cereals, food and forage legumes, and the animal wealth. These practices and techniques are being used on a large scale in farmers' fields in some Arab countries in cooperation with the agricultural extension services in these countries. It has carried out also special studies pertaining to supplemental irrigation and its relationship with fertilization.
- It has made a number of studies on the exploitation of the renewable energies (biogas, wind, and solar) in the arid areas.
- As the water resources in the Arab world are limited, at the time when demand for water increases and the water resources are exposed to deterioration, both qualitatively and quantitatively, ACSAD has realized that the integrated management of the water resources is an urgent need that requires studying some factors including the institutional structures working in the field of the water resources and the management of the available water resources so as to meet the demand for water. While conserving it qualitatively and quantitatively, ACSAD has carried out some research and studies in this field.
- In order to contribute to the realization of the objectives of the Arab water security, ACSAD carried out an analysis and evaluation of the state of knowledge of the water resources in the Arab countries and has identified the water shortage which will face the development process in 2030. It has established the water information bank in the Arab world and completed the mathematical models for management of water resources in some Arab water maps at different scales, showing the distribution of water resources in the Arab world and the common aquifers identifying their locations and the changes in their quality and quantity.
- It has carried out a number of studies pertaining to the evaluation of the water resources pollution in the Arab world, and also completed many studies on the rationalization of the use of water and the introduction of new techniques in the management and exploitation of the water resources.
- It has prepared a number of socioeconomic studies on analyzing the farming systems and evaluating the economic effects of the technical constraints facing the various agricultural sectors. It also made feasibility studies of the results of its own research and studies.

- It has carried out many integrated projects, which included integrated research and studies dealing with a number of the agricultural resources at the same time (soil, climate, water, rangelands, animal wealth, etc), in addition to some socioeconomic studies in a specific area in one Arab country or in some Arab studies to draw up an integrated plan to develop the concerned area.

The most important studies carried out by ACSAD in this field include those on the Hamad Basin Project, Al-Kouf National Park in Libya, Wadi Al-Taweel in Algeria, Al-Araba in Mauritania, and the determination of the best farming system in the Arab rainfed area.

Monitoring and Combating Syrian Steppe Desertification

This project deals with desertification through the use of the remote sensing techniques and the Geographic Information System (GIS), combined with the people's participation and the field activities with the aim to identify the causes of this phenomenon, select the best solutions for combating it, draw up a methodology to monitor it, and rehabilitate the lands affected by desertification.

This Project started in late 1993 on an area of 1,800 ha with the cooperation between ACSAD and the Ministry of Agriculture and Agrarian Reform, the General Organization for Remote Sensing and the Peasants' General Union in Syrian Arab Republic and the German Agency for Technical Cooperation (GTZ). The Project activities include making thematic maps and field and socioeconomic surveys in addition to the organization of field days for the farmers and the decision-makers to acquaint them with the results of the sound uses of the steppe lands and the success of the measures aiming to rehabilitate the deteriorated areas. It is worth mentioning that the Project has been able to achieve positive and important results during a short period.

ACSAD has carried out, many country-projects in the Arab World under which technical experience and

genetic material (seed, seedlings, improved animal breeds) are made available, modern techniques are introduced, local personnel are trained in the place of work, and some field and laboratory equipment and chemical materials were also provided.

- It has given special attention to the transfer of techniques and technical knowledge suitable for the Arab conditions, and also to the development of the Arab human manpower working in the field of development and environment in the arid and semi-arid areas through holding training courses on the different fields of its work and through exchange of experiences and organization of scientific meetings (seminars, workshops and scientific conferences), which are considered as an important way of enriching the scientific knowledge and informing those concerned of the scientific and theoretical and developments.
- It has given great attention to the technical cooperation as one of the effective means for carrying out its programs and activities and realizing its objectives. It established links and relationships with 48 Arab and international organizations and scientific research centers and cooperated with more than 26 agricultural scientific research centers in the Arab countries. It also signed technical cooperation contracts and agreements with many of these organizations and centers.
- It has published, until 1998, more than 1200 scientific reports and 950 scientific publications. It also publishes the Journal of Agriculture and Water in the Arab World, the Camel Science Journal, the Camel Newsletter, and the Date Palm Newsletter.

REFERENCES

- ACSAD Work Strategy, 1998.
 ACSAD Plan of Work for 1999-2000.
 Report of ACSAD Director General for 1998.
 Report of ACSAD Executive Council for 1996-1997.
 Technical reports of ACSAD divisions.

Approach to Sustainable Dryland Development in Arab Region

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ABSTRACT

In 1997, the Arab Organization for Agricultural Development (AOAD) began an initiative for "A 2025 Year Projection for Agriculture and Food" to evaluate current conditions and trends in food production in the Arab Region and to facilitate an Arab Regional consensus on the directions of policy that should be taken over the next 25 years. Among the most hotly debated elements in the AOAD projections and approaches is the extent and effect of dryland degradation. AOAD perceives that dryland degradation poses a potential threat to food production in Arab Region. Further expansion and intensification of food production could also have a potentially degrading effect on the environment.

The technical difficulties of assessing dryland degradation, the weakness of existing databases, and the poorly explored linkages between dryland degradation and other aspects of rural development has led to depletion of natural resources creating major environmental problems. Natural agricultural resources which include land, water, and animals, in addition to forest and natural rangelands, constitute the main components for activities and projects for dryland development in Arab Region. It is well known that such natural resources are exposed to such factors such as desertification, soil erosion, degradation of natural vegetation cover, soil salinization, and sand dune encroachment, urban construction creeping, etc, in addition to land and water development, which includes land reclamation and water management. Water security is crucial to realizing sustainable agriculture development in the dryland concept of AOAD's future approach.

INTRODUCTION

During the 1990s, AOAD strategy has stressed achieving sustainable agricultural development in the dryland in the Arab Region. AOAD calls for sustainable development approach to be adopted by Arab countries, and always emphasizes the need to redefine the concept of development to cater for the attainment of the basic needs of people and to improve their opportunity to fulfill their objectives for a better life and to maximize their profits without depriving future generations of their rights to meet their aspirations.

This concept of sustainable development focuses on the urgency of managing natural resources. It calls for creating some sustainable measures for protecting, conserving, and developing of the existing natural resources. The concept also pays special attention to participation of people in planning for, and implementing of, development, especially natural resources

development. The concept of sustainable development attempts to reduce the present levels of energy consumption and aims, in the long run, at substituting non-renewable resources with renewable sources of energy.

It is clear from the above discussion that sustainable development in the drylands is a complex concept concerned with environmental, cultural, social, ecological, economic, technological, humanitarian, and political aspects of life of the people in these areas. Thus, it becomes very difficult to define a measure or a quantity for this concept due to the strong interlinkages between its qualitative and quantitative dimensions. To achieve sustainable agricultural development, people have to think about the environment, ecology socioeconomic systems, indigenous "know-how" and culture in terms of complex interactions, processes, adjustments under very changing circumstances.

A recent call for supporting "Low External Input and Sustainable Agriculture (LEISA) aims at optimization of the use of the locally available resources in an integrative and complementary way to maximize benefits, minimize costs of production, and enhance sustainability and regeneration of resources in the farming systems. It tries to seek the best alternative approach to using and applying external inputs in the most efficient way. In a nutshell, sustainable agriculture aims at enhancing productivity of farming in the traditional sub-sector, together with the protection and preservation of the environment.

The concept of sustainability in agricultural development and conservation of the environment in the dryland cannot work properly unless the development of technology needed is carried out through collaborative efforts of all interested parties, i.e., scientists farmers, financial bodies, development planners, and above all, the decision-makers.

Dryland Development Challenges Beyond 2000 in the Arab Region

The land resources include not only the soil, but also water, vegetation, landscape and the microclimatic components of the ecosystem. Land degradation refers to a temporary or permanent decline in the productive capacity of the land. Land improvement, is an increase in this productive potential.

Land degradation in the long-term, negatively affects food production. Drought is a recurring natural condition from which indigenous adapted vegetation would recover by itself if there is no human-induced damage. Drought-affected land is more susceptible to wind and water erosion. Desertification is understood to be a kind of land degradation in the drylands, and drought is a contributor to desertification - but not the

cause. Therefore, desertification is defined as "irreversible destruction of the biological potential of the land", and can lead ultimately to desert like conditions. The principal dryland degradation processes are identified as shown in Table 1.

The main challenges to dryland development in Arab Region can be summarized as follows:

- a) Desertification is considered the result of many factors, namely, land conditions, mismanagement of the plant cover, non-sustainable agricultural practices, poor soil structure, mismanagement of water resources, and people displacement.
- b) Pollution by agrichemical; excessive amount of fertilizers and pesticides causes severe damage to the dryland resources.
- c) Irrigation-water born diseases, like Malaria and Bilharsia, which are drastically affecting the human resources responsible for dryland development.
- e) Urbanization pressure will definitely decrease agricultural lands and increase the loss of valuable biological diversity.

The problem of water security is the greatest challenge facing the sustainability of dryland development in the Arab Region. Therefore, reconsidering water-use policies in the Arab Region is very important. This may require improving water-use methods at farm level as well as developing traditional and non-traditional water resources.

AOAD Approach to Land Degradation and Improvement

The AOAD actively enhanced and encouraged sustainable development of dryland since its inception in 1972 and it has compiled experiences in conducting studies, training courses, and seminars on most problems related to land degradation in the Arab Region. It can cite many examples reflecting its efforts and experiences on various aspects of dryland degradation systems in Arab Region, correlated between various parameters to these sites to provide baseline data for site of the local, national and regional levels so these particular sites become useful in assessing trends.

Tested sites can be covered by multi-disciplinary teams of specialists in climatology, plant science, soil science, and social science, together with local farmers. The objective is to solve this complex problem through interaction and joint work of all these partners to generate appropriate technologies suitable for any particular site. If the site is representative then the findings can be applied to wider areas, so the selection of the test site is crucial for wider scale application. In reviewing the literature on this subject, AOAD refers to the paper by World Research Institute (WRI) on Environmental Indicators (1995). Most of the definitions and characteristics were taken from this reference.

An indicator is something that provides a clue to matters of larger significance or makes a perceptible trends or phenomenon that is not immediately detectable. Indicators quantify information so that its

significance is quite apparent. The choice of environmental indicators in the context of sustainable development depends on the desired purpose. *Pressure* indicators measure policy effectiveness more directly whether forest depletion increases or decreases. *State* indicators measure the quality or "State" of the environment, particularly decline attributable to human activities, while *response* indicators measure progress towards regulatory compliance. In addition, there are indicators of resource depletion.

These indicators directly measure the sustainability of dryland resource use and thus provide a signal of the effectiveness of dryland resources policies that may be important economically. The index of dryland depletion indicates the degree of departure from sustainable resources use, assuming that the depletion of dryland resources is sustainable if their use leads to the creation of other assets of equal value. The elements, on which this methodology is based, contain surveys and evaluations of the biophysical, and socioeconomic levels of inhabitants in these affected areas.

Plan of Work for Sustainable Dryland Development

The AOAD proposes the following plan of work for sustainable development of the dryland in the Arab Region.

- a) Selection of a common problem or problems among the countries of the region e.g., degradation of natural vegetation cover, soil salinization, etc.
- b) This problem should cover a wide area representing most ecosystems and landforms.
- c) Some work should have already been done on this problem, at least defining its climatological and soil characteristics.
- d) Then, ecosystem-based resources management will be applied to the area, involving the required specialists, beneficiaries, and covering all aspects aimed at (e.g., rehabilitation of degraded vegetation cover) and sustainable ecosystem productivity.

Data generated from these representative areas will be analyzed to show trends in various aspects of this complex problem within a time-frame already set, e.g., 2-5 years in the short term or 5-10 years in the medium term, and 15 years or more in the long term, depending on the locality and resilience of the ecosystem. Work in the representative areas is continuously monitored. Appropriate packages of technology will merge as well as developing and testing of various aspects of indicators, i.e., pressure indicators measure, technology effectiveness measure, etc. These findings and technology packages and indicators will be commonly applied in wider areas after being tested in these representative areas.

Table 1. Dryland degradation processes.

Component	Degradation	Improvement
1. Physical soil	Crusting Compaction Sealing Wind erosion De-vegetation Over-tillage	Soil conservation barriers Terracing Replantation of denuded lands Soil de-compaction Breaking-up of pans Cover crops Windbreaks Soil deposition Improved tillage
2. Soil water	Impeded drainage Waterlogging Reduced water-holding capacity Salinization	Irrigation Water harvesting Field drainage Drainage of water logged areas Filter strips
3. Soil nutrient and organic matter	Alkalinization Acidification Nutrient leaching Removal of organic matter Burning of vegetation residue Nutrient depletion	Fertilization Composting Green manuring Animal manuring Flushing of saline Alkaline soils Liming acid soil Acidulation
4. Soil biology	Over-application of agrichemicals, Industrial contamination	Introduction of biotic organisms Biological N fixation
5. Vegetation	Decline in vegetative cover Decline in biodiversity	Increased vegetative cover Increased species diversity
Decline in species Decline in availability valued species.	Improved species composition. Improved availability of valued of species	

ACTIVITIES IN SUSTAINABLE DRYLAND DEVELOPMENT IN THE ARAB REGION

In pursuing its objective AOAD has promoted programs and activities at both country, and regional levels, which could be discussed under four groups of activities, namely, 1) implementing agricultural and rural development projects, 2) preparation of technical and economic studies, 3) organization of conferences, seminars, and 4) training courses and provision of technical assistance to member countries. The following are a few examples of studies and projects related to conservation of resources and sustainable development in the Arab Region.

Technical and Economical Studies

Irrigation Efficiency

The study assessed the current on-farm irrigation management practices, and development of methodology for introducing improved irrigation practices including operation and maintenance. The study pointed out that due to the growing water scarcity in the region and the continuous stress on the available water resources, further development of irrigated agriculture is seriously jeopardized. This situation points to the need for appropriate strategies for water resources management, particularly in irrigation which accounts for up to 90% of the total water resources consumption. In most irrigation schemes, water use efficiency is very poor, averaging about 45% in the traditional surface irrigation systems. The introduction of drip irrigation was more appropriate for dryland especially for horticultural

crops and greenhouses. It improved water efficiency, up to 90% and suited most of the soils, including very permeable sandy soils.

Agrometeorology in Irrigation

The study showed that the use of agrometeorology plays an important role in irrigation management, and in defining crops' water requirement and irrigation scheduling, thus resulting in significant improvement of irrigation efficiency, and saving of water resources destined for irrigation.

The study pinpointed that the need for extension in using agrometeorology in irrigation management in and nowadays semi-arid areas is imperative as water scarcity in the Region becomes increasingly critical. Yet, the use of agrometeorology is still so far very limited due to number of constraints such as:

- a) Lack of adequate infrastructure for operation and maintenance of agrometeorological networks.
- b) Inadequate spatial distribution of agrometeorological networks.

Sandy Soil Reclamation Research

The study aimed at identifying the on-going research in the field of sandy soil reclamation and also identifying the pressing problems and constraints facing reclamation processes. The adaptation of appropriate technologies will help in solving such problems and overcome constraints.

The study reviewed modern irrigation methods which could be used in the reclamation processes in addition to mechanical and chemical methods. The chemical methods include use of petroleum by-products. The biological methods in soil reclamation include usage of plant residues and animal by products to improve the physical properties of the soil and raise plant tolerance for salinity.

The study found that the most appropriate technologies suitable for reclamation of sandy soils in dryland development is by using organic fertilizers, plant residues and sawdust to improve the physical condition of the soil, in addition to the synthetic additives which were incorporated in to the soil. Synthetic additives include polymer, bitumen, and poly-cations which make direct electrostatic linkage with the sand particles.

New Technologies for Biological Fertilizers

The study highlighted the new technologies used worldwide in the field of production and application of biological fertilizers. It discussed the types of the organic and chemical fertilizers and emphasized the positive and negative effects of their application on the ecosystem and their economic importance. It also discussed nitrogen fixation techniques, industrial fermentation and production of biological fertilizers, whether from animal by product or plant residues. It was found that application of organic fertilizer improves the

physical condition of sandy soils and water-holding capacities by about 200%.

The integrated fertilization techniques (combining chemical and biological fertilizer) are essential for conservation of soil fertility, reduction of costs, and conservation of environment.

Problems of Sustainable Development

The study aimed at examining the impacts of agricultural development on the environment and also the environmental influence on the agricultural development process. The study discussed the balance relation between agricultural development and the environment which guarantees sustainable agricultural development on one hand and preserves environmental capacity as a renewable resource on the other hand. The study reviewed policies and legal instruments as well as project proposals based on the principles of sustainable agricultural development.

Degradation of Arab Rangelands

The study indicated that there are no accurate assessments of the size of deteriorated rangeland in the Arab Region. Destruction of the ecological balance and the last spread of desertification can be used as a measure of scope of rangeland degradation. The study examined the integrating relationship between the range deterioration and the destruction of the overall ecological balance and the speedy spread of problem of desertification of Arab Region. It reviewed the different methods and techniques which are suitable to be used in the field of rangeland rehabilitation and development.

Environmental Impacts of Agriculture Development

The study attempted to investigate the environmental problems associated with agricultural development in the Arab countries, considering its causes, features, and spatial extent, together with their impacts on agricultural development at large. The study also considered the mitigation measures taken to address these problems, and the cost and benefits of these measures. The study recommended actions, which are socially, economically, politically, and institutionally possible and acceptable to help decision- and policy-makers in their efforts to achieve sustainable development. The approach followed in the study is considered positive in the sense that it describes the problems and recommends possible solutions.

Natural Resources Inventory

The aim of the study through standardized geo-referenced database for sustainable agricultural development, planning and environment conservation was to complete, standardize, organize, and make ready available resource data on soils, water, land vegetation and climate in the Arab Region, in order to achieve a more efficient and sustainable utilization of the land and to

conserve the environment. The study showed that the present problem in land use was related to the various physical and chemical constraints of the soils, excessive irrigation and over exploitation of the land and water resources. This has led to salinization, desertification, and land degradation.

Inter-regional sustainable development requires a regional approach based on an interregional system for the exchange of resource data. The establishment of Geographic Information System (GIS) and their component resource databases enable the systematic and comprehensive storage and retrieval of all necessary data. Introduction of this technology would strongly enhance the organization of natural resources data and application to regional and national resource studies, planning, and strategies. The proposed project will enable application of the results and quantified interpretation of the available maps to follow-up projects related to land-use planning, determination of rangeland, forest areas, land salinization, and desertification.

Project Implementation

This category of activities include projects which has been implemented by AOAD as a result of its cooperation with international and regional organizations, together with cooperation of institutions at the country level.

Green Belt Project in Arab Region

The green belt project aims to draw up, develop, implement and follow-up a joint environmental, development regional plan which includes *integrated, pilot and model activities to combat desertification and restore the biodiversity in the arid and semi-arid areas with the participation of the population living in the areas adjacent to the project. The project activities include integrated afforestation, improvement, and development of rangelands and forests, fixation of sands, improvement, and stabilization of rainfed crops, development of wildlife, and expansion of the green areas.*

The project identifies the constraints which impeded the process of the green belt for the countries of North Africa, Arab Mashreq, and Arabian Peninsula, so as to overcome these constraints and enable the project to achieve its objectives in conserving plant natural resources, halting the spread of desertification, and making the arid regions green.

Biogas Technology in Syria and Tunisia

The project intends to introduce and disseminate biogas technology in rural areas in Arab countries through conducting research to determine suitable farm and domestic household digesters in order to overcome the problems related to energy shortage in such remote areas and to better utilize farm by-products.

The main objective of the project is to demonstrate, on the basis of an integrated research and development as well as technology transfer program, that the

application of biogas technology is *technically feasible, socially acceptable, and economically viable* in rural areas of Arab countries. The biogas produced by the utilization of crop residues as well as animal and human wastes will provide a major portion of the residential rural energy requirements.

Soil Disinfection through Solarization in Lebanon

This projects aims to use solar energy for soil disinfections, especially in greenhouses or open fields through covering the land with polyethylene sheets. This work should be done before starting the cultivation process during the summer (July-August) when the temperature reaches its maximum. Scientific research and results have proven the efficiency of soil disinfection through solarization instead of using chemical and pesticides, which may have dangerous consequences on the environment and health.

Solar Energy for Domestic Use in Rural Areas of Tunisia

In order for solar energy to play a nationally significant role in the rural household sector, the AOAD proposed use of solar energy technology to cover the rural energy needs for the three main use in *rural household, cooking, heating and lighting.*

There is an increasing demand for the use of renewable energy sources in rural areas to reduce firewood consumption and thus reduce the rate of cutting of trees in the fragile ecosystem.

TECHNICAL CONSULTANCIES

The AOAD responds to member countries requests and recruit highly qualified Arab experts to undertake short-term consultations on specific agricultural problems.

Soil and Land Reclamation in Qatar

The consultancy attempted to collect and interpret the available data that have been collected in the survey areas in State of Qatar. The data include detailed information about types of soils, evaluation of land characteristics and qualities, land utilization types and uses, irrigation water quality, in addition to training of the agricultural cadres.

Treated Domestic Sewage Effluent used for Irrigation in Bahrain

Although using treated effluent for irrigation over the years has not caused serious problems, one of the aims of the consultancy is to study all aspects of sewage effluent and propose appropriate standards. The treated sewage effluent is used to meet the increasing demand for irrigation water and conserve other water resources from depletion. The study follows the physical, chemical and biological changes of concentration of different

elements in the soil crops, surface, and ground water when using treated domestic sewage for fear of contamination.

Strengthening Sub-Regional National Capacities

The paper was submitted and presented by AOAD at the international expert group meeting for the preparation of a sub-regional action Program in Western Asia to combat desertification. Participants encouraged and supported joint cooperation of the Western Asian countries in the field of exchanges information and experiences relative to their on going efforts to combat desertification at the national level. They concluded that four thematic programs networks (TPNS) should be established and coordinated by the sub-regional institutions as well as the United Nations Agencies, other major actors and "grass roots" organizations to participate in the development of SRAP in Western Asia.

Conference on Preserving the Arab Environmental Resources

Participants highlighted the importance of preserving and developing the environmental resources. They evaluated the present status of the environmental resources in the Arab countries, specifying all constraints and hindrances facing strategies for protection and development of these resources. They stressed the importance of the role of rural women on preservation of agricultural environmental resources. One of the main recommendations of the conference was conservation of biological biodiversity and genetic resources for the natural balance in the biosphere. Participants examined different methods and techniques which were suitable for use in the field of conservation, *rehabilitation and development*.

The First Arab Symposia on Water and Desertification

The AOAD submitted and presented a paper on the role of strengthening efforts to combat desertification under limited water resources. The paper tackled the advanced proper technology to halt the spread of desertification and degradation. The paper evaluated the current modern irrigation techniques used to conserve natural resources and arrest the process of desertification.

Development Benchmarks and Indicators

The AOAD submitted and presented a support paper of the international expert group meeting in Muscat. The paper defines the terms "Benchmarks" and "Indicators" and reviewed the status of existing instruments used in countries of West Asia region for desertification-process monitoring and desertification-impact assessment. AOAD proposed a method of selection of common problem (s) among the countries of the region, which covered a wide area representing most ecosystems and landforms. This was followed by application of the ecosystem-based resource management involving the required specialists.

Regional Conference on Agricultural Residue and Recycling Technology

The paper dealt with developing alternative uses of plant residue in fields like paper manufacturing, and woods or biomass production. The paper reviewed the experiences of some countries such as Syria, Iraq, Palestine, and Jordan which adapted some programs to encourage research work in energy conversion, paper manufacturing or organic fertilizers. The real problem lies in the development of technology to be adopted for easy and economic use of any one of these resources. The paper took into consideration the balance between resources utilization of plant residues at one hand and soil nutritional demand provided by crop residues on the other hand.

Expert Meeting on Legislation Pertinent to Environment

The paper reviewed the current legislation and laws concerning environmental protection in the Arab countries. The paper discussed the main legislation and institutional constraints facing the protection and development of environmental resources. The present policy and legislation proved to be inadequate to organize agriculture, irrigation, and other activities. There are some of the environmental related components not covered directly by legislation and laws, like protection of air from pollution, wildlife, soil, plant genetic resources etc.

SYMPOSIA AND SCIENTIFIC CONFERENCES

Symposia, conferences, regional workshops, and training courses constitute important activities of AOAD in the area of natural resources protection and development (Fig. 1). During the period of 1998 and first half of 1999, AOAD conducted 61 regional symposia, conferences, training courses, which is more than it conducted during the period of 1994-1997, about 59.

Figure 2 shows that the number of participants in those activities during 1998, and the first six months of 1999 (about 1493) are more than participants during the period of 1994-1997 (about 1038).

Potential Adopted Technologies to Meet Dryland Development

Dryland agriculture in the Arab Region is based either on traditional or non-traditional systems; technologies used are mostly dependent on manpower and these technologies are no longer adequate for developing and improving dryland in the Arab Region. Mechanization, in addition to using chemical and biological technologies, is expected to realize vertical expansion.

Scarcity of productive drylands, low dryland services, economic and social infrastructure, and adoption of new technologies are among the factors governing the choice of models of technological dryland

development. Some Arab countries are unable to adopt new technologies, thus leading to a technology gap for dryland development. This will eventually affect the competition of agricultural dryland producers in local and international market.

shrubs plantation in some Arab countries, and developing range cooperative, besides establishing wildlife reserves.

The following policy recommendations of AOAD strategy aim to conserve and improve agricultural

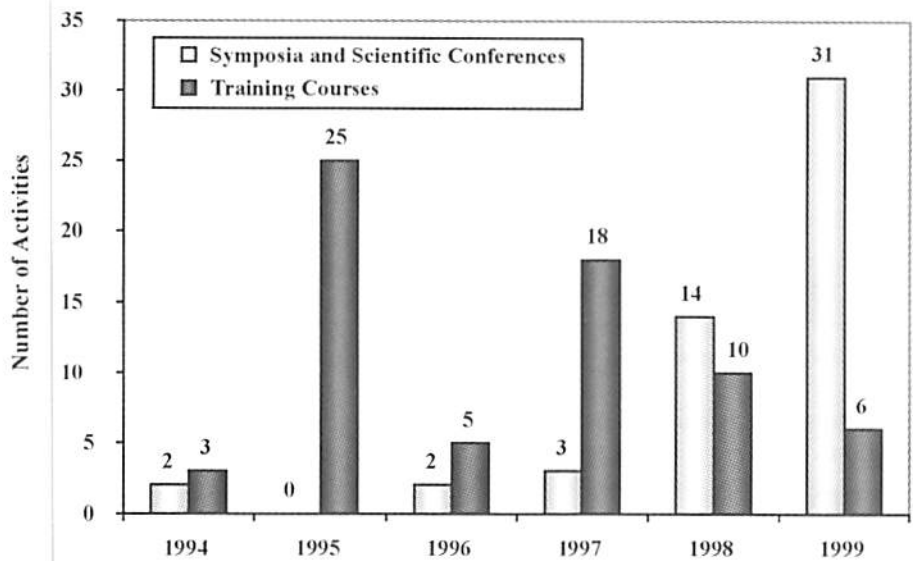


Fig. 1. Specified symposia, conferences, and training courses on natural resources protection conducted during the period 1994-1999.

Modernization of dryland development technologies emerges among the top challenges. The changes imposed by world economy, make it necessary that drylands conservation should be related to the ability of agricultural dryland producers to compete in the local and international markets.

Strategies for Dryland Development

Continued dryland degradation to year 2025 will present problems in Arab Region. Dryland degradation poses a significant threat to food security, local economic activity and important environmental products and services. Future strategy interventions should focus on such hot spots. Many bright spots for improving dryland qualify hopefully to be identified. Priority concerns to year 2025 will increasingly relate to environmental damage to drylands in Arab Region, i.e. deforestation, over-grazing, water issues, and or chemical pollution. This degradation is expected to continue to be linked with food security problems and to lack of technologies for sustainable agricultural intensification in areas of rapid population increase. The principal degradation problems are those that threaten irrigated food supply (salinization), and the livelihood of the poor dryland areas (devegetation).

Generally speaking, in the Arab Region, degradation of soil and vegetation of drylands is widespread. Water erosion and declining soil fertility are major processes of dryland degradation in addition to wind erosion, percentage waterlogging and salinization. The recent bright spots, for agricultural dryland are the installation of modern water-harvesting technology,

drylands:

- a) Improve information systems for land management.
- b) Increase research and technology development for land improvement.
- c) Promote investment in dryland improvement.
- d) Modify property rights to encourage long-term dryland investment.
- e) Support local organizations to manage dryland resources
- g) Develop marketing infrastructure.
- h) Encourage rural income growth.

CONCLUSIONS

The drylands deterioration could indeed be a potentially serious threat to food production by the year 2025. Further expansion of cultivation into areas of fragile soils or critical habitats of biodiversity preservation can lead to significant environmental deterioration unless carefully managed. Poor agricultural drylands management in 2025 could also threaten water availability, quality, and human health. It is urgent that policy-makers assess the types of degradation issues that will be critical in 2025. AOAD, in collaboration with other sisterly organizations-and the international community, can play a catalytic role in promoting such planning, supporting research, and development of information systems, and comparing expenses of Arab states with different policy strategies and policy instrument.

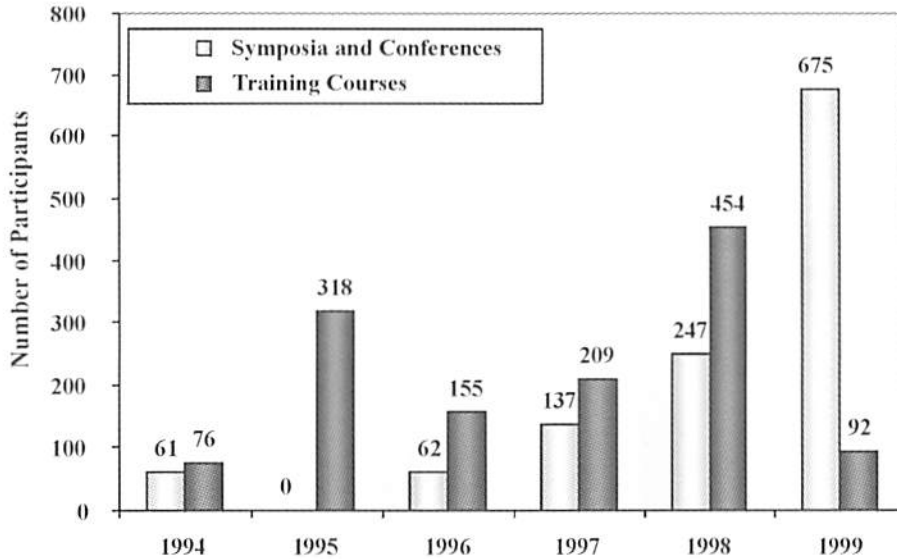


Fig.2. Number of participants who attend specified symposia, conferences and training courses in natural resources protection

REFERENCES

- Abdella, T.E.B. 1999. Soil malnutrition and holistic approach for sustainable soil use. 10th International Soil Conservation Organization (ISCOP) Indiana, USA.
- AOAD, 1996. Environment protection and natural resources development program (1997-1998).
- AOAD, 1996. Objectives and achievements with special emphasis on environmental issues.
- AOAD, 1998. Role of AOAD in conservation and sustainable use of plant genetic resources for food and agriculture.
- AOAD, 1996. Achievements and work plan (1997-1998) and suggested proposals for cooperation with International Irrigation Management Institute (IIMI).
- AOAD, 1996. Strengthening the role of rural women in sustainable agricultural development of Arab region. World Resources Institute, 1995. Environment Indicators.
- AOAD, 1995. AOAD paper on experience and efforts in higher agricultural education and research and its future role in agricultural and environmental sustainability.
- ACSAD, 1998. The green belts projects in the Arab Region.
- AOAD, 1998. Study on suitable modern technologies for forest wealth development in the Arab Region.
- AOAD, 1998. A study on the advanced technologies for production and use of biofertilizer in the developed countries and the possibilities of their application in Arab countries.
- FAO, 1976. Prognosis of salinity and alkalinity.
- AOAD, 1999. Environmental protection and natural resources development program, work plan.
- AOAD, 1999. AOAD efforts for development of adopted technologies, for desertification control in Arab Region. 1st Arab Conference for Water and Desertification, Cairo 17-19 April.
- AOAD, 1999. Natural and regional coordination supporting capacity building of remote sensing for agricultural development in Arab Region.
- AOAD, 1994. Environment effects on Arab Region agriculture.
- AOAD, 1999. Environment protection and natural resources development program, work plan.
- AOAD, 1999. Work plan, human development program.
- AOAD, 1999. Work plan, scientific research, and technology program.
- AOAD, 1999. Program on monitoring the impact of regional and international changes in Arab agriculture.
- AOAD, 1999. Arab food security program.
- AOAD, 1999. AOAD efforts for development of adopted technologies, for desertification control and rehabilitation of degraded lands in Arab Region (**in Arabic**). 1st Arab Conference for Water and Desertification, Cairo 17-19 April.
- AOAD, 1999. Study on environmental impact assessment for soil pollution and land degradation (**in Arabic**).
- AOAD, 1999. Interrelated impacts between the environment and agriculture development in Arab Region (**in Arabic**).
- AOAD, 1999. National and regional coordination supporting capacity building of remote sensing for agricultural developments in Arab Region.
- Scherer, S., and S. Yadav. 1996. Land degradation in the developing world implications for food, agriculture, and the environment 2020. Food, agriculture and the environment discussion paper. International Food Policy Research Institute.
- Scherer, S. 1999. Soil degradation, a threat to developing countries food security by 2020. International Food Policy Research Institute.

Agricultural Development Strategy for Remote Desert Areas in Egypt

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ABSTRACT

The present and future development plans of Egypt call for the integrated development of vast desert regions, mostly in remote areas, to meet the increasing food demands and promote the migration of population to the newly developed areas. Through the last few decades, Egypt has gained considerable experience in the various fields of desert development. However, the greater majority of the newly developed desert areas were adjacent or connected to the old Nile Valley systems. The large areas earmarked for present and future developments are remote desert areas, which require the adoption of a strategy that varies considerably from that of the development of areas adjacent to the Nile Valley.

The proposed strategy addresses, in an integrated way, the rational for use of limited and mostly non-sustainable water resources, use of land resources of varied limitations, appropriate cropping patterns, use of inputs and processing of products, energy requirements, and socio-economic and manpower developments. The strategy takes into consideration: (i) The relevance of development patterns to the potentials and constraints of the available natural resources; (ii) The main controlling factors relevant to technical, economic and social aspects; (iii) Integration with possible non-agricultural activities; (iv) Flexibility to meet the ever-changing variables of world trade and economic conditions.

It is of paramount significance for the planning and execution of these developmental activities to adhere and adopt integrated measures to minimize the environmental impacts of factors of degradation, processing and recycling of wastes, combating pollution of the available resources to achieve sustainable development and sound environmental conditions.

INTRODUCTION

Agricultural development of desert areas in Egypt started in the fifties and gained momentum in the sixties. The main driving force behind these developments was the long-term storage of Nile water through the construction of the High Dam, leading to the saving of huge quantities of water. These additional water resources were used to reclaim and develop over one million feddans (acres) in the desert areas adjacent to the Old Nile Valley, especially in the fringes of the Delta. The development involved vast areas of desert land. The main systems of irrigation, energy, communication, and marketing were extensions of those of the

Old Nile Valley, and still are interrelated and connected.

Other concurrent experiences of macro-scale desert area development were those in the New Valley in the Western Desert of Egypt, where developments were based on groundwater resources, mainly of the huge Nubian Sandstone Aquifer, that were subject to developments for the expansion of the limited cultivated areas in the Old Oasis. This Old Oasis had limited infrastructure with limited access and connections with the Old Valley in Upper Egypt.

Elaborate and diversified developmental activities of desert areas of varied characteristics, constraints, and potentials were encountered over a span of three decades; there were many success and failure stories, experiences gained and manpower developed. Such experiences were developed under changing economic conditions, the role of State and, significance of the role of private sector. These controlling factors varied considerably over the years starting from the fifties through to the eighties. It started with the complete domination of the State's role, including planning, capital investment, execution, and management, and ended up with ever-increasing role of the private sector. Policies of resource use and management varied considerably at the field level to address the varied socio-economic conditions. The approach and regulations of land allocation and migration of population and personnel to the newly developed areas also varied over time, types, and scales of development.

Among the significant features of accomplished desert developments are the surge of desert-related scientific research activities, field surveys, data compilation, testing of relevant new technologies and application of new cropping systems. No doubt, the experiences gained through the desert development activities in these four decades have given Egypt a great wealth of knowledge, expertise, and capacity-building of the relevant State and private organizations, institutions, cooperative societies and private investors at the various levels. In the eighties, more desert developments were called to meet the demands of an ever-increasing population. The objectives of these developments were to help to alleviate the population pressure mounting on the limited area of the Old Nile Valley, in addition to the creation of increasing job opportunities since agricultural developments are among the most labour-demanding activities.

Presently, large national projects in several desert areas are earmarked for development. These desert areas are in remote locations in the Western Desert and Sinai, with very weak or non-existing connections to

the Old Nile Valley systems. In most cases, these areas are different from the previously developed areas with respect to resource base and accessibility. Water resources are of varied quality compared to the Nile waters and, in many cases, of limited duration. Arable land resources are varied in nature, extension, and accessibility. Those in remote deserts are practically void of infrastructure and population and, in most cases, represent isolated ecosystems of distinct characteristics. Therefore, the rational and sustainable development of these areas require the adoption of a strategy that differs considerably from that of the development of areas adjacent and interconnected to the Old Nile Valley systems.

MAIN CONCEPTS

Development of remote desert areas in Egypt involves potentials, constraints, and basic attributes. The ideal development systems would maximize the potentials, minimize the constraints, and take into consideration the basic attributes.

Potentials

These include the promotion of migration of population from the limited and densely populated areas of the Old Valley to the newly developed areas. The significance of such migration is enhanced if we have in mind that it is projected that the population of Egypt would reach 90 million by the year 2025, when population stability is expected to be achieved. The development of the new areas would create new societies with large and diversified job opportunities in the fields of agriculture, industry, urbanization, tourism, services, and others. Such job opportunities are badly needed, especially for the younger generations who graduate in huge numbers from varied levels of education. Among the anticipated potentials is to help to improve food security, further development of the national economy, and reduce the deficit in the agricultural trade balance.

The development of virgin, and in many ways, confined ecosystems, would represent a definite advantage over the development of ecosystems that are riddled with environmental problems in the form of pests, weeds, and active factors of degradation, including pollution from varied sources. Therefore, the feasibility of producing safe agricultural products based on environmentally sound practices is enhanced. If properly planned and executed, measures and regulations to safeguard and conserve the resource base, the ecosystem, and the living habitat could be applied and maintained in a sustainable manner. The need for innovative and non-traditional systems for developments of new areas could provide significant opportunities for diversification of traditional agricultural commodities produced in the Old Valley. This would lead to improved possibilities of exporting commodities that would contribute to improved national trade balance.

Constraints

These mainly include the remoteness of location and limitation of accessibility, which imposes constraints relevant to the availability of the infrastructure, ease of communication, means and costs of transporting inputs and produced commodities, as well as marketing possibilities. Among the major constraints in areas relying solely on groundwater, resources are the limitation of resource quantity, availability, projected duration of development, the anticipated changes in cost of water extraction, and sustainability of the whole process.

The economic feasibility of agricultural developments in these areas requires the proper choice of farming systems that will ensure the maximum economic returns while sustaining the development of the reclaimed lands. The need for providing added socio-economic incentives to attract and promote the migration of the younger generations with suitable qualifications. Improved and appropriate living conditions in areas of mostly harsh climatic conditions are essential. Among the constraints is the provision of infrastructure and energy requirements for developmental activities and innovative techniques to use the available renewable energy resources. Other important requirements include the availability of human resources of certain skills and capabilities.

Basic Attributes

Among the major attributes of the areas to be developed are the characteristics of water, soil, and agroclimatic conditions.

Water

Water resources vary considerably from one area to another. In Northern Sinai, an estimated 400,000 feddans are to be reclaimed using the water conveyed by the Al Salaam Canal, which is a mixture of Nile and agricultural drainage waters with no anticipated limitations to sustainability. In other areas of Sinai, development would depend mainly on groundwater of varied quality and salinity levels, in addition to the possible harvesting or water spreading of the limited rainwater to enhance agricultural development and minimize the hazards of flash flooding. On the other hand, the water resources of East Owienat, Western Desert Oasis, and Darb Al-Arbien are groundwater resources (Nubian Sandstone Aquifer) of mainly good quality, but with limited sustainability since it is considered a non-renewable water resource.

Soils

Types of soil and their properties in these areas are highly influenced by geomorphic and pedogenic factors. The main features of the desert areas are poor soil fertility, and low nutrient-supplying power of most macro-nutrients, and especially micro-nutrients, very low organic matter content, alkaline pH, and inferior physical properties and moisture characteristics related

mainly to the textural variation, with dominance of the coarser soil classes. Other features, in many areas, include high CaCO_3 , high salinity contents and, in some cases, gypsum. Physical constraints are mainly due to hard pans, which are formed at varied depths of the soil profile under the influence of many cementing agents, including CaCO_3 , amorphous oxides, and soil compaction. The characteristics of these resources vary considerably from one location to another, due to the mode of formation, mostly wind deposition of varied sediments, in addition to impacts of terrain attributes.

Agroclimate

Agroclimatic conditions are variable from one location to another. The main variations from the northern areas of Sinai to the southern region in the Western Desert are in the annual rainfall, temperature averages, wind speed, and direction. Therefore, the severity of aridity increases towards the southern border; extreme variation in temperature and very high evapotranspiration are encountered.

Proposed Strategy Objectives

The main objectives of the agricultural development of remote desert areas can be summarized as follows:

- Sustainability of agricultural development.
- Contribute to the national economy and enhance the national food security.
- Maximize potentials, minimize constraints, and take into consideration the basic attributes of the available natural resources.
- Provide for the appropriate allocation, rational use, and efficient management of the resource base.
- Conservation of the ecosystem and improvement of living habitats.
- Production of safe commodities with assured qualities to meet the requirements of World Trade regulations, export specification and the future economic challenges.

PROPOSED STRATEGY: MAIN FEATURES

Integrated Planning

Integrated planning of agricultural development is a fundamental element for successful and sustained development. The strong interrelations and inter-dependence of the allocation, management and conservation of water, land, energy, human resources and other related activities, dictate the necessity of integrated planning from the very beginning, contrary to independent sectoral or sub-sectoral plans of development. Indeed, integrated planning should not be confined within agricultural development only, but it should include the overall planning for agricultural, industrial, and urban, infrastructure, services, touristic, and other components of development of a given area.

Basic to integrated planning is the availability of a credible information network and databases to be

established early on, including credible data relevant to assessment, surveys, and characteristics of available natural resources, climatic data, available infrastructure, previous developments, environmental aspects, and relevant studies and investigations. Such an information network and specific databases, should be compiled and geo-referenced using modern techniques, including remote-sensing, geographic information systems, and electronic databases.

The availability of such a database at the onset of development activities could serve as the important base for future and projected monitoring processes that are of vital significance for the assessment of rates of development achievements failures, "hotspots" and needs for mitigation. On the other hand, data and information at the beginning of development would be made available and verified as the processes proceed.

To formulate appropriate developmental alternatives and options, the need for credible data is complemented by the use of Decision Support Systems (DSS), and Expert Systems. The experts and expertise gained from the previous desert developmental activities in Egypt, lessons learnt from desert developments in other countries and regions of similar environmental conditions could contribute to formulation of appropriate developmental alternatives. Presently, there are available expert systems in the Agricultural Research Center for crops and cropping patterns and DSS for irrigation projects available at CEDARE, and other systems developed in other institutions in Egypt and abroad. Such systems will allow also for the inclusion of Environmental Impact Assessment (EIA) of the proposed developments. The inclusion of environmental considerations and EIA at the early planning stages is essential to identify and minimize the negative impacts and suggest the most effective mitigation actions.

The significance of the environmental considerations and EIA is enhanced under the conditions of development of desert areas in general, and remote areas in particular, in view of the fragile nature of the ecosystem, which responds rapidly to factors of developments and degradation. Therefore, the adopted patterns should enhance the processes of development and minimize the impact of factors of degradation. Such concepts will not reflect only on the technical feasibility, but will have significant impacts on the economic feasibility as well. The formulation of appropriate developmental patterns will facilitate the assessment and projection of the basic requirements for the proposed development plans, including investments, technologies, energy, and human resources.

Relevance to Resource Base

Water: Limiting Factor

Regardless of the nature of the available water resources in a given area, water availability will always represent the major limiting factor for all developmental activities, including agricultural, industrial, urban,

touristic, and others. Therefore, water resource allocation and use should be carefully planned in an integrated, non-independent, sectoral approach to achieve optimum rational use. As the areas to be developed would represent, in most cases, isolated desert ecosystems, therefore, careful consideration of the overall policy of water use per given area should include elements of conservation, proper allocation, requirements, losses, reuse, economic returns per unit of applied water, environmental consideration and impacts on the water resource base.

Water Resource Sustainability

Impacts of water sustainability on the developed area should be assessed on short, medium, and long-term bases. In areas where the projected plan of development is limited to a certain duration - Owienat development for 100 years - alternative scenarios for sustainability should be assessed and evaluated early on, taking into consideration that future technology developments could cut down on costs, and enhance economic and technical feasibilities. An area like Owienat after 100 years development, as planned, would reach the situation where the drawdown of groundwater within the developed area would drop down to a level making groundwater extraction unfeasible economically or technically. Options for sustainability of development could include the possible extraction and transport of groundwater from a non-developed neighboring area, reuse of treated wastewater, and other feasible future developments that would sustain the developed areas. The constraints and potentials of such options should be weighed against the abandonment of the developed area and migration of its inhabitants.

Water Resources Planning and Allocation

Agricultural development is by far the largest consumer of water resources. Agricultural activities should be planned based on the optimum returns per unit of applied water rather than the returns per unit of reclaimed desert area. Adoption of such an approach could allow for the consideration of cost of water extraction and its progressive changes as developmental activities proceed. Such approach would also help in appropriate evaluation of marketing and trade policies of the produced commodities in such areas. Rational use and optimum returns of water resources should be a major concept of the alternative farming systems to be applied. Farm management techniques, particularly methods of irrigation should be selected based on high water efficiency, minimum water seepage and atmospheric losses as well as maintenance of the depth of water-table in order to prevent the possible salinization and waterlogging of land resources.

Reuse of Wastewater

Appropriate plans for the reuse of wastewater including agricultural drainage, as well as urban and industrial

wastewater should be carefully considered. Cost-effective and modern treatment techniques of wastewater, including of bio-remediation for these waters, should be adopted to ensure that the quality of treated waters are appropriate for its possible reuse on a sound economical and environmental basis. Such an approach would mitigate many of the adverse environmental impacts of the reuse of such waters, especially the pollution of land resources and groundwater, the main water resource in many areas. The possible reuse of treated wastewater for the production of non-conventional crops, amenities, combating mobile sand and fixation of mobile sand dunes would have significant positive impacts towards combating desertification (El Bagouri, 1998). Many of such activities, aside from its anticipated economic returns, would have considerable positive impacts on microclimatic and environmental conditions.

Appropriate Farming Systems

The choice of appropriate farming systems and cropping patterns should be based on several concepts, including rational and conservative use of water resources, development of the poor fertility, and inferior properties of soil resources, minimal and complementary use of chemical fertilizers, which represent the most costly inputs in terms of production and costs of transport. In addition, irrational use of fertilizers and other agriculture chemicals (pesticides and herbicides) would cause pollution of the soil resources and the production of agricultural commodities of inferior quality and specification. The introduction of innovative cropping patterns and desert crops of low nutrient needs, water requirements and special products, (chemical, pharmaceutical, cosmetic, ... etc.) could be of great significance.

Agro-Industrial Processing

Agro-industrial activities complement the agricultural developments with the objectives of processing the agricultural commodities to enhance its economic values, reduce its gross volume, improve the feasibility of its transport, and reduce costs, and would significantly improve the economic returns. Meanwhile, agro-industrial wastes could be properly treated and recycled back to the reclaimed soils to enhance its development and productivity. Priorities should be given to agro-industrial processes capable of using renewable energy sources, i.e., solar, wind, solar/wind hybrid sources. These agro-industrial processes could include fruit preservation and processing, extraction of chemical ingredients and special products, as well as other processes.

Environmental Concepts

- Measures should be strictly adhered for the protection of the local ecosystems from the invasion of pests, pathogens, weeds, and pollutants that could

be communicated to the ecosystem through inputs, amendments, seeds, organic and chemical fertilizers and agrochemicals.

- The choice of agricultural techniques applied in the field should include environmental safety as a basic requirement, even if it requires added costs.
- Solid urban wastes, industrial wastes, water wastes, and hazardous wastes could be major sources of pollution to the ecosystem. Treatment processing and recycling of these wastes, through modern and proven techniques, could achieve the following: (i) Minimize the hazards to the ecosystem, (ii) Reduce the volumes of wastes to be disposed of, and (iii) Recycling would provide economic gains and usable commodities and materials.
- The early establishment of *Environmental Monitoring Systems* is of great significance to have early and rapid responses to possible environmental problems. With the use of proper environmental indicators, it is possible to have efficient monitoring and possible prediction and early warning systems of any adverse environmental condition. This would facilitate the adoption of appropriate mitigation measures.
- Assessment and conservation of endogenous flora and fauna and establishment of a local genebank is very important for present and future developments. Establishment of reserve and protected areas to safeguard the biodiversity should be addressed in the integrated planning in the areas to be developed.
- In view of the ever-increasing role of the private sector for development, the use of economic instruments, including tax reductions, incentive subsidies, disincentive measures and other economic instruments to encourage the use of environmentally friendly inputs, technologies and production processes with minimum pollution hazards and impacts. Environmental standards should be developed by relevant national institutions, including effective techniques of monitoring and enforcement.
- Wind erosion, mobile dunes and sand encroachment represent, in many cases, active environmental hazards of regional and local scales. Effective means to combat such land degradation factors should be implemented at both scales. The local scale could be handled by the local investors. The regional or area scale should be planned, coordinated and implemented at the early stages of development by national institutions and authorities concerned with environmental issues, with the participation of the parties concerned (farmers, investors, urban dwellers, ...). Cost-sharing devices and mechanisms could be developed and adopted.

Extension Services and Research Activities

The significance of the role extension services and research activities in the development of the desert

areas could not be stressed more. After the increased role of private sector in development, probably the most needed and important role of Government authorities and institutions is to offer effective, efficient, and environmentally sound extension services. Such services should be based on modern information, data, and appropriate expertise and research findings relevant to the various aspects of agricultural desert developments. The data and expertise gained through the previous desert developments through the last four decades in Egypt should provide a solid and fruitful wealth of information.

Research activities based on actual needs and demand should address technical and environmental problems encountered through developmental activities. Research on appropriate farming systems, cropping patterns, rational use of water resources, integrated land and water management, enhancement of the rate of agricultural developments, environmental issues and impacts of socio-economic concepts on production and marketing are among the major issues to be of interest. National institutes, research centers, universities, regional organizations and funding agents could cooperate to implement well designed and prioritized research programs.

Manpower Development

Training and capacity-building programs to develop manpower needs, especially for skills and qualifications in short supply, as well as orientation programs for personnel of varied categories, should be offered. On-the-job, training activities could be offered by relevant national institutes and specialized companies. The production of well-designed radio/T.V and press media programs for educational purposes and public awareness could be of considerable positive impacts. The development of disciplines needed for desert development in the educational institutes at various levels is required in view of the macro-scale national development projects in several locations.

CONCLUSIONS

Provision of the appropriate mechanism to implement the strategy is just as important as its formulation. It is proposed that an independent Managing Authority would be established for each macro-scale area. The Authority could be affiliated to the Council of Ministers as a strong link to all ministries concerned. The organizational structure of the Authority would include specialized committees formed of integrated disciplines and experts. Such committees should allow and encourage the participation of the main parties and local personnel concerned with the development of the area to secure the participatory approach in discussions, deliberations, and decision making relevant to management and development.

REFERENCES

- Abou Zeid, K.M. 1996. Introduction to decision support systems in water resources management. *CEDARE Publ.* Cairo, Egypt.
- Abou Zeid, K.M. 1996. Expert Systems: A set-up from decision support to decision-making systems. *CEDARE Publ.*, Cairo, Egypt.
- Abou Zeid, K., and M. Bayoumi. 1999. Environmental Impact Assessment Decision Support System (EIADSS) for irrigation projects. *CEDARE Publ.*, Cairo, Egypt.
- Academy of Scientific Research and Technology. 1989. Encyclopedia of Western Desert of Egypt. Cairo, Egypt.
- El Bagouri, I.H. 1992. Environmental protection and soil degradation. In Bishay A.(Ed.) Strategy for Sustainable Development in Egypt. UNDP Task Force. Cairo, Egypt.
- El Bagouri, I.H. 1994. Management of soil salinity under conditions of newly reclaimed desert soils. First Electronic Mail Conference on Soil Salinity in the Arab Region. CEDARE, Cairo, Egypt.
- El Bagouri, I.H. (Ed.). 1996. Alternative farming systems for the sustainable development of desert calcareous soils. DRC/NARP Joint Res. Proj. Egypt.
- El Bagouri, I.H. 1997. Recycling of TSE in agriculture - Experiences, potentials, and constraints. The Regional Workshop on Technologies of Wastewater Treatment and Reuse. Sponsored by UNEP (ROWA), CEDARE, ACSAD, and the Arabian Gulf University. Bahrain, 2-4 June 1997.
- El Bagouri, I.H. 1999. Pollution of Land Resources in the Arab Region: its Control, and Mitigation. AOAD Regional Workshop on Environmental Protection of Land Resources in the Arab Region. 19-21 June, 1999.
- El Bagouri, I.H., and A.A. Abu-Hussein. 1996. Areas affected by wind erosion and sand encroachment in the GCC states - A regional review. 2nd Electronic Mail Conference of Wind and Water erosion. CEDARE, 30 Oct.- 3Nov. 1996.
- El Bagouri, I.H., M. Wassif, and M. Afifi. 1995. The use and management of calcareous soils of various classes. Final Report. Academy of Scientific Research and Technology. Cairo, Egypt.
- El-Swaify, S.A., and D.S. Yakowitz. 1999. Multiple objective decisions making for land, water, and environmental management. World Association of Soil and Water Conservation, Pacific Regions. St. Lucie Press. N.W., Boca Raton, Fl. USA.
- ICARDA, 1998. Resource Management. The Nile Valley Regional Program, Phase II, ICARDA Regional Office, Cairo.
- Sherif, Y. 1998. Study on use of economic instruments for combating pollution from industrial sources. *CEDARE Publ.* Cairo, Egypt.

Impact of Desert Fringe Reclamation of the Nile Valley on Water and Soil Quality

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ABSTRACT

The interaction between human activities with water and soil quality has recently been studied in the sandy desert areas adjacent to the Nile floodplain. The area located west of Tahta, Upper Egypt, is subjected to intensive reclamation processes. The use of traditional irrigation techniques in the area affects the adjacent low cultivated land in the Nile Valley. In this work, water regime and the geochemistry of water and soil in the area have been investigated. Results revealed that land reclamation activity in the desert fringes led to changes in the groundwater regime and some water and soil chemical properties. Water losses from the irrigation system are mainly due to the non-suitable irrigation methods and subsoil types. Also, high flow of groundwater as seepage toward the adjacent traditionally cultivated land is inevitable. Such waterlogging problems led to soil salinization (with a dominance of chloride and sulfate salts) and consequently degraded more than 400 hectares (ha). The study strongly recommended future plan to avoid the waterlogging problems in the traditionally cultivated land. This could be essentially by installation of an effective drainage system in the reclaimed area and traditional land as well.

INTRODUCTION

After the construction of Aswan High Dam, additional surface water has been available for land reclamation. About 300,000 ha on the fringes of the Nile floodplain have been reclaimed since 1967 by surface water diverted from main canals. A few years after the reclamation and cultivation, drainage problems appeared in some areas of the adjacent traditionally cultivated land. Therefore, development plans for the Nile floodplain and adjacent desert fringes should effectively help to relieve the waterlogging problems prevailing in the traditionally cultivated areas and conserve the groundwater reserves in the desert (RIGW-IWACO, 1989).

This work aims to investigate the hydro-geological and hydro-geochemical relationships that may affect the changes in some water and soil chemical characteristics, that occurred due to land reclamation activities in Tahta area. It includes a variety of problems that can be solved through the development and management of water and soil resources.

PHYSICAL SETTING

Topography, Climate, and Land Use

The Tahta area is located in Sohag Governorate west of the Nile Valley on the desert fringes, adjacent to Tahta; a large reclamation scheme (2,000 ha) is implemented after the construction of the Aswan Dam. The reclaimed area is known as "West Tahta" between topographic contour lines 60 and 80 m above mean sea level, and about 20 m above the adjacent cultivated land.

The climate in Sohag Governorate is hot and dry in the summer, and cold with almost no rainfall in the winter. The average maximum temperature varies from 37.9°C in June to a minimum of 5.6°C in January. The average monthly evapotranspiration varies from 3.5 mm/day in January to 9.9 mm/day in June, while evaporation ranges from 2.1 mm/day in January to 8.3 mm/day June (Abdel Moneim, 1987).

The soil in the reclaimed area consists predominantly of fine sands, with clay and silt contents of 5% and 10%, respectively. There is salty clay in the adjacent old land. This soil structure is characterized by infiltration rates of about 0.66 m/day and 0.87 m/day in the cultivated and reclaimed land, respectively (Abdel Moneim, 1987). The major winter crops are wheat and berseem, while maize, cotton, vegetables, and fruits are the main summer crops.

Irrigation and Drainage

The traditionally cultivated land in the floodplain and the reclaimed zone in the adjacent desert fringes are entirely used for agriculture. The main source for irrigation in the floodplain is surface water diverted from the Nile River and the main irrigation canals, namely West Nag Hammadi, El Girgawia, and El Tahtawia canals.

Flood irrigation is the predominant irrigation method. The frequency of water application is twice a month in winter and four times in summer. The drainage system is mainly represented by the Tahta Drain. To the west of the floodplain at Nag El Hish area, the surface irrigation water is raised from Kombadr Canal to the new reclaimed areas by using four electrical pumping station, which are connected with each other by transport canals. This water is distributed to the area through three canals, and is applied to the farms on a rotation basis. No drainage system exists in the reclaimed area, while along its boundary with the traditionally cultivated land, and interceptor channel has been dug to capture seepage water.

The groundwater in the floodplain represents an auxiliary source for irrigation, domestic, and even industrial purposes. In the desert fringes, irrigation with groundwater is limited to those areas at the tail ends of canals and to the extension of the desert.

Hydrogeology

Geometry and Hydraulic Parameters

In the desert fringes, the aquifer is unconfined, consisting of Quaternary graded sand and gravel with intercalation clay lenses, while in the floodplain the aquifer is semi-confined capped by clay-silt. The aquifer system is faulted against the Eocene limestone in the east, and is underlain by Pliocene clays.

The thickness of the aquifer varies from 150 m in the central part of the floodplain to about 50 m in the desert fringes. The average hydraulic conductivity of the aquifer is about 70 m/day, whereas the average hydraulic conductivity of the semi-pervious top layer to vertical flow is about 4 cm/day (Attia, 1985). The transmissivity coefficient of the aquifer ranges between 4000 and 6000 m²/day (Abdel Moneim, 1987).

Groundwater Flow and Depth

Simplified hydraulic profile of the water-table map of the aquifer is based on the data from existing observation and pumping wells. The main flow direction in the floodplain follows the northeast and east near the Nile. The groundwater is available at depths varying from 0.5 m below the ground surface. It is highly dependent on the topographic elevations and the water level in the irrigation canals and drains.

In the desert land, the depth to the groundwater is 10 to 30 m. The main component of groundwater flow is to the east. Most of the groundwater flow is not affected by the interceptor drain (Kombadr drain). Accordingly, the traditionally cultivated land is above the groundwater leakage from waterlogging. This leads to an upward groundwater leakage from the aquifer through the semi-pervious top layer. Furthermore, the evaporation processes causes major salt marshes, giving rise to salinization and crusting in these lands.

The waterlogged area extends over a distance of 8 km (south-north), with an average width of 0.5 km covering an area of 500 ha unproductive acres. This area is expected to increase due north, south, and east directions with time, due to the continuous seepage of groundwater from the reclaimed area.

GEOCHEMISTRY

The geochemical evaluation of water and soil in the studied area was determined through major ion analysis. Surface water samples were collected from the irrigation system, nine groundwater samples from shallow wells in the floodplain, and five samples from productive wells in the reclaimed area. Three soil profiles with varying depths of 50, 100, 150, and 200 cm from the

ground surface, respectively, were selected. These samples from each profile were water-logged.

In the field, water temperature, conductivity (EC), and pH values were determined. Laboratory work, including chemical analyses of major ions for water and soil extracts samples were carried out at the Geochemical Laboratory of the Geology Department, Assiut University (Rainwater and Thatcher, 1960; Jackson, 1973).

Water Chemistry

The water chemistry exhibits large spatial diversity. In the reclaimed area and adjacent desert, it is brackish water (TDS ranging between 1292 to 3200 ppm), and of sodium-chloride type. The salt assemblage is: NaCl, MgCl₂, MgSO₄, Mg (HCO₃)₂, and Ca (HCO₃)₂. The origin of this water is not easy to explain. It could be either mixture of surface runoff from the wadis and infiltrated surface water, or connate water.

On the other hand, the chemistry of the groundwater in the Nile floodplain shows that the salinity of groundwater varies from 802 ppm in the east to 1045 ppm in the west. The water samples are differentiated into two groups. The first group includes those samples that are located at the boundary of the adjacent reclaimed area, and the second group includes those samples near the Nile River. The second group has water salinity ranging between 822 and 910.

The main salt assemblage is NaCl, Na₂SO₄, NaHCO₃, Mg (HCO₃)₂, and the water type is bicarbonate-calcium. This water is related to the infiltrated surface water from canals. The first type is chloride or sulphate sodium. The salt assemblage is mainly represented by NaCl, Na₂SO₄, MgSO₄, Mg(HCO₃)₂, and Ca(HCO₃)₂. In contrast, this group is higher in salt content, while chloride and sulphate ions prevail and the salt assemblage includes MgSO₄ as a new type.

These chemical variations between the two groups are mainly attributed to the different rates of seepage and drainage in various parts of the area. In the west, the relative increase in the salt content is due to the seepage of large amount of drainage water from the reclaimed area, which has a considerable content of soluble salts. This seepage water is also responsible for the rise of groundwater levels and waterlogging of soil over the tracts. The dry climate accelerates direct evaporation to be very effective, leading to the dominance of chloride and sulphate salts in the groundwater (NaCl, Na₂SO₄ and MgSO₄).

Based on the classification of the water types in Tahta area according to Piper, (1944), it is clear that the water samples from the floodplain, which are located at the boundary of adjacent reclaimed area, are close up to the water samples in the reclaimed area, while the water samples near the Nile related to the samples of the surface water.

Soil Chemistry

Chemical analyses of the investigated soils depict the effect of the water-table on the soil, soluble cations, and anions. Generally, there are no salinity problems in the soil Profile III (EC. 0.08-2.0 mmhos/cm), whereas salinity is serious problems in the soil Profile I and II (EC. 2.35-5.24 mmhos/cm). The cationic composition of the soluble salts revealed highest concentration of Na. Similarly the anionic composition, sulphate dominated the salts of the soil Profile I and II, and chloride salt dominated in Profile III. Remarkably, concentration of salts decreases with depth in all profiles. This is simply ascribed to deposition of salts in the surface layer.

SUMMARY AND RECOMMENDATIONS

The main points drawn from this study are:

1. The unsuitable method of irrigation used in the desert fringes of West Tahta has led to excess water, above the consumptive use of plants, which infiltrates through the sandy soil.
2. In land adjacent to the reclaimed desert area, the water flows eastward and seeps to the reclaimed desert area and traditionally cultivated land, and causes a rise of the groundwater levels and soil waterlogging.
3. In the waterlogged area, data of chemical analyses showed some changes in the chemical properties of the groundwater and soil deterioration. This deterioration is attributed to the change of both salt and water regimes.
4. Attempts must be made to lower the existing groundwater level by at least 2 m. It is recommended to improve and re-schedule the irrigation practices, and install a drainage system in the reclaimed area and traditional land. It is highly suggested to follow the changes in the chemical properties of the groundwater and soil, in addition to evaluating the methods of both irrigation and drainage systems.

REFERENCES

- Abdel Moneim, A.A. 1987. Hydrogeology of the Nile Basin in Sohag Province, M.Sc. *Thesis*, Geology Dept., Fac. Sci., Assiut Univ., Sohag Branch, Egypt.
- Attia, F. R 1985. Management of water systems in Upper Egypt. Ph.D. *Thesis*, Fac. Eng., Cairo Univ., Egypt.
- Jackson, M.L. 1973. *Soil chemical analysis*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey, USA.
- Piper, A.R., 1944. A graphic procedure in the geochemical interpretation of water analysis. *Trans. Amer. Geoph. Union. Trans.*, 25: 914-923.
- Rainwater, K.H., and L.L. Thatcher. 1960. Methods of collection and analysis of water samples. U.S. *Geol. Surv. Water Supply Paper*, 1454.
- RIGW-IWACO, 1989. Groundwater development for irrigation and drainage in the Nile Valley. Groundwater development in the area of West Tahta. Internal Report. *Tech. Note* 70. 124-89-50.
- RIGW-IWACO, 1990. Detailed hydrogeological map of the Tahta area (1:100,000). Research Inst. Groundwater, Min. Public Works and Water Resources, Cairo, Egypt.

Desertification Indicators of Arid Territories in Central Asia

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ABSTRACT

Water and wind soil erosion, vegetation destruction, deflation, and soil salinization, and reduction of organic matter content are the main natural processes causing desertification. Irrational human economic activity has an essential effect on desertification. Desertification processes cover many natural climatic zones of the planet, but only arid conditions favour the desertification because of the peculiarities of hydro-meteorological processes.

Environment quality depends on mutual interaction of biotic and abiotic components. Their change caused by external impacts disturbs ecological balance, and results in unpredictable consequences. The halo-agrochemical cycle is disrupted most essentially in the Central Asian region. It is explained by that fact that at present the Aral Sea cannot be a natural salt-receiver with surface flow because of the Sea drying out.

Consequently, the increase of mineralization of atmospheric precipitation and surface water is observed all over the territory; soil salinization is rising, and the concentration of aerosols of soil origin is augmented in the atmosphere of the region. Aerosols are being transported with air masses all over the region and fall on the surface of adjoined territories. Thus, desertification development in the region can be defined with the indicators characterizing dynamics of salt concentration change in the biosphere: soil, vegetation, dry and wet atmospheric fallout, aerosols, surface, and underground water.

INTRODUCTION

Taking the Aral Sea basin as an example, and in view of suggested indicators to evaluate the desertification development, we considered the dynamics of change of water-soluble salt concentrations in the biosphere in order to use this index as one of the desertification indicators. The most important characteristics of ecological state of the country are the characteristics of soil quality. It should be mentioned that the population of Uzbekistan has increased 2.7 times during the last 35 years. At the same time, the irrigated lands have increased only by 1.6 times. Augmentation of agricultural output has resulted from increasing the irrigated lands and their intensive chemigation. These processes have resulted in soil salinization and pollution by pesticides and heavy metals, decrease of humus content, and erosion development.

Intensive soil salinization in Uzbekistan is caused by two major factors: irrigation and natural processes, which are characterized for arid zone with complicated orography. About 50% of all irrigated lands in the country are saline and, in some cases, strongly saline.

The scale of the process is unequal. In the Upper Syrdarya and the Upper Amudarya, less than 10% of soil is saline, and in the Lower Amudarya, it is more than 95%. More than 50% of land is saline in Bukhara, Navoi, and Syrdarya provinces (Table 1).

In non-irrigated lands, it is difficult to control the processes of salinization. The investigation of dynamics of change of the dried area in the Pre-Aral region, caused by the processes of the Aral Sea drying out, has enabled to reveal the follows. Increases of the dried part of the Sea bottom and water salinity in the Sea are related with enlarging areas of Solonchaks located in the Pre-Aral region, Bukhara, and Navoi provinces (Table 2).

On the whole, all the above-listed processes have resulted in deterioration of soil fertility, i.e., a decrease of humus content from 2-4% to 0.5%, increase of soil salinity, already the indicator of desertification. Taking into consideration the relation between processes of soil erosion and wind deflation, it is necessary to note genetic dependence of chemical composition of aerosols and precipitation upon soil cover.

Chemical composition of aerosols in Uzbekistan is characterized by abnormally high content of water-soluble mineral salts. On the whole, chemical composition of aerosols can be characterized as natural, being of soil origin. Typical correlation between major ions in the soil composition are the same for aerosol particles composition. It testifies to the important role of soil in the formation of aerosols in surface atmospheric layer.

Over the territory of Uzbekistan, ion composition of aerosols of surface atmospheric layer is characterized by abnormally high content of water-soluble salts, from 10 to 20% and more. Hydrocarbonates, sulphates, chlorides prevail in anion composition, and Na^+ , Ca^{2+} , Mg^{2+} , K^+ in cation composition. Abnormally high content of water-soluble salts in aerosols increases chemical activity of the atmosphere. It has led to an increase of corrosion-inducing ability, and influenced the precipitation composition. Aerosols with such composition are active nucleic of condensation, which affects the change of hydrological cycle of cloud- and precipitation formation.

Table 1. Dynamics of salinization of irrigated lands of Uzbekistan¹

<u>Provinces</u>	<u>Survey²</u>	<u>Investigated Lands</u>	<u>Including Saline Lands</u>		<u>Highly Saline</u>	
		--10 ³ × ha--	--10 ³ × ha--	-%-	--10 ³ × ha--	-%-
Republic	I	450	430	95	250	55
Karakalpakstan	II	442	426	96	258	58
Andizhan	I	266	62	23	22	8
	II	226	69	30	28	12
Bukhara (Navoi)	I	355	336	95	102	29
	II	271	253	93	74	27
Dzhizak	I	269	175	65	101	38
	II	249	121	49	43	17
Kashkadarya	I	461	283	61	110	24
	II	422	287	62	72	17
Namangan	I	251	14	6	4	2
	II	208	32	15	23	11
Samarkand	I	333	49	15	6	2
	II	303	55	18	1	4
Surkhandarya	I	284	98	34	39	14
	II	263	114	43	38	15
Syrdarya	I	284	266	94	154	54
	II	271	253	94	145	54
Tashkent	I	360	37	10	3	2
	II	314	22	7	2	0.6
Fergana	I	323	48	15	19	6
	II	287	61	21	43	15
Khorezm	I	239	174	73	48	50
	II	212	136	64	20	24
TOTAL	I	3879	1971	51	853	22
for Republic	II	3468	1748	51	787	22

¹Data of the Institute "Uzgirozem" of Ministry of Water Economy, Republic of Uzbekistan. ²I. Soil-salt surveys conducted in 1982-1987; II. conducted in 1990-1992.

Table 2. Physico-geographical changes in the Aral Sea (1961-'95).

<u>Characteristic</u>	<u>1961</u>	<u>1993</u>	<u>1995</u>
Sea level	53 m	36.93 m	-
Water surface area (×10 ³ km ²)	66	33	32.1
Sea depth			
-maximum	66.1 m	50 m	-
-average	17.7 m	8.4 m	-
Salinity of water	10 - 11‰	35 - 36‰	41‰
Water volume	1 064 km ³	277 km ³	
Drying area	0	32,700 km ²	33,900 km ²
Solonchaks (adjoint territory)	98.5 km ²	4,292 km ²	

It should be mentioned that under the impact of the specific climatic and physical-geographical conditions, the concentration of mineral water soluble components in the atmospheric aerosols exceeds 2-fold maximum permissible values, and sanitary-hygienic standards, especially during dust storms and drifts. This factor has negative influences on population health, inducing higher sickness rate of upper respiratory tracts. Thus, abnormally high aerosols content in the atmosphere is one of the criteria of desertification. Aerosol particles are removed from the atmosphere with precipitation, due to turbulent diffusion and gravitation deposition (dry deposition).

Over the territory of Uzbekistan, chemical composition of precipitation is formed due to regional and local factors. Presence of closed drainage saline lakes (the Aral Sea and others), peculiarities of soil cover, and anthropogenic emission sources have a substantial influence on chemical composition of precipitation. In this connection, zoning of the territory of Uzbekistan according to chemical composition of precipitation (total minerals) presents an interest. The source of aerosol formation producing the components of marine salts (the aquatory and the dried part of the Aral and

Kara-Kum, which in turn have strong influences on formation of aerosols containing considerable amounts of soil components. The power of this source of aerosols is high, while the portion of soil ingredients in precipitation is high all over the region, including background stations. It should be mentioned that both of the considered zones are situated on the plain of the Central Asian region between 132 m (Karague in the South part of Mangyshlak) and 500 m above sea level. In the central part of the Kyzyl-Kum desert there are island mountains of 922 m (Tamdy-tau). Total minerals in the precipitation is from 70 to 200 mg/l.

The third zone of aerosol formation is situated in the mountain and foothill areas and covers the zone from 500 to 7500 m above sea level. The peculiarity of this zone is the presence of large industrial enterprises. Mountain ranges promote accumulation of admixtures in the surface atmospheric layer. Aerosols from the first and the second zones also get in this zone. More frequent precipitation is characteristic of this zone. Mineral content fluctuates from 20 to 30 mg/l at background stations and from 150 to 200 mg/l in the industrial zones (Fig. 1).

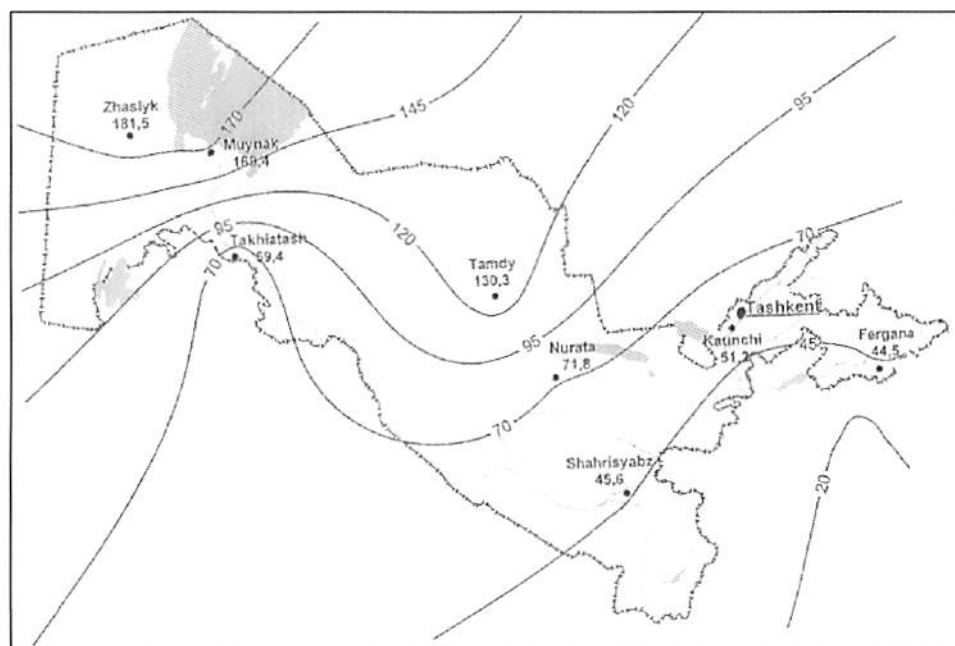


Fig. 1. Mineralization of precipitation (mg/l).

Caspian Sea) occupies a considerable area. These aerosols are transported with air masses a distance of 150-200 km in the coastal zone. An insignificant part of these components is further removed with air currents. Distance of transfer depends on physical factors: particle dimensions, dispersive state, and primary wind direction. Total minerals in precipitation is more than 200-300 mg/l.

Thus, the zone of formation of aerosols of soil components is located. It is situated on the territory of the two large Central Asian deserts, Kyzyl-Kum and

As has been noted above, gravitation dry precipitation - dry atmospheric fall-out (DAF) is a typical process of removal of aerosols of salts in arid zones. Stored experimental material has revealed a series of typical peculiarities of this process for the territory of Uzbekistan to assess the role of DAF as an indicator of desertification. Investigation of chemical composition of water-soluble part of mineral components of DAF on the territory of the region began in 1981, together with research of the processes of salt and dust transfer from the dried part of the Aral Sea. Sampling was

conducted on the current network of hydrometeorological stations according to the techniques worked out in SANIGMI and SANIIRI.

The DAF sampling has been conducted at the following stations: Muynak, Zhaslyk (since 1982), Takhiatash (since 1993), Buzaubay, Chagyl (since 1984), and Uyaly, Chimbay, Chabankazgan, Tamdy, Ak-petki in the periods of expeditionary investigations (1990-92). Chemical analysis of samples was carried out according to the technique worked out in SANIGMI.

Determined were percentage of water soluble and solid particles, pH, electro-conductivity, sum of ions, Na^+ , Ca^{2+} , Mg^{2+} , K^+ , hydrocarbonates, sulphates, chlorides, and nitrates (Table 3). The data obtained according to the average long-term values of pH, sum of ions, percentage of water-soluble and water-insoluble components in the DAF samples, sampled on the territory of the Republic of Uzbekistan are shown in the Table 3. Accordingly, pH value of water extracts of water-soluble mineral components from DAF samples are close to the data obtained for precipitation. For several stations, these values are less by one, what can be the result of the local factor influence: emissions of the enterprises, which are situated, near the stations and the peculiarities of chemical composition of soil cover.

Values of total minerals of water extracts from DAF samples also change in the wide interval from 280 to

1231.2 mg/l. On the whole, total mineral content of DAF samples is higher than of precipitation on the average by 2-5 times; at the stations situated close by the aquatory and the dried part of the Aral Sea at a distance not more than 25 km, mineral values range from 886 to 1231.2 mg/l. The highest values of minerals are observed at the Muynak station. High level of mineralization was observed at the Takhiatash station, caused by the impact of industrial enterprise emissions on pollution of DAF samples. Data obtained testify to the impact of process of salt and dust transfer in the coastal zone of the Aral Sea on the formation of chemical composition of DAF.

Analysis of percentage of water-soluble and water insoluble part of DAF samples has shown the follows. At the stations situated in the dried area (Uyaly, Ak-petki, Muynak), the removal from non-fixed part of the formed sand-solonchak desert exerts the main influence on chemical composition of DAF. At the Zhaslyk station we observed the increase of content of water-soluble part in DAF (to 61%), which can be the result of removal of sand and salt aerosol and marine salts from the aquatory to Ustyurt during dust storms. At the Takhiatash station the increase of water-soluble components was observed in DAF samples. It is caused by anthropogenic sources influence, as it has been mentioned above.

Table 3. Chemical composition of dry atmospheric fall-out sampled at the region stations.

Station	Total DAF	Sum: Ions	Na	K	Na+K	Mg	Ca	Cl	HCO_3	SO_4
-----kg/ha-----										
G. Abramov	294	106	1.16	0.25	-	39.4	19.6	12.9	8.2	4.4
Buzaubay	1060	346	50.62	20.90	-	25.8	33.6	36.4	158.3	47.6
Zhaslyk	522	331	28.47	11.71	-	20.3	30.1	87.0	55.4	93.8
Kuyumazar	583	471	-	-	28.5	60.4	43.0	88.4	140.8	110.3
Mashikuduk	378	144	-	-	14.0	2.7	4.2	17.8	91.5	13.8
Muynak	1108	351	27.70	1.82	-	27.3	40.4	41.0	88.9	132.6
Nur-ata	2508	366	11.09	3.32	-	19.2	28.0	29.6	206.8	55.4
Chagyl	410	310	9.64	2.14	-	13.7	26.1	27.3	180.1	37.7
Repetek	280	173	-	-	14.0	10.2	11.2	20.4	102.5	15.2
Bukhara	1061	213	-	-	16.8	23.8	32.8	31.2	58.1	50.7
Olot	643	184	-	-	13.6	17.3	11.5	19.6	98.1	24.2
Gizhduvan	322	262	-	-	17.0	29.0	23.3	26.9	118.9	47.6
Gazli	762	231	-	-	16.0	16.2	25.1	29.3	111.3	33.1
Peshku	1897	407	-	-	19.3	47.5	50.6	60.4	109.8	119.5
Karaul-bazar	1150	190	-	-	12.7	11.1	24.6	14.1	86.2	41.2
Tashkent	1420	151	-	-	11.8	8.7	12.6	23.8	82.3	12.3
Chatkal	426	164	-	-	12.5	9.4	13.8	18.1	89.4	20.7
Almalyk	1900	132	-	-	9.0	9.5	14.9	8.9	67.1	23.0
Tuaybuguz	1628	1481	-	-	492.7	49.0	146.7	63.5	550.1	32.6

The interesting data have been observed at the Chagyl station, situated at a distance of 260 km from the Caspian Sea and of 350 km from the Aral Sea. Evidently, head currents of salt of marine origin, transported with air masses, cause the presence of a high portion of water-soluble components just in this zone.

Change of anion and cation concentrations in DAF samples has revealed the following: Abnormally high contents of Na^+ are observed at the Muynak, Uyaly, and Chimbay stations, situated near the Aral Sea. The same situation is observed at the Chagyl station. Rather high Ca^{2+} content is marked at the Uyaly, Ak-petki, and Chabankazgan stations, situated close by the strong source of sand and salt aerosols in Ak-petki massif. The Mg^+ content in DAF samples is the highest at Chabankazgan, the desert station situated at a distance of about 75 km from the Aral Sea aquatory. Hydrocarbonate content in samples sampled at the stations changes in the following order: Chimbay, Takhiatash, Chagyl > Buzaubay > Zhaslyk > Chabankazgan > Muynak > Ak-petki > Uyaly.

At the stations situated near the aquatory, hydrocarbonate content decreases on the average by two times. The order of sulphate concentrations is as follows: Uyaly, Zhaslyk, Muynak, > Ak-petki > Buzaubay > Chagyl > Chimbay, Takhiatash. Taking into consideration the definite contribution of the dried zone and the aquatory in the formation of sand and salt aerosol composition, abnormally high sulphate content at the stations situated in this zone should be mentioned.

The highest content of chlorine ions is observed in the samples at Ak-petki, the former part of the Sea. Concentrations of Cl^- at other stations were in the following order: Ak-petki > Muynak, > Chabankazgan > Uyaly > Buzaubay > Takhiatash > Chimbay > Chagyl > Zhaslyk. Thus, there is some regularity of abnormally high Cl^- content in the samples taken at the stations situated in the zone of the influence of the aquatory and the dried part.

There is a genetic relationship between the status of components of biosphere. One of the most important indicators of environment status is the level of various components accumulated in plants. Migration and transformation of individual components are connected closely with the impact of different factors of anthropogenic and natural origination. During the last years on the territory of Bukhara and Navoi provinces, bio-productivity of pastures has been reduced; their condition has become worse. According to the view of some experts, one of the factors influencing the pastures condition is dust and salt removal from the dried part of the Aral Sea.

Complex analysis of the levels of accumulation of water-soluble components of mineral salts in the environment includes investigation of surface vegetation. During expeditionary investigations, sampling of plants was conducted in particular solyanka of Rikhter, wormwood. Chemical analysis of water extracts to define content of Na^+ , K^+ , Ca^{2+} , Mg^{2+} has been carried out.

Data obtained have shown that salt macro-component composition of plants depends on the place of sampling, time of year, type of plant, proximity to salt emission sources, and way of their getting into the plants tissue. Plants sampled on the territory of Bukhara province are characterized by slightly alkaline pH of the water extracts; Na^+ , K^+ , SO_4^{2-} , HCO_3^- , Cl^- predominant. Salt composition of sampled wild plants depends considerably on soil composition upon which they grow. On the other hand, salt with air masses exerts a definite influence. Plants were sampled in Navoi province (in the area of industrial gold exploitation) and Tashkent province, near by Almalyk town and Bukhara province. The samples in Navoi province are characterized by slightly acid pH, higher content of sulphates, hydrocarbonates, and Na in comparison with Bukhara samples. It is caused not only by the peculiarities of local soils, but also by the anthropogenic pollution impact.

Sulphate content has been defined in the samples on the territory of Tashkent province near Tashkent and Almalyk. In wild one-year grass, SO_4^{2-} content changed depending on the place of sampling and type of plant, in the range from 5.5 to 15 g/kg. In cotton, SO_4^{2-} content changed in the range from 25 to 50 g/kg. High content of SO_4^{2-} in cotton is caused by species features. On the whole, the samples of plants in this region are characterized by higher content of sulphates in plant tissues than plants sampled in Bukhara province. It appears to be due to location of sampling points, which are under the influence of industrial enterprise emissions.

On the whole, plants sampled on the territory of Bukhara and Navoi provinces are characterized by more high levels of mineral component accumulation than on the territory of Tashkent province, except the ones which are the components of industrial emissions (compounds of sulphur and fluorides). The results obtained while analyzing washoff from plants surface present a substantial interest for the assessment of atmospheric fall-out.

Comparative analysis was conducted for different sampling points; the average data has revealed the following: Values of pH change in the interval from 5 to 8. While approaching the Aral Sea, concentrations of cations Na^+ , Ca^{2+} , Mg^+ , and anions chlorides and hydrocarbonates become higher. Abnormally high concentrations of sulphates are observed nearby their anthropogenic sources.

Thus, it should be mentioned that levels of mineral accumulation in plants could result from the impact of local sources of salt and dust emissions and, to some extent, the regional features. Probably this technique of definition can be indirect confirmation of definite influences of salt and dust transfer on surface vegetation. Our experimental and theoretical investigations permit determination of some indicators of desertification of arid territories of Central Asia, which include definite

levels of water-soluble mineral components content in the biosphere. Suggested indicators for aerosols,

precipitation, soil, surface vegetation surface waters are shown in Table 4.

Table 4. Indicators of desertification, i.e., salinization water-soluble salts.

Aspect of Biosphere	Average level Initial stage	High level Intensive process
Atmospheric air	Water soluble salts	
Aerosols, %	5 - 10	10 - 20
Wet precipitation, mg/l	30 - 40	40 - 100
Dry atmospheric fall-out, mg/l	150 - 300	300 - 800
Soils, %	2 - 5	> 5
Plants, g/kg	10 - 25	> 25
Surface Waters, g/l	0.5 - 1	1.5 - 2

LITERATURE SOURCES

Gorelkin, N.E., G.A. Tolkacheva, and V.O. Usmanov. Hydrometeorological aspects of desertification. Proceedings of seminar "Days of National Realization of UN Convention to Combat Desertification in the Republic of Uzbekistan", Tashkent, 1998, p. 33-38.

Molosnova, T.A., O.I. Subbotina, and S.G. Chanysheva. 1987. Climatic consequences of economic activity in the zone of the Aral Sea. - M.: Gidrometizdat, - 119 p.

Temporary methodic instructions for collection of DAF samples. 1983 - Tashkent, Uzgidromet, - 20 p.

Tolkacheva, G.A. 1997. The influence of salt and dust transfer storms on the environment in the Central Asian basin. Fist JAS/WMO International Symposium on Salt and Dust Storms (JSSD-S-1) WMO/TD - N 864, Damascus, Syrian Arab Republic, 2-7 November 1997, p. 275-283.

Tolkacheva, G.A. 1999. Working out the Methodic Scientific Basis for Atmospheric Fall-Out Monitoring in Central Asia. p. 533-537. Proceedings of EUROTRAC Symposium 98. P.M. Borrell and P. Borrell (Ed.), WIT PRESS, Southampton.

Tolkacheva, G.A., L.A. Aksenova, L. Kaluzhskaya, and A.M. Shepelin. 1989. About choice of method of DAF according to classes of priority ingredients. Proceedings of SANIGMI. - L. Gidrometizdat - Pub. 135 (216): 20-25.

Tolkacheva, G.A., L.A. Aksenova, and V.G. Konyukhov. 1987. Monitoring of atmospheric deposition in the Central Asian region. WMO Environmental Pollution Monitoring and Research Program. Tech. Document WMO/TD, N 151.

II. Water Management and Conservation

Groundwater in South Tarim Basin's Fragile Ecology

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ABSTRACT

The Quaternary aquifers with the Tertiary impermeable bed, both confined and unconfined, formed by loose diluvial and alluvial cobble gravel, gravel, sand gravel, fine sand and clay, are the main aquifers. The thickness of aquifers is about 200-900 m, the depth of groundwater table varies from 50-100 m in piedmont slope plain to 1-3m in the fine soil plain; the water salinity is 1-3g/L in the former and 3-5g/L in the latter. Water quality in the ancient channels is better than that other regions. The majority of groundwater resources are seepage transformation of surface water, including runoff and irrigation water, which accounts for more than 94% of total groundwater recharge.

Groundwater has been changing extensively, affected by climate change and human activity. In human history period, climate still played a leading role in the evolution of groundwater. Sustained arid climate resulted in reduced runoff and change of river courses, which influenced recharge and distribution of ground water. As with the development of civilization of human society, the impacts of human activity to water system played a more and more significant role environmentally.

Resulting from that, the groundwater reduced 26.2% in 46 years from 1950 to 1995 in the south of Tarim Basin. At the same time, groundwater-table dropped 3-5 m, and spring water was also reduced by about 28.7%, although exploitation and utilization of groundwater is very limited i.e., about 2.3% of groundwater resources. The regulating and controlling role of groundwater in an ecosystem is very dominant, especially the eco-environment in the south of Tarim Basin. The groundwater-table suitable for desert plant growth is 3-4 m from the surface. If higher than that, salinization will rise, and lower than that, plant degeneration and land desertification are caused. From now on, the development and utilization of water based on their potential and water-saving techniques not only promote the regional economy, but also protect groundwater and improve the environment.

INTRODUCTION

Tarim Basin, the largest inland basin in China, and with the world's second largest desert, i.e., Taklimakan Desert in it, lies in the hinterland of Eurasia surrounded by high mountains. It is very difficult for the wet air-stream to arrive, thus the condition for water resource formation is extraordinary harsh. Both groundwater and

the ecosystem are extremely vulnerable to climate change and human activities, especially the south edge of Tarim Basin, which belongs to a typical vulnerable ecological zone. Groundwater is vulnerable, being an ecotone between oasis and desert, between agriculture and husbandry, between mountains and plain, and between surface water and groundwater as well.

On the other hand, it is becoming increasingly important to meet the demand for water resources in line with expansion of the oil exploitation scale in Tarim Basin. But there is no surface runoff, and the groundwater is very poor both in quantity and in quality near the oil field in the hinterland of Taklimakan Desert. The focus of people's attention is then concentrated to the south of Tarim Basin, which is nearer than the north part, and where several rivers go through the desert and may store up rich and fresh groundwater. However, the hydrogeological condition and groundwater status still keep an insoluble mystery to people.

There are a lot of examples for serious environmental problems resulting from blind exploitation of groundwater all over the world, especially in the arid land with scarce precipitation and intensive evapotranspiration (Danielopol, 1994; Gulani, 1996; Nutalaya et al., 1989). Thus, our study on the characteristics of groundwater and its role in the fragile eco-environment in the south of Tarim Basin is very meaningful and urgent to solve problems, both in practice and in theory.

HYDROGEOLOGY

The south edge of Tarim Basin cuts across two structural geology units, i.e., the southwest depression (Hotan Depression) and the southeast depression (Yutian-Roqan Depression). In the later Tertiary, with the violent fold uplift of the Tianshan geosyncline and the Kunlun geosyncline, Tarim Basin began to subside quickly and developed an integrated vast inland basin. At the same time, the Basin extensively accepted continental clastic sediments, which is the impermeable bed of the Quaternary aquifers. Since the end of Pliocene epoch, with continuing rising of the surrounding mountains and subsiding of the piedmont depression, the Basin accepted deep loose diluvial and alluvial deposits, and some eolian and lacustrine deposits, which formed the good water-storing aquifers of 200-900 meters thick.

Controlled and affected by geological structure and hydrological factors, the hydrogeology and hydro-geochemistry distributed as several regular zones corresponding to the geomorphic and sedimentary from the piedmont to the basin center. The south piedmont slope of the Gobi plain is formed into single cobble-gravel

aquifers, in which the specific capacity is 20-500 m³/d×m, and coefficient of permeability is 1-6 m/d. At the front of slope plain, the Quaternary aquifers are formed by loose diluvial and alluvial cobble gravel, gravel, sand gravel, fine sand and clay, in which the specific capacity amounts to 200-1000 m³/d×m and coefficient of permeability is up to 50-212 m/d. Then with the grain turning finer, the permeability and capacity becomes smaller and smaller.

The confined aquifers are not widespread and, just between Keriya River and Niya River, extend 70.5 km from south to north and cover approximately 9517 km², with two layers of impermeable clay at 150 m depth. The depth of groundwater table varies from 50-100 meters in piedmont-slope plain to 1-3 meters in the fine-soil plain; water salinity is 1-3g/L in the former and 3-10g/L in the later. The corresponding groundwater chemistry changed from Cl-HCO₃-Ca-Mg or HCO₃-Cl-Mg-Ca to Cl-SO₄-Na-Mg or Cl-Na. The water quality in the ancient channels is generally better than that in other regions.

GROUNDWATER RESOURCES

Groundwater resources can be classified into two parts: repeated and is unrepeated groundwater. The former, transformed by surface runoff, is recharged by seepage of natural channel, canal system and field irrigation. The latter is recharged by side ground runoff and rainfall penetration. Then it can be written as:

$$G = R_g + R_i + R_f + G_l + X$$

Where:

- G ≡ natural groundwater resources, and
- R_g ≡ recharge of channel seepage.

There are 36 rivers with total surface runoff of 7.26X10⁹m³ flowing out the Kunlun Mountains. In the Hotan region of south edge of Tarim Basin. The seepage rate differs from different water season and different rivers (Table 1).

The recharge of channel seepage is 1.24X10⁹m³, which accounts for about 17.1% of the surface runoff. R_j -recharge of canal system seepage, about 58.4% of

the surface runoff is drawn to an artificial conduit, of which the utilization coefficient is from 0.40 to 0.49 with pebble lining, concrete lining, and plastic film lining. With R_f -recharge of field seepage through irrigation, excepting for consumption as evapotranspiration for grape growing, there is still some water seepage to recharge groundwater, where groundwater level is no more than 5 m deep because of backward irrigating technique. Field water coefficient of utilization is about 0.80 to 0.84. For G_l-recharge of side ground runoff, there is a large fault-hills zone of 10 to 35 km width between bedrock fracture aquifers in Kunlun Mountains and the Quaternary aquifers in the plain of Tarim Basin. The side ground runoff from fracture aquifers is very limited, due to the drought climate and scarce rain; rainwater penetration only occurs in the irrigation area where groundwater table depth is no more than 5 m and rainfall intensities much than 10 mm. The coefficient of penetration is about 0.04 to 0.18.

The total groundwater recharge resources are 3.681X10⁹m³ (Table 2). The majority of groundwater resources are from seepage transformation of surface water, including runoff and irrigation water in the canal system and field, which accounts for more than 94% of total groundwater recharge. The precipitation, infiltration and side-base flow only accounts for no more than 6%. The extensive evapotranspiration is the main loss of groundwater in the fine soil plain while enormous springs drain groundwater in the slope plain; at the edge of that a great part of groundwater overflows aquifers and transforms to surface water again which is the main source of the river runoff and groundwater in the lower reach of river basin in the desert.

GROUNDWATER IN THE FRAGILE ECOLOGY

Connected by transformation of surface runoff and groundwater, the Mountains, oases (artificial and natural) and desert formed into an integrated physical water-ecosystem in each river basin in the south edge of Tarim Basin (Fig. 1).

Table 1. The infiltration rate of main rivers in south edge of Tarim Basin.

Water Season	Karakax	Ywungkax	Keriya	Niya	Yawatongguz.	Andir
	-----%					
Low-water	85	82	82	87	100	100
Normal-water	50	50	65	73	100	100
High-water	11	23	58	64	85	81

Table 2. Groundwater resources of the piedmont plain at south edge of Tarim Basin.

River Basins	Surface Runoff	Seepage			Side-Base Flow	Rainwater Penetration	Groundwater Resources
		Channel	Canal	Field			
		(R _g)	(R _i)	(R _f)			
-----10 ⁹ m ³ -----							
Pishan R.	0.705	0.150	0.255	0.009	0.032	0.009	0.455
Hotan R.	4.391	0.113	1.244	0.041	0.058	0.016	1.472
Qira R.	0.581	0.191	0.191	0.005	0.017	0.009	0.413
Keriya R.	1.007	0.367	0.344	0.012	0.038	0.015	0.776
Niya R.	0.576	0.421	0.084	0.020	0.025	0.015	0.565
Hotan Region	7.260	1.242	2.118	0.087	0.170	0.064	3.681

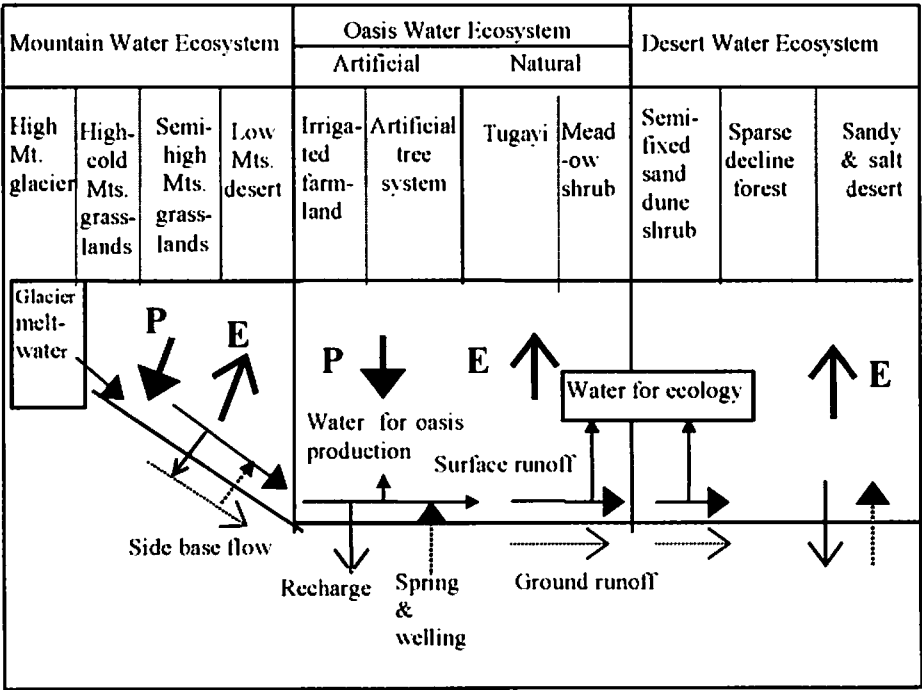


Fig. 1. The water ecosystem structure of Tarim Basin River Basin.

In the system, water is not only a very valuable resource, but also an important and active environmental factor. Excepting for the action of surface runoff, groundwater actively participates in the movement and transformation of matter and energy in nature. The regulating and controlling role of ecology of groundwater is paramount, especially in the fragile lower reaches where the surface runoff cannot arrive. Groundwater level and quality influence the soil environment (moisture and salinity) and, consequently, natural plant growth. The groundwater table suitable for desert plant growth is 3-4 m from the surface (Table 3); higher than that, salinization will rise, and lower than that the plant degradation and land desertification must be caused. However, the groundwater change has resulting in great change of the eco-environment.

GROUNDWATER INFLUENCE ON ECOLOGY

Groundwater has been changing extensively due to climate change and human activity. It was indicated that from late Pleistocene the climate of Tarim Basin

tended to severe aridity, and groundwater depended mainly on the runoff which was composed of melted glacier and snow and rainfall from Kunlun Mountains. The change of temperature in geologic period led to the altering of runoff flow to Tarim Basin and then caused a change of groundwater recharge. In the human history period, climate still played a leading role in the evolution of groundwater. Continuous arid climate resulted in reduced runoff and a change of channels which influenced recharge and distribution of groundwater.

As the development human civilization progressed, the impacts of transformation and destruction of human activity to the water system played a more and more significant role environmentally. In modern times, population growth and improvement in socio-economic conditions brought about rapid expansion of artificial oases rapidly which needed to consume large amounts of water. As a result, the artificial irrigation canals took the place of natural channels, and artificial reservoirs took the place of natural lakes which enhanced the space-time redistribution of surface water based on the natural evolution, and so did groundwater.

The groundwater was reduced 26.2% in 46 years from 1950 to 1995 in the south of Tarim Basin based on a yearly population increase rate of 2.7% and a water use rate increasing from 24.6 to 58.4%(Table 4). Groundwater was mainly recharged by natural channel

As a result of water resources utilization and reduction of groundwater recharge, a groundwater level drop of 3-5 m is widespread except in some irrigation areas and surroundings of plain reservoirs. Spring water also reduced about 28.7% (Table 5) although exploitation

Table 3. Relationship of desert plant growth and groundwater at south edge of Tarim Basin.

Desert Ecology	Geomorphic	Soil Quality	Organic Content	Soil Salinity	Ground- Water Level	Groundwater Salinity	Dominant Plant and Growth
			-g/kg-	-g/kg-	--m--	-g/l-	
Young Tugayi	Flood- plain	Alluvial silt	<25	<10	1 - 2	1 - 3	fine <i>Populous</i> with <i>Tamarix</i> and herb
Mid-age Tugayi	Low- terrace	Silt with dead leaves	10 - 40	10 - 20	2 - 4	1 - 3	luxuriant <i>Populus</i> with herb, dense canopy
Mature Tugayi	Palaeoplain	Silty soil	10 - 30	15 - 25	5 - 10	5 - 10	overmature <i>Populus</i> with spars <i>Tamarix</i>
Decline Tugayi	Palaeoplain	Sand clay salt shell	--	20 - 50	5 - 10	5 - 20	decline <i>Populus</i> and <i>Tamarix</i>
<i>Tamarix</i> shrub	Low terrace depression	Silty soil & sand clay	10 - 30	10 - 20	2 - 4	1 - 5	fine <i>Tamarix</i> and <i>Idalimodendron h.</i>
Salinized meadow	Flood plain	Silty soil	10 - 50	5 - 15	0.5 - 2	1 - 5	dense middle life herb
Salt shrub	Low-terrace depression	Sand clay with humus	10 - 20	10 - 20	2 - 4	1 - 5	fine shrub and herb
Desertified Meadow	Interrupted streamrank	Clay & silty soil	10 - 20	10 - 15	4 - 6	3 - 5	sparse withered herb
Sparse <i>Tamarix</i>	Sand dune (1 - 6m)	Silt with Dead sleeves	2 - 6	--	3 - 10	3 - 30	withered <i>Tamari x</i> shrub

Table 4. Water resources development and groundwater evolution in the south edge of Tarim Basin.

Period	Draining Water	Water- use Rate (%)	Canal Use Coefficient	Seepage			G1+X	Groundwater Resources
				Channel	Canal	Field		
				-----10 ⁹ m ³ -----				
1950s	1.800	24.6	0.2	3.263	1.440	0.051	0.234	4.988
1960s-1970s	3.284	44.8	0.23-0.3	1.824	2.299	0.157	0.234	4.514
1980s	3.721	50.7	0.35-0.41	1.414	2.235	0.302	0.234	4.185
1990s	4.239	58.4	0.4-0.49	1.242	2.118	0.087	0.234	3.681

Table 5. The yield of spring water in the piedmont plain in the south edge of Tarim Basin.

River Basins	α	1950	1970	1981	1985	1995
-----10 ⁹ m ³ -----						
Pishan R.	0.015	0.117	0.101	0.087	0.083	0.071
Hotan R.	0.014	0.784	0.668	0.581	0.557	0.484
Qira R.	0.015	0.144	0.124	0.107	0.102	0.088
Keriya R.	0.010	0.411	0.336	0.304	0.295	0.267
Niya R.	0.015	0.153	0.132	0.113	0.109	0.094
Hotan Region	0.013	1.609	1.361	1.192	1.146	1.004

seepage which accounted for 65.4%. But now, the artificial canal system seepage give primary play to groundwater recharge, which is up to 57.6%, while the former reduced to 33.7%.

and utilization of groundwater is very limited, i.e., which is about 2.3% of groundwater resources. At the same time, groundwater pollution is beginning to rise quickly. In some towns and irrigation areas, a lot of organic nutrients such as NO³-N, NH⁴-N, DOC and

SRP are brought to aquifers where groundwater is recharged by surface water. Groundwater evolution has also led to serious plant degradation and sandy desertification in the south edge of Tarim Basin.

The natural *Populus* forest was reduced from 120.0×10^3 ha of the beginning of 1950s to 18.0×10^3 ha at the end of 1980s. The *Tamarix* forest also was reduced from 37.0×10^3 ha to 10.0×10^3 ha. Consequently, land desertification area amounts to 16.7×10^3 ha, of which cultivated land accounts for 35% in the Hotan Oasis. In some irrigation areas, salinization is also very serious due to backward irrigating techniques. The total salinized area is up to 35.2×10^3 ha, which accounts for about 15.8% of the cultivated land.

THE SUSTAINABLE DEVELOPMENT OF GROUNDWATER

There is potential to a certain degree for groundwater development. But the safe yield is different according the surface water utilization rate. If the surface water use continues as now, the maximum safe yield of groundwater is about 2.05×10^9 m³/a, i.e., is 55.8% of the groundwater recharge. Thus, the evapotranspiration discharge will reduce 60.4%, while spring water will reduce 35.6%. If the surface water use rate is up to 80% and coefficient of canal water use in the future, the maximum safe yield of groundwater will reduce to

1.85×10^9 m³/a with the groundwater recharge reducing to 3.1×10^9 m³. The quantitative aspect of resources availability for sustainable use is a basic concern for the evolution of water management. However, the quality aspect is also of critical importance and is closely linked with the quantity aspect. The protection of groundwater quality must be taken seriously. Assessing and mapping of groundwater vulnerability, and setting up groundwater quality controlling program are key measures and plans. Besides legislation, administrative management and the technology construction and wherewithal are also critically important and necessary.

REFERENCES

- Danielopo, D.L. 1994. Ecological aspects of groundwater management. p. 377-379. In J.A. Stoford and H.M. Valett (Ed.) *Proceedings of the Second International Conference on Groundwater Ecology*.
- Gulani, U. 1996. The adverse effect of water resources development and use on groundwater and aquifers. In *Proceedings, Stockholm Water Symposium*.
- Nutalaya, P., R.N. Yong, and T. Chumnankit. 1989. Land subsidence in Bangkok during 1987-1988. Workshop, Bangkok Land Subsidence What's Next. Asian Institute of Technology, Bangkok, Thailand.

North African Aquifer System: Shared Resource for Desert Development

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ABSTRACT

North African countries are currently experiencing severe water shortages that increase with time. Surface water supplies are insufficient to meet the escalating water demands. Non-conventional water resources, such as desalinated seawater, are technically difficult and economically expensive to develop. The need to provide for the exploding population in the region and their socioeconomic development has led to increasing dependence on groundwater resources, which have a limited recharge. The huge and extensive North African aquifer system offers an alternative water resource to alleviate present shortages, at least for the foreseeable future. Large parts of this system, however, are shared by more than two countries. The sustainability of this precious resource depends on the peaceful cooperation among the countries involved.

Several issues related to exploiting shared groundwater resources must be tackled in a mutual cooperative spirit. They include problems of common pool resources, hydrogeological uncertainties, and a paradigm shift from the fragmentary conception of separately isolated aquifer sub-systems to a holistic "mega-watershed" approach covering the whole region. Certain strategic and managerial guidelines must be formulated. Alternative water-saving development models may be considered. Regional socioeconomic integration should be encouraged. Failure to achieve these objectives enhances competition and speeds up the exhaustion and deterioration of this valuable resource. The ensuing economic problems can lead to socio-political strife and trigger conflicts that will potentially endanger the peace and stability in the whole region.

INTRODUCTION

The relation between man and his environment in North Africa had been stabilized throughout the centuries by the establishment of production systems and socio-political structures based on subsistence economies and a simple way of life. The misguided application of modern technologies and production systems from the highly developed economies of the humid western countries has upset the intricate balance between the subsistence economies and the meager natural resources of the region, including water.

Conventionally available water resources on a renewable basis are simply insufficient to meet the insatiable water demands of the present modes of economic activities and resource exploitation. *Non-conventional water resources are limited in quantity and highly expensive to develop and maintain.*

Thus, the whole region is becoming increasingly dependent on unsustainable "mining" of local groundwater aquifers that are presently threatened by depletion and pollution. Rising water demands and uncontrolled population growth has compelled some countries in the region to extend groundwater resources development and exploitation to the huge southern aquifers that are mostly shared by other countries of the region. Proper management and rational utilization of these aquifers offer the co-riparian countries a very good reason for regional cooperation and socioeconomic integration. Uncontrolled competition and individualistic approaches, however, may trigger unnecessary conflicts that can potentially disturb the peace and stability of the whole region and hamper its progress. This article is intended to clarify certain aspects of the North African aquifer system that may furnish the grounds for cooperation and eliminate misconceptions and pitfalls leading to conflict.

PRESENT WATER RESOURCES

The population of North Africa increased from 49.5 millions (M) in 1955 to 118.1 M in 1990, and is expected to reach more than 188 M by the year 2025 (UNDP, 1994). The total annual renewable fresh water supplies available in the region have been estimated at the fixed rate of 113.1 km³/yr (PAI, 1995). According to these figures, the regional annual average per capita water availability has been reduced from 2285 m³ in 1955 to 958 m³ in 1990 and is expected to reach 602 m³ by the year 2025. Thus, the whole region is already experiencing water scarcity that is getting more severe with time. As indicated in Table 1, however, these regional averages mask the spatial variability of the severity of water scarcity on a country-by-country basis. Even within the same country, water availability varies widely from one location to another. But since almost all-surface water. Supplies have been already developed to their full potential, the above fact implies increasing dependence on groundwater resources wherever they are technically and economically feasible to develop and exploit.

Table 1. Total renewable available water supplies and population distribution in the North African countries.

Country	Water Supply			Population per Capita Water Availability			
	---km ³ /yr---	1955		1990		2025	
		---M---	-m ³ /yr-	---M---	-m ³ /yr-	---M---	-m ³ /yr-
Egypt	58.9	24.7	2385	56.3	1046	87.1	676
Morocco	28.0	10.1	2764	24.3	1151	36.3	770
Algeria	17.2	9.7	1770	24.9	690	40.4	426
Tunisia	4.4	3.9	1130	8.1	540	11.8	369
Libya	4.6	1.1	4103	4.5	1017	12.4	332
Total	113.1	49.5	2285	118.1	958	188.0	602

Sources: UNDP (1994); PAI (1995).

Most of the significant groundwater resources, however, are located in the southern Saharan and Sub-Saharan regions far away from dense population centers and major socioeconomic activities. This situation posed the question of whether to move people and economic activities to where groundwater can be explored and economically exploited or to pump water and mass transfer it to where it is most urgently needed. The countries of the region are responding to both alternatives in varying degrees with more emphasis on one alternative than the other.

Libya, for example, has emphasized huge mass water transfer schemes through its Great Man-made River project (Alghariani, 1997). Egypt is contemplating large-scale agricultural settlement projects and industrial centers in the western and southwestern desert with the objective of reducing population pressure in the Nile Valley and exploiting the waters of the Nubian sandstone aquifer. The other countries may start similar projects when they feel the need and get the means.

Several issues concerning the sustainability of the North African aquifer system and its role in the future development of the region must be raised and satisfactorily settled. These include the basis for sharing a most likely non-renewable common resource, the need for its cooperative regional study and management, conflict avoidance and risk aversion, and socioeconomic integration among the countries involved.

NORTH AFRICAN AQUIFER SYSTEM

The North African aquifer system is composed of numerous groundwater sub-systems ranging in a real extent and storage volume from the several localized groundwater basins scattered along the Mediterranean coast in the north to the huge and extensive Saharan and Sub-Saharan aquifers in the south. Time and space do not allow a comprehensive hydrogeological description of these aquifers, and the discussion in this article is limited to certain aspects of the major shared groundwater basins and their prospective potential as means for fostering peaceful cooperation towards sustainable development or as triggers for igniting regional

conflicts and environmental disasters. These major groundwater basins, which are briefly described below, include the Dakhla-Kufra-Sarir Nubian sandstone aquifer complex shared by Egypt, Sudan, Chad and Libya, the Murzuk-Hamada-Ghadames aquifer complex shared by Libya, Tunisia, Algeria, and Niger, and the Great Erg aquifer complex shared by Tunisia, Algeria, and Libya.

Dakhla-Kufra-Sarir Complex

This Nubian sandstone aquifer covers an area of two M square kilometers in Egypt, Libya, Chad, and Sudan. It is considered the most important groundwater system in North Africa in terms of storage volume, high productivity, and good water quality. Its thickness may reach up to 5000 meters in Egypt and 3000 meters in Libya and Sudan. The volume of stored groundwater in the whole complex has been estimated at 75,000 km³ of which 50,000 km³ are located in Egypt (Hesse et al., 1987).

Isotopic investigations in the same study revealed that the age of stored groundwater ranges between 10,000 and 33,000 years. In the Dakhla region of Egypt, water quality changes from less than 100 ppm in the southwest to 10,000 ppm near Siwa and Quattara depression. In the Kufra region, inside Libya, water quality does not exceed 300 ppm. Average transmissivity ranges between 10⁻⁵ and 10⁻⁴ m/s. Water moves in response to a hydraulic gradient towards the north and northeast where the aquifer system discharges into the salt marshes and depressions surrounding the Gulf of Sirte in Libya and the Quattara depression in Egypt.

Present abstraction is estimated at 700 M m³/yr in Egypt and around 500 million m³/yr in Libya. An extra 800 M m³/yr will soon be extracted after the final completion of phase one and phase two of the Great Man-made River project in Libya. Ahmad (1993) proposed the construction of 2000 wells distributed in the western desert to pump more than 4.7 billion m³/yr for future agricultural development in Egypt. The long-range impacts of present abstractions and proposed future exploitation are difficult to assess at the present time. This issue will be discussed in further detail later in this article.

Murzuk-Hamada-Ghadames Complex

This regional groundwater aquifer system extends over an area of 900,000 km². It is surrounded by the Algerian Meguid Al-Biod fault system in the west, the Atlas flexure, and the Gafsa-Madnine-Khoms Fault in the north, the Abu-Nujem-Hun Graben in the east and the basement complex outcrops in the south. This extensive aquifer system is hydrogeologically divided into two groundwater basins by the east-west axis of the Qarqaf uplift in Libya. The northern basin includes the sub-basins of Al-Hamada Alhamra in Libya and Fort Polignac in the Great Erg Oriental between Algeria and Tunisia. A third sub-system including parts of western Hamada and eastern Polignac has been recently designated as the Ghadames sub-basin. The southern basin is mainly composed of the Murzuk aquifer system in Libya and Algeria and parts of the Chad basin in Algeria, Niger, and Chad. The hydrogeological formations of this complex aquifer system range from the Paleozoic to the Quaternary and are lying on a displaced impervious crystalline basement.

The Paleozoic and Nubian sandstone formations are the major water-bearing strata in this aquifer system complex. In the Murzuk basin, groundwater moves in response to a piezometric head that ranges from 700 m in the southwest to 250 m near the Hun Graben in the northeast. Transmissivity values are within 10^{-2} and 10^{-3} m²/s, and water quality is within 150 and 1000 ppm of total soluble salts. The lower confined Cambro-Ordovician sandstone aquifer outcrops at the Jabal Fezzan region, where it becomes unconfined and empties into the Hamada sub-basin. This aquifer will provide the abstraction of more than 800 M m³/yr that are planned to feed Phase Two of the Great Man-made River project in Libya.

In the northern Hamada-Ghadames basin, the Paleozoic formations become deeper and their water quality deteriorates. The most important aquifer in this basin is the lower Cretaceous sandstone which is vertically recharged by upward flow from the Paleozoic and downward rainwater infiltration in the northwestern Hamada. It may even receive some long-distance recharge from the Desert Atlas Mountains in Algeria. Water movement in this aquifer is from southwest to northeast, and water quality ranges between 1000-2000 ppm.

Great Erg Aquifer Complex

This extensive aquifer system is composed of two basic sedimentary groups. The lower group is known as the Continental Intercalaire and extends over an area of 500,000 km² covering all the northern Sahara in Algeria and Tunisia. This group is generally homogeneous and represents a single continuous aquifer ranging in thickness from 250 m to 1000 m in the center of the basin. The water-bearing strata had been filled during the Quaternary pluvials and continue to receive significant amounts of recharge by rainfall infiltration at

the Erg Occidental, estimated as 8 m³/s, by runoff seepage from the Desert Atlas estimated as 12 m³/s and by floods from the Tadmit plateau estimated as 3 m³/s.

This significant recharge contributes to groundwater movement in two directions according to a hydrodynamic system that discharges in a large extended areas of the basin. One direction is from the north to the south and southwest, where the aquifer discharges through a large number of foggaras and wells. The other direction is towards the Tunisian coast in the east and northeast, where water is discharged into the scattered salt depressions west of the Gulf of Quabes.

The upper group is known as the Continental Terminal and represents water-bearing formations ranging between the upper Cretaceous and the Tertiary. The group extends over 350,000 km² to form a non-homogeneous confined aquifer in the center of the basin. Both the upper and lower groups are hydraulically connected and unconfined at the basin boundaries. Water quality changes from less than 500 ppm near the Erg Occidental to more than 2000 ppm in the eastern region. Both groups can sustainably provide up to 2.2 billion m³/yr in Algeria and 656 M m³/yr in Tunisia (UNESCO, 1972).

REASONS FOR COOPERATION

Common Pool Problems

The increasing dependence on these shared aquifers will soon bring about several problems that are usually related to the exploitation of common pool resources (Gardner et al., 1990). The basic characteristics of a common pool resource are its subtractability and the costly exclusion of users from exploiting the resource. Subtractability means that a unit volume of groundwater withdrawn and utilized by one country is not available for use to the other countries sharing the same resource. *The high exclusion cost is self-evident since it is almost impossible to convince one or more countries to stop exploiting a shared resource without compensations in excess of, or at least equal to, their lost benefits.* The only other alternative is to resort to force and, hence, armed conflicts that are politically damaging and financially expensive.

Common pool problems arise in shared-water resources when a rationally optimal water use by one country leads to undesirable results as viewed by the other countries sharing the same water resource as a group. There is always an institutionally feasible better strategy to collectively manage a common-pool resource such as shared groundwater aquifers. The realization of the most appropriate strategy, however, is usually hampered by the inadequate economic and institutional framework within which the resource is exploited. This inadequacy was discussed in detail by Qashu (1993).

Common pool resources have been used according to a rule of capture in an open-access framework. When no single country owns the resource, the sharing

countries have no incentive to raise water-use efficiencies and conserve for the future. Thus, mere self-interest of single countries leads them to over-exploiting the resource. Where the shared aquifers are non-renewable, or the renewal rate is much less than that of the withdrawal, the increased competition among co-riparians will eventually lead to aquifer exhaustion and water quality deterioration.

To effectively manage this unsustainable situation and to avoid the development of potentially possible future conflicts, the sharing countries must cooperatively formulate a long-term rational plan for exploiting their shared resource on sustainable basis. However, before such a plan can be formulated on sound basis, a large amount of detailed hydrogeological and socioeconomic information must be accurately collected and analyzed within a regional holistic framework that encourages further cooperation and confidence building among prospective users.

HYDROGEOLOGICAL UNCERTAINTIES

The most important uncertainties surrounding the North African aquifer system are related to regional recharge, aquifer branching and hydrogeological interconnections. Several intensive hydrogeological investigations and mathematical modeling have been made in many countries of the region with the purpose of well field designs for localized groundwater exploitation and mass water transfers. The accumulating information, however, has not been interpreted and integrated to give a comprehensive picture of the whole regional aquifer system and its ramifications, especially with respect to sources and rates of recharge.

Available information confirms that significant annual recharge is limited to the small size groundwater basins scattered along the Mediterranean coastal regions, where annual precipitation exceeds 100 mm per year. Most of these sub-units of the North African aquifer system may be considered as localized within-country sub-systems of limited extent and trans-boundary mobility. These aquifers are not expected to exhibit the common problems normally related to shared resources, despite the fact that they have been severely exploited and mismanaged as a common-pool resource by the local beneficiaries in each country.

As to the more significant and extensive Sub-Saharan and Saharan aquifers, it is believed that the Great Erg aquifer complex receives a significant annual recharge of no less than 700 M m³ per year, mostly by rainfall infiltration in the western parts and annual floods from the Desert Atlas (UNESCO, 1972). Recharge of the other significant aquifers of Murzuk-Hamada-Ghadames and Dakhla-Kufra-Sarir basin complexes is still uncertain, however, these aquifers are acquiring increased importance as basic water resources for mega-sized development projects such as the Great Man-made River project in Libya (Alghariani, 1997) and the other proposed and planned settlement projects in Egypt (Ahmad, 1993). The ques-

tion of their recharge and renewal must be satisfactorily answered before any appropriate management plan can be successfully implemented.

Conflicting conclusions have been reached by different investigators. Ball (1927) was convinced that the Nubian sandstone aquifer of Dakhla-Kufra-Sarir complex is significantly recharged by direct rainfall infiltration and runoff seepage in the high altitude regions of the Erdi-Ennedi and Tibesti mountains, where precipitation ranges from 328 to 920 mm per year. In 1934, for example, the outpost village of Aozou, near Tibesti, received 370 mm of rainfall that produced great floods during 3 days (Walton, 1969). In another investigation, Sandford (1935) came to the conclusion that the Nubian aquifer receives at least 4.6 M m³ per day of subsurface flow from Wadi Howar, south of the Erdi region in Chad and Sudan. On the other hand, Hellstrom (1940) and Murray (1952) indicated that this aquifer is made up of fossil water and does not receive any recharge at the present time.

The present hydraulic gradients towards the north and northeast those are responsible for the movements of large volumes of water through the Kufra-Sarir basin complex have been attributed to a variety of mechanisms. Pallas (1980) attributed them to the slow emptying of this huge area that was filled up by rainfall during the Quaternary pluvial periods. Burdon (1977) related these gradients to residual heads, basin tilting, aquifer compaction and evaporation in the discharge zones of coastal depressions. To ensure the sustainability and sound management of these aquifers, the question of recharge must be decisively answered by further investigations that take into consideration all the regional variables of climate, hydrology, geomorphology, hydrogeology and socioeconomic activities. Different approaches and techniques must be used for this purpose.

NEED FOR A NEW PARADIGM

The North African aquifer system has been traditionally divided into more than 17 separate, localized, groundwater units that are geographically distributed all over the region. They have been frequently investigated and conceptualized according to vertical logging data and hydrodynamic tests obtained from a few scattered boreholes that seldom represent the actual geological formations or accurately reflect their complexities. This simplistic approach normally leads to a highly idealized "layered-cake" model of confined or unconfined water-bearing strata that rarely describe their actual hydrogeological properties. Technically speaking, however, groundwater basins can be defined as *complex hydrogeological systems that are spatio-temporally open to both vertical and horizontal interactive exchanges of hydrological variables with their environments*. These exchanges occur across any arbitrarily selected boundaries that are based on *geography, geomorphology, hydrogeology, or administrative and political frontiers*.

While the above simplified approach to groundwater basins facilitates their investigation, data collection and modeling their behavior for rational management, it *should not*, however, mask the fact that they are an integral part of an overall regional or continental, if not a global, hydrological cycle dominating the whole North African region. Recent realization of this fact has led to the development of the integrated systems approach as exemplified by the "mega-watershed" concept for groundwater development and management (Bisson, 1995).

Recent advances in satellite imagery and data acquisition technology by remote sensing have opened the way for the establishment of a highly sophisticated computer-based Geographical Information Systems (GIS) that can be efficiently used for large-scale monitoring and evaluation of all the regional components of the hydrological cycle as related to the climatology and geomorphology of North Africa. A "megawatershed" of the North African aquifer system could be synthesized and used for the optimization of both exploration and management of the different aquifers within the system, especially those that are shared among the countries of the region such as the Nubian sandstone and the Ghadames aquifers. The collected data can also provide important information on the sources and amounts of local and regional recharges as well as the most productive locations for prospective future well fields, emphasizing the need for the regional cooperation in the detailed investigation of these shared aquifers.

PERSPECTIVES OF EXPLOITATION

It is expected that the most intensively exploited regions of the North African "megawatershed" will be in the Nubian sandstone aquifer in Libya and Egypt. Libya has been exploiting this resource out of necessity. The coastal aquifers in the most populated north-western and northeastern parts of the country has been over-drafted and are presently exposed to *severe pollution* by *seawater intrusion*. Surface water supplies are almost negligible compared to demand. Socio-political considerations necessitate the development of the strategic coastal areas surrounding the Gulf of Sirte, which represents a demographic and geo-political vacuum that separates the most economically and socio-politically important parts of the country. Comparative studies indicated that mass water transfers from the southern Kufra-Sarir and Murzuk-Hamada aquifers to the coastal areas offer the best available option. Hence, the Great Man-made River project was conceived and implemented (Alghariani, 1997). After its completion, the project will abstract 1.2 billion m³/yr from the Kufra-Sarir basin and 0.8 billion m³/yr from the Murzuk-Hamada basin.

The problems in Egypt are of a different nature; however, the major objective is to relieve the pressure of high population density in the Nile Delta and Valley through creating new comprehensive development projects such as the New Valley, the Southern Wadi, and

the Al Ouenat in the western desert. These projects are planned to resettle millions of people in newly developed agricultural and industrial communities that will require huge amounts of water under the extremely arid desert climate (Abu-Zeid and El-Shibini, 1997). Ahmad (1993) proposed the construction of 2000 wells arranged in five well fields that are distributed along the Libyan-Egyptian border and designed to abstract 4.7 billion m³/yr from the Kufra-Sarir-Dakhla aquifer complex.

Principles of Abstraction

The increasing groundwater abstractions on both sides of the Nubian sandstone aquifer raise some questions about the sustainability of the implemented and proposed development projects and their environmental impacts, especially when the previously discussed hydrogeological uncertainties are considered. Planning for an optimum exploitation and regulating the abstracted flow is not possible at the present level of knowledge base. However, general guidelines and indicators may be followed until further comprehensive information becomes available. These guidelines and indicators which apply to both water transfers and *in situ* water use, must include the following strategic considerations:

1. Water transfers from this aquifer system should represent a surplus after including all the present and projected needs of the local human and natural ecosystem activities in the reasonably foreseeable future.
2. The water requirements for different uses must be reduced to the minimum possible amount that does not impair economic production efficiency and threaten environmental integrity. All alternate water resources should be evaluated before exploiting the aquifer system. These alternate resources may prove to be more economically feasible and environmentally sound in the long run than mining a most likely non-renewable fossil water.
3. It has not been proven yet that the Nubian sandstone aquifer system is hydraulically connected with any sources of recharge in the region. Long-distance secondary porosities and scanty occasional rainfall infiltration are suspected to contribute some recharge, but this has not been conclusively confirmed. Thus, it should be considered that pumped water from this aquifer system will not be replaced once it is withdrawn. Therefore, its development and exploitation should be undertaken with the full understanding that it will be depleted within a limited period of time depending on the aquifer storage volume that can be economically pumped and utilized. Within this period, the implemented and proposed development projects should generate economic returns sufficient to develop other water resources, such as desalination, to replace the exhausted supplies.

- 4. It must be recognized that a water resources development project, once made, becomes essential to the welfare, if not the existence, of the people it serves. Thus, the project must be continued in service or replaced by another source of water. Otherwise, all the socioeconomic activities based on the project cannot be sustained in the future. The developed water resource is a new element added to the physical environment and it certainly enhances economic development and population growth. If the developed water supply were to be discontinued due to aquifer exhaustion or any other reason, human activities based on this resource would experience catastrophic curtailment unless other alternate supplies are secured.
- 5. It must be realized that the development projects based on this resource will have profound economic, hydrological and environmental impacts, both during their construction and throughout their operating lifetimes. The resulting socioeconomic and environmental costs of these impacts must be borne by the national or regional authorities in the countries concerned. Such costs should be recognized and mitigated in advance. They must be partially or fully compensated for by water users through an efficient and effective water-pricing system.

WATER MANAGEMENT ISSUES
Sustainability Considerations

Sustainable water resources management implies the three basic principles of achieving *equity*, *economic efficiency* and *environmental integrity*. To realize these objectives in the face of increasing water scarcity and rising demand for water use, North African countries must establish water management strategies oriented towards doing more with less through the development and adoption of new innovative water-saving technologies and development of policies that increase water-use efficiencies with minimum environmental hazards.

As to the question of the sustainability of the water supply in these aquifers, there is no clear and definite answer yet. All the present time, studies are based on the assumption of 50 years of continuous operation. The results obtained from simulation models and pumping tests of operating well fields in Libya and Egypt indicate that maximum regional draw down after 50 years of continuous pumping at the design discharge for the proposed projects do not exceed 100 m in the center of well fields (Ahmad, 1993). Radial influences of the predicted drawdowns are not expected to extend to more than 300 km radius. Pallas (1980) estimated that the saturated aquifers of the Kufra-Sarir basin alone can provide up to 40,000 M m³/yr with a 1 m per year lowering of the watertable over the whole reservoir extent of more than 500,000 km².

Thus, the question of sustainability seems to depend on water production costs and managerial skills rather than on available water supplies which are apparently

sustainable for hundreds of years even in the absence of natural recharge of the aquifers. Sustainability can be assured if the exploited water is utilized in such a way as to provide the national economies of the countries concerned with the means and strength that enable them to develop alternate water supplies when the groundwater resources of the aquifers become uneconomical to pump or are exhausted altogether.

Environmental Impacts

It must be realized that any attempt towards satisfying, even partially, the increasing food demands of an ever-exploding population growth through expanding irrigated agriculture can be achieved only on the expense of the non-renewable water storage in the local aquifers. But since irrigated agriculture in the mostly arid climates of the region is essentially a high intensity evaporator, the accumulation rates of salts and other pollutants in the production environment are relatively high and must be contained within tolerable limits if sustainable irrigation in particular and the development process in general are to be maintained.

Assuming equilibrium salt precipitation and dissolution by chemical processes and negligible salt uptake and removal by biological activities, the general salt-balance equation for an agricultural production environment can be expressed in its simplest form as:

$$(I) (C_i)-(O) (C_o) = \Delta SS \dots\dots\dots (1)$$

Where:

(Ci) is the average salt concentration of the total annual water inputs (I) entering the production environment, (Co) is the average salt concentration of the annual outflows (O) leaving the production environment, and (DSS) is the change in salt storage within the physical boundaries of the production environment.

Equation (1) is presented here to illustrate two points upon which management strategies may be based. First, salts and other pollutants will continue to accumulate in the production environments as long as the outflow rates leaving these environments are insufficient to remove the added salts accumulating through the process of evapotranspiration. With highly mineralized groundwater, this fact will eventually lead to an environmentally destructive unsustainable situation that is technically difficult and economically expensive to ameliorate. Second, to achieve development sustainability within production environments at any level of acceptable salt content and pollution load, Equation (1) becomes:

$$(C_i) = (O) (C_o) \dots\dots\dots (2)$$

implying that a certain percentage of the water inputs utilized within the production environments must leave them with drainage outflows.

This percentage can be estimated as

$$(O)/(I) = (C_i)/(C_o) \dots\dots\dots(3)$$

This concept has been widely used to manage salinity in irrigated agriculture.

Increasing Water-Use Efficiency

The concept of WUE is highly controversial and can be clarified only according to one's perspective within the context of several interrelated factors. When generally defined as the total benefits (material goods, services, or financial returns, etc.) produced by each unit of water used, it can be directly linked to demand-water management, opportunity cost of water uses, comparative production advantages, and other economic manipulations.

In irrigated agriculture, however, its use has been directly related to irrigation efficiency when water is the only factor limiting crop production. Under this condition, any water management practice that improves irrigation efficiency tends to increase WUE. But in all cases, both WUE and irrigation efficiency should be optimized within the constraints of achieving the maximum potential yields of crop plants and maintaining the minimum basin outflows that are required by the environmentally acceptable salt balance as indicated by Equation (3). Precautionary measures should be taken against deficit irrigation with its correlated crop water deficiencies and soil salinization.

The highest priority has to be given to realizing potential crop yields by removing any production constraints other than water. Present crop yields in the region are depressingly low. The WUE of cereal crops in Egypt, for example, is close to 0.5 kg per cubic meter of water (Higgins et al., 1988). Similar figures are expected throughout the North African countries. In modern high-input systems of irrigated agriculture, it is hoped to obtain WUE values for cereal crops approaching 1.5 kg per cubic meter. Here lies the potential for getting more with less.

ECONOMIC INTEGRATION AND SOCIO-POLITICAL MANIPULATIONS

In view of the present and expected future water scarcities in the region, irrigated agriculture cannot grow and expand in parallel lines with the demand for food by an increasing population. When the other projected rising water demands of urbanization and industrialization are considered, irrigated agriculture cannot be sustained, even at its present level of production if new water resources by importation or desalting are not developed.

The future concerns with water management will be most likely related to allocation problems of the limited water supplies. The economic and socio-political challenges are enormous, but not insurmountable. The opportunity cost of water in the competing sectors for

water use should be one of the guiding criteria for water allocation. Subsidies must be limited to the minimum equity requirements for the poor and unprivileged. Water-pricing and water rights systems should change the conception of water supplies from water as a "free common-pool" resource to water as an *economic commodity* in the market place. Irrigated agriculture will certainly be a loser under these institutional arrangements. But irrigation does not have to be necessarily expanded, or even maintained at its present level, as long as the re-allocated water supplies from the agricultural sector to the other sectors produce economic activities for the population and sufficient financial returns for food importation from the international markets. Agriculture may be restricted to crops of relatively high and competitive comparative production advantages at the regional and global levels.

The present trends of pursuing the mirage of food security and self-sufficiency through the government and donor-sponsored irrigation projects of the "green revolution" and the lavish provision of subsidies to the private sector are major contributors to the present crisis. These trends must be reversed by re-orienting the present socio-economic systems towards privatization and the introduction and encouragement of other development models such as light industries, commerce and tourism that use less water with more economic returns. The geographical location and the favorable climate of the region are highly conducive to these activities. Linking this region with the rest of the African continent by modern transportation and communication systems will enhance this transformation. Sustainable development is a holistic approach that can be realized through several options and alternatives. It should not be restricted, however, to a single economic activity on the expense of the socioeconomic system as a whole.

CONCLUSIONS AND FUTURE PROSPECTS

The North African region is facing an increasing water scarcity that imposes severe constraints on its future development. The huge and extensive groundwater aquifer system in the Saharan and Sub-Saharan areas offers the promise of alleviating a large part of these constraints, at least until other more favorable water supply options become available. The exploitation of this shared "megawatershed" has already started on the basis of an incomplete and, in some cases, erroneous knowledge base. The countries involved should develop cooperative strategies and managerial policies that ensure the sustainability of this precious resource. Regional cooperation eliminates the negative hydrological and environmental impacts that may trigger conflicts and socio-political strife. Fortunately, all the countries of the region are ethnically, religiously and culturally homogeneous, a fact that fosters understanding and cooperation, if not economic and socio-political integration. The continuation of the presently *misguided policies and incompatible paradigms of resource utilization are highly unsustainable* and should be

completely reconsidered and reoriented towards other development models that are more adaptable to the local conditions of meager resources and environmental aridity.

REFERENCES

- Abu-Zeid, M., and F. El-Shibini. 1997. Towards improved environmental conditions through horizontal expansion in Egypt. *Proceedings: international conference on "Water Management, Salinity and Pollution Control Towards Sustainable Irrigation in the Mediterranean Region."* Sept. 22-26, 1997. IAM, Valenzano (Bari), Italy.
- Ahmad, M. 1993. A model to develop groundwater resources in Egypt. *Proceedings: International Symposium on "Water Resources in the Middle East: Policy and Institutional Aspects."* Oct. 24-27, 1993. Urbana, Illinois, USA.
- Alghariani, S.A. 1997. Managing water scarcity through man-made rivers. *Proceedings: 27th IAHR Congress on "Water for a Changing Global Community."* Aug. 10-15. San Francisco, California, USA.
- Ball, J. 1927. Kharga Oasis: its topography and geology. Survey Department, Cairo, Egypt.
- Bisson, R.A. 1994. Space-age integrated exploration and treatment of renewable regional sources of pristine groundwater in fractured rock Megawatersheds." *Desalination J.*, Vol. 99.
- Burdon, D.J. 1977. Flow of fossil groundwater. *J. Eng. Geology*.
- Gardner, R., E. Ostrom, and J.M. Walker. 1990. The nature of common pool resources. *Rationality and Society*, Vol. 2.
- Hellstrom, B. 1940. The subterranean water in the Libyan Desert. *Geografiska Annaler*, Stockholm, Sweden.
- Hesse, K.H. 1987. Hydrogeological investigations in the Nubian aquifer system: Eastern Sahara. Technical University, Berlin, Germany.
- Higgins, G.M., P.J. Dielman, and C.L. Abernethy. 1988. Trends on irrigation development and implications for hydrologists and water resources engineers. *J. Hydrol. Sci.*, 33: 1&2.
- Murray, G.W. 1952. The Artesian water of Egypt. Survey Department of Egypt, *Paper No. 52*, Cairo, Egypt.
- PAI (Population Action International), 1995. Sustaining water: population and the future of renewable water supplies. Washington, D.C., USA.
- Pallas, P. 1980. Water resources of the Socialist People's Libyan Arab Jamahiriya. The Geology of Libya, Vol. II, Academic Press, London, U.K.
- Qashu, H.K. 1993. Partnerships in regional water resources developments. *Proceedings: International Symposium on "Water Resources in the Middle East: Policy and Institutional Aspects."* Oct. 24-27, Urbana, Illinois, USA.
- Sandford, K.S. 1935. Sources of water in northwestern Sudan. *Geography J.*, 85(5), London, U.K.
- UNESCO, 1972. Etude des ressources en eau du Sahara Septentrional, Algérie/Tunisie, 1,2,3,4,5,6. UNESCO, Paris, France.
- UNDP (United Nations Population Division), 1994. World population prospects. The 1994 Revision, UN, New York, U.S.A.
- Walton, K. 1969. The Arid Zones. Aldine Publ. Company, Chicago, Ill., USA.

Decline of Groundwater Quality in the Khanasser Valley (Syria) due to Saltwater Intrusion

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ABSTRACT

In drylands, water usually is the most limiting factor for soil productivity. Intensification of agricultural production is therefore often based on the development of irrigation. However, if the water quality is unsuitable, irrigation will lead to soil degradation in the long term. The paper presents the case of the Khanasser Valley, where irrigation using groundwater is leading to soil salinization. The Khanasser Valley in northern Syria is located about 70 km southeast of the city of Aleppo, close to the Jaboul Salt Lake. The introduction of tube-well irrigation in the past 10 years has led to a substantial increase in groundwater withdrawal from the upper aquifer. Recent observations indicate an increase in soil salinity, which may lead to soil degradation and possible land degradation. A survey of groundwater levels, water quality, and water use was carried out to assess the impact of water use on groundwater quality. 100 wells were surveyed and detailed analyses were carried out for 37 wells. The results show that the recent increase in irrigation has had a significant effect on the groundwater quality. Electrical conductivity values of 10,000 $\mu\text{S cm}^{-1}$ indicate that a large part of the groundwater is affected by salt-water intrusion due to intensive groundwater use during winter and summer. Electrical conductivity of the irrigation water ranged from 10,000 to 20,000 $\mu\text{S cm}^{-1}$ and Sodium Absorption Ratio (SAR) was 20 in almost half of the wells. The results are in line with internationally accepted standards for high to very high sodium and suggest that alternative options for groundwater use need to be developed, which will reduce water use and which will protect the Khanasser Valley from salinization.

INTRODUCTION

Land resources, due to the increase in population and degradation if the carrying capacity is exceeded. Without the development of land-use practices, long-term agricultural production may irreversibly destroy its potential. This is particularly so for polluted lands (Skogerboe, 1991; Szabolcs, 1991). An alternative way to accommodate

increased pressure on the land resources is intensification. *Less land is more intensively used, but also more intensively cared for and investments are made to enhance its productivity.* Classic examples are the shift to market crops (fruit, vegetables) and irrigation farming. However, these alternatives also bear potential for further degradation. In dry areas, soil moisture is usually the most limiting production factor. Intensification naturally tends to be based on moisture conservation and irrigation (Wolff, 1997). Provided the water resources are adequate, both in quantity and quality, investments in irrigation usually guarantee a worthwhile return for the farmer (Stein, 1998). However, often long-term implications of irrigation are often not taken into consideration when farmers develop irrigation water resources. Over long periods, irrigation may affect the quality of the soil in various ways and lead to soil salinization. If the water quality is unsuitable for irrigation, salinization processes will be accelerated and may render the land useless for any cultivation after relatively short periods.

In the Khanasser Valley, farmers are investing in irrigation to maximize the returns from their land. Because of the lack of surface water, they use the groundwater from the shallow unconfined aquifer for irrigation. This aquifer is recharged by local rainfall (200–250 mm/year) and has therefore a limited capacity. Excessive pumping will therefore lower the groundwater table significantly, especially at peak-irrigation periods. The groundwater system in the Khanasser Valley is linked to the Jaboul Salt Lake. Prolonged lowering of the groundwater table will cause salt-water from the salt lake to enter the sweet-water aquifer. This will affect the irrigation-water quality.

In the Khanasser Valley, the first signs of soil salinization are already evident. Farmers have noticed that the water tastes salty. In the village of Shreema, near the Salt Lake, an irrigated cotton field showed stunted growth due to soil salinity. However, farmers in other areas of the Valley, not yet affected by salinity, continue to invest in irrigation wells.

Similar conditions exist in other dryland regions. *The Khanasser Valley is an example of how inappropriate groundwater use for irrigation may destroy the productivity of the land.* This paper tries to highlight the danger of soil salinization due to increased and uncontrolled irrigation-well development.

MATERIALS AND METHODS

The Study Area

The Khanasser Valley is situated approximately 70 km southeast of the city of Aleppo and adjacent to the Jaboul Salt Lake in northwestern Syria. The area can be classified as semi-arid and is located at the fringe of the Syrian Steppe, in Stabilization Zone 4 (Soumi, 1991). The annual rainfall of the area is 200-250-mm, with high annual and inter-annual irregularity. The rainfall comes in winter and falls in the period between November and April/May, with a peak in January.

The orientation of the Khanasser Valley is north-south. The Valley lies 300-400 m above sea level, between the hill ranges of Jebel Al Hoss in the west and Jebel Shbith in the east. The Valley connects the Harayeq Depression in the south with the Jaboul Salt-Bottom Depression in the north. A gently undulating plain with a shallow network of wide dry erosion channels characterizes the Valley. The hill ranges of Jebel Al Hoss and Jebel Shbith form gently rolling plateaus, which end in well-defined steep scarps towards the Valley with v-shaped erosion channels.

The soils in the Valley floor are fine and moderately textured dark-brown to brown Calcisols, Gypsisols, Leptisols, and Cambisols (Louis Berger International, 1982; van de Steeg and Zebisch, 1999). The soils of Jebel Al Hoss and Jebel Shbith plateaus are Inceptisols. In general, the soils are well drained and have a high infiltration capacity. The slopes and the plateaus are extremely stony. Soil depths range from less than 1 m at the foot of the slopes to 16 m in the center of the Valley.

There are three main types of agricultural production systems in the Valley, i.e., rainfed farming, irrigated farming, and livestock rearing. Most households practice a combination of crop production and livestock rearing. Rainfed farming, with barley as the dominant crop, occupies the major part of the arable land. However, irrigation farming has developed rapidly over the past 10 years. Irrigation is practised only in the middle of the Valley, where the soils have the highest fertility. The total land under actual irrigation covers only approximately 150 hectares, with an increasing trend. Most irrigation farmers practice a rotation with cotton and wheat, and sometimes fallow. The hill slopes and the eastern plateau are exclusively used for grazing.

Hydrologically, the Khanasser Valley is situated on the border between two surface-water catchments. The northern part of the area belongs to the Jaboul catchment and the drainage pattern is directed towards the Jaboul Salt Lake. The southern part belongs to the steppe catchment and surface water drains towards a salt depression (*sabkha*) in the south. The dividing line between the two basins lies in the vicinity of the line between the villages of Al Hobs and Serdah.

Geology and Groundwater Hydrology

The Maestrichtian is the oldest formation in the area (Technoexport, 1964) and believed to be a water-confining layer of 150-200 m thickness, consisting of marl, clay, clayey limestone flints, and phosphate inter-beds. On top of this formation, the Paleogene system is positioned with a maximum thickness of around 225 m. The Paleogene formation in the Khanasser Valley consists of Lower Eocene and Middle Eocene, which comprise clayey, chalky limestones and silicified limestone (Technoexport, 1964). Both the middle and the lower Eocene contain localized aquifers with low productivities (ACSAD, 1984). Upper Miocene Basalts are situated on top of the Paleogene rock and can be found on Jebel al Hoss in the west and Jebel Shbith in the east. The average thickness of this basalt layer is 10 m, with a maximum of 30 to 50 m. In the Valley, a layer of up to 25 m thick Quaternary deposits is present. These are pro-luvial, alluvial, and lacustrine deposits. In the lacustrine deposits, gypsum beds can be found.

In the Khanasser Valley, the Paleogene and the Quaternary formations contain the unconfined groundwater in conglobreccia, and sometimes sand. According to Technoexport (1964), the amount of groundwater is directly dependent on the rainfall in the area. In the early 1960s, the groundwater occurred at a depth of 18-20 m below ground level (Technoexport, 1964). The water is prevented from downward percolation by water-arresting strata in the Middle Eocene formation and by the Maestrichtian clayey limestone and marl.

During the fieldwork for this study, the farmers in the northern-central part of the Valley showed a sample of a layer that they discovered when they dug their wells. The farmers call this layer '*Rommel Furat*' or '*Rommel Aswad*', which means 'Sand of the Euphrates' or 'Black Sand'. It consists of dark sand and pebbles that are well rounded. Some pebbles are up to 15 cm in diameter. Pieces of the layer look like concrete; according to the farmers, this layer is the best aquifer in the area.

In the early 1960s, Technoexport (1964) described the quality of the groundwater in terms of 'mineralization' (g L^{-1}). To convert these values to electrical conductivity [dS m^{-1}], the formula of Abrol et al. (1988) was used. In the center of the Valley, in the Quaternary deposits, the salt content of the water ranged between 1 and 3 g L^{-1} (1.6 and 4.7 dS m^{-1}). The water was described as odorless and tasteless, with a small amount of dark sediment. Temperature was between 18 and 22°C . Water samples from the Valley were classified as having a mixed composition of ions, i.e., there were no dominant anions or cations. On the eastern and western sides of the Valley, in the Middle and Upper Eocene rock, the water had a salt content less than 1 g L^{-1} (1.6 dS m^{-1}). This high quality water was transparent and without odor or taste. Predominantly, the water was described as the 'hydro-carbonate type' or 'mixed type'. Usually, calcium cations were predominant.

Well Types and Pumping Practices

The typical wells that are used in Khanasser Valley are a combination of two types of wells, a tube-well, and a traditional Arab well. The typical Arab well has a diameter of 1.25 m and is dug until to 5-10 m below the groundwater level. At the bottom of the well, a 3-m high chamber is excavated that has a diameter of three m. This chamber serves as a reservoir for additional water storage. To increase the rate and amount of water flowing to the well, several horizontal holes (*daharas*) are drilled radially from the storage chamber. These *daharas* have a diameter of 2.5-5.0 cm and can be up to 250-m long (Hoogeveen and Zöbisch, 1999). About one meter away from the Arab well, a tube-well is drilled. The chamber of the Arab well is then connected to the tube-well by a horizontal hole. The pump is located at the bottom of the tube-well. With this system, the farmers can pump continuously for about 3 hours before the collection chamber is empty. With this system, most farmers can irrigate up to 3 hours in the morning and then for another 2 to 3 hours in the evening.

Field Survey Methods

The field survey consisted of extensive groundwork and questionnaires for the farmers. Each well identified in the Valley was registered: type, geographic location, total depth, static groundwater level, and pumping gear. For all wells, water temperature, pH, and electrical conductivity were measured.

The questionnaire for the farmers was aimed to gather information on the well history (i.e., its year of

construction and water yield development over the years), the area irrigated and the crops grown, pumping practices and irrigation method used.

In total, 165 wells were surveyed in the area (Fig. 1). From 37 representative wells, water samples were taken and analyzed in the laboratory for their contents of salts. Sodium Adsorption Ratios (SAR) were calculated to assess the suitability of the water for irrigation.

RESULTS AND DISCUSSION

Tube-well Inventory

An inventory of the wells in the Khanasser Valley (Hoogeveen and Zöbisch, 1999) showed that, in 1998, 154 wells were used for irrigation of wheat, barley, and cotton from the unconfined aquifer. The first irrigation wells in the area were drilled between 1975 and 1978 in the villages of Qorbatieh, At Shaneh, Sirdah, and Khanasser. However, a rapid development of wells began around 1990. The main driving force for the rapid increase in wells was that the few farmers who started irrigation in the Valley were very successful. Then, many other farmers also invested in irrigation.

Between 1990 and 1995, 82 wells were drilled, which is 56% of the total number of wells in the Valley. Farmers who had the first irrigation wells in the Valley complained that the duration they can pump water until the wells run dry, has decreased from 24 to about 5 hours a day, since more farmers started to drill wells.

Fig. 1 shows that most of the wells are located in the northern part of the center of the Valley. In this area, the layer of black sand and pebbles (*Rommel Furat*) is present (see before). According to the

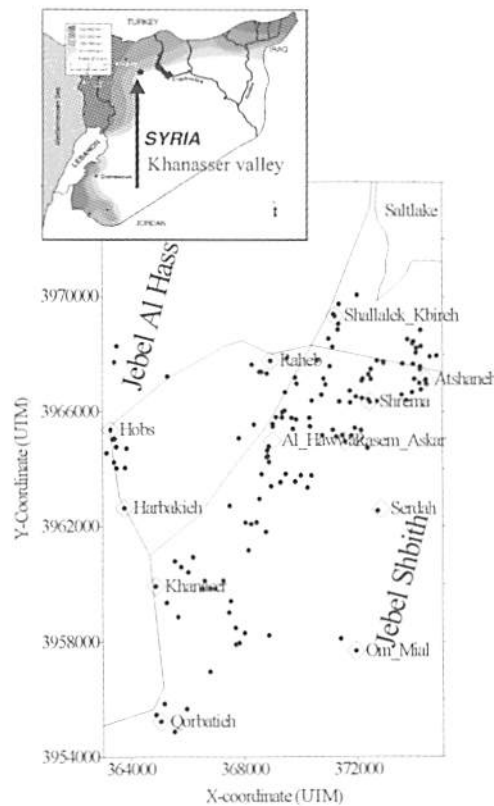


Fig. 1. Location of wells in the Khanasser Valley.

farmers, this is the best aquifer, and it allows pumping more water than in the other parts of the Valley.

Groundwater Extraction

In 1975, the total irrigated area in the Valley was only 5 ha. Until 1990, this area expanded to around 100 ha and, in 1998, the pumping capacity in the Valley could irrigate around 450 hectares. However, the actual irrigated area in the Valley in 1998 was only around 150 ha (Nielsen, 1999). According to farmers, the groundwater was not sufficient to irrigate all the fields they had hoped to irrigate. However, more farmers want to drill wells and construct *daharas* because the returns from irrigation, they claim, are still significantly more attractive than from rainfed barley farming.

Irrigation farming has only a short history in the Valley and farmers cannot be considered as traditional irrigation farmers. Basin flooding is the only irrigation method used. Systematic irrigation scheduling is not practiced, and farmers irrigate when they feel that moisture is needed, without any specific justification for it. Regardless of the type of crop and growth stage, approximately 50 mm of water are applied for each irrigation. For cotton, water is applied as much as 20 times over the growing season (van de Steeg and Zöbisch, 1999). There is certainly a lot of scope for improve-

ment of the irrigation methods applied and more economical irrigation-water use. From the well survey, the total water extraction from the wells for irrigation was estimated around 7.7 million cubic m for the entire Valley.

Groundwater Levels and Flow System

The groundwater levels were measured throughout the Valley (Fig. 2). During the field survey, the water level of the Salt Lake was 314 m above sea level. For the groundwater-level iso-height map, only groundwater levels were used of wells that were not pumped at that time or had not been used for a few hours. The groundwater levels in Khanasser Valley generally follow the topography of the area. On both sides of the Valley, in Jebel Al Hoss and Jebel Shbith, the groundwater level is high compared to that in the Valley. In the southern part of the Valley, groundwater flows underground from the western (Jebel Shbith) and eastern (Jebel Al Hoss) mountain to the Valley. From there, it flows underground to the south in the direction of the Village of Qorbatieh. In the northern part of the Valley, the water flows underground from both mountains and is then pumped from the wells in the area of Shallaleh Kbireh and At Shaneh.

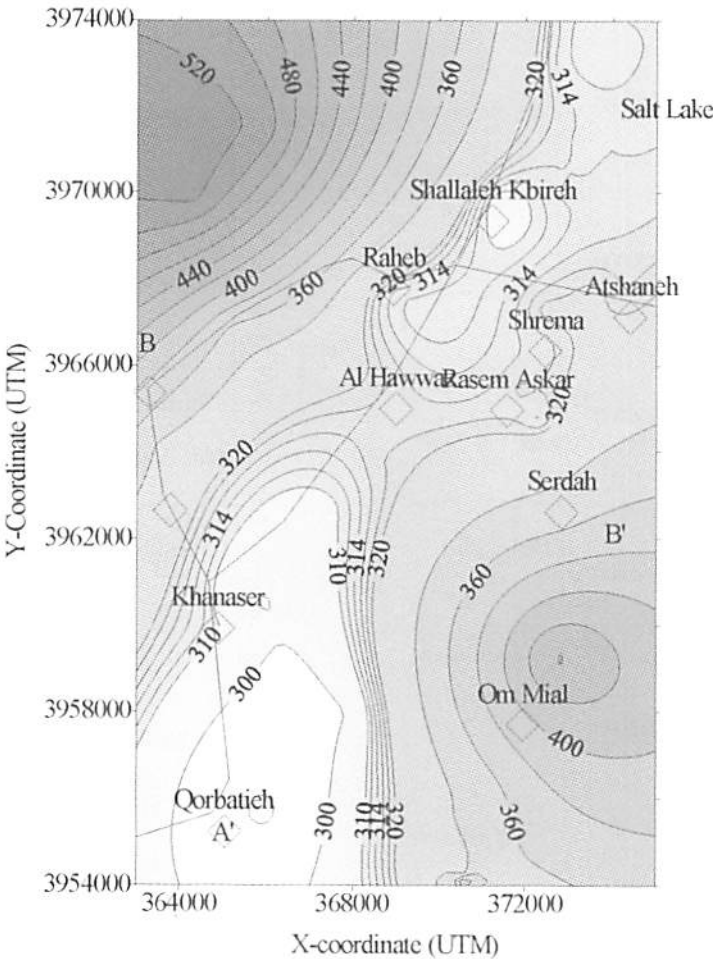


Fig. 2. Groundwater levels (m above sea level) in the Khanasser Valley in 1998.

When the farmers irrigate their crops, they empty the collection chamber of the Arab well on average twice a day. This means that a drawdown cone develops around the well that lasts until the well is refilled. This cone is enlarged because of the horizontal holes (*daharas*) drilled around the collection chamber. As some of these holes are 250-m long, the wells are effectively closer to each other, and the drawdown cones overlap, especially in the central northern part of the Valley. This causes a larger regional lowering of the groundwater level, especially in the area between Shallaleh Kbireh and At Shaneh. In this area, the drawdown effect of surrounding wells that were pumped could be observed very clearly; the water level was below that of the Salt Lake, causing water from the Lake to flow towards the wells of that area.

In the area around Al Hawwaz, the groundwater levels ranged between 314 and 320 m above sea level. In the beginning of the summer of 1998, when the measurements were made, more than half of the wells in the Valley were pumped to irrigate summer crops. Nielsen (1999) estimated that a total area of 100 to 150 ha of cotton is irrigated in the Valley. About 13 ha of cotton are irrigated on the village territory of Al Hawwaz alone. In this area, no drawdown was observed, but it is expected that during the summer months, periodically, groundwater levels drop so that water from the Salt Lake may reach the unconfined

aquifer. The high permeability of the extensive sand and pebble layer of the aquifer, which extends up to Al Hawwaz, enhances this groundwater flow from the Salt Lake into the unconfined aquifer. When water from the Salt Lake has reached the village of Al Hawwaz, it may flow to the south of the Valley towards the lower groundwater levels in Qorbatieh.

Salt-Water Intrusion

In the previous section, it was postulated that water from the Salt Lake could enter the unconfined aquifer in the center of Khanasser Valley. Fig. 3 shows the effect of this salt-water intrusion on the electrical conductivity (EC) of the groundwater in the Valley. The EC of the water of the Salt Lake reached up to 43 dS m⁻¹ in early summer of 1998, and the water was of the sodium chloride (Na⁺Cl⁻) type, with sodium and chloride are the dominant ions in the water as used in the "Stuyfzand"-classification (Stuyfzand, 1993). Towards the south, EC values dropped to 20 dS m⁻¹ for the groundwater of the area between Shallaleh Kbireh and At Shaneh. Further to the south, the values decreased to 10 dS m⁻¹, while in the area around Qorbatieh, they dropped to 2 dS m⁻¹. In the early 1960s, the highest EC values measured in the Valley were 4.7 dS m⁻¹ (Technoexport, 1964). This indicates that, since that time, salt-water intrusion has affected a large area of the center part of the Khanasser Valley.

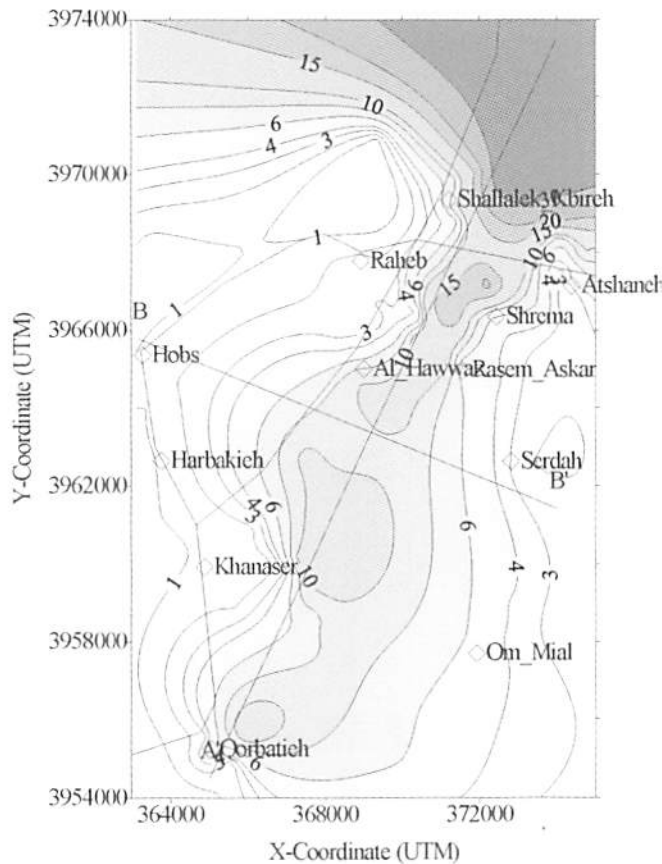


Fig. 3. Spatial distribution of electrical conductivity (dS m⁻¹) of the groundwater in the Khanasser Valley.

Also, the groundwater types changed in the Valley. The mixed-type, no dominant cation or anions, that was identified by Technoexport (1964) in the early 1960s is no longer present in the area. The magnesium-calcium-mixed-chloride type water that is found between 8 and 15.5 km south of the Salt Lake is a typical example of a water type resulting from salt- water intrusion. The Na^+Cl^- water enters an aquifer in which sweet water of the type magnesium-calcium- mixed was present. In this sweet-water aquifer, the cation exchangers have absorbed $\text{Ca}^{2+}/\text{Mg}^{2+}$. When Na^+Cl^- water enters, Na is exchanged for $\text{Ca}^{2+}/\text{Mg}^{2+}$ and the water type becomes $\text{Ca}^{2+}/\text{Mg}^{2+}\text{Cl}^-$ (Appelo and Postma, 1993). The water type close to the Salt Lake is Na^+Cl^- .

It is most likely that the exchangers in the aquifer have exchanged the $\text{Ca}^{2+}/\text{Mg}^{2+}$ with the water, and now that Na is absorbed to the exchangers, the water is in equilibrium and no further $\text{Ca}^{2+}/\text{Mg}^{2+}$ ions are exchanged.

A particularly interesting area exists further south, between 16.5 and 17.5 km from the Salt Lake. Here, the water is of the sodium-sulphate ($\text{Na}^+\text{SO}_4^{2-}$) type, which suggests freshening of the aquifer. Fresh water of the calcium/magnesium-sulphate ($\text{Ca}^{2+}/\text{Mg}^{2+}\text{SO}_4^{2-}$) type enters the aquifer; it exchanges the cations with the Na ions that were attached to the exchangers in the aquifer (Appelo and Postma, 1993). The resulting water type is $\text{Na}^+\text{SO}_4^{2-}$. This sweet-water front can also be seen on the EC map in the area around Khanasser Village. It is caused by sweet groundwater coming from a small side-valley of the Jebel Al Hoss Mountain in the west. This freshening of the aquifer probably happens every year in spring.

At the front of the salt-water intrusion, the water is of the sodium-mixed/chloride type. No exact reason for this can be given at this moment, but it might be that the salt-water intrusion did not reach this area yet and the EC is increased by irrigation return-flow. It could also be possible that this water is a mix of the freshening water, the irrigation return-flow, and the intruding Salt-Lake water, and that therefore no specific type can be identified.

Soil Salinity Hazard

The water that results from the saltwater intrusion is already causing problems to some farmers in the Valley. Two farmers in the village of Shreema in the northern part of the Valley cultivated cotton in 1998, but the cotton did not grow beyond 10-cm height. According to the farmers, this was caused by "salt in the water". The EC of the water from this well was 23 dS m^{-1} , which indeed represents an extreme degree of salinity. In the center of the Valley, the SAR ranges between 6 and 12. According to the USDA assessment system for irrigation-water quality (Richards, 1954), the water in the Jebel Al Hoss Mountain (in the west), around the villages of Al Hobs and Harbakieh, has a medium-salinity hazard and a low to medium-sodium hazard. The water in Shbith Mountain (in the east) has a high salinity hazard and a low to medium sodium hazard. In the rest of the Valley, the water has a high to very high sodium and salinity hazard. This indicates that irrigation with this groundwater will lead to soil salinization.

A survey of soil salinity in the area by van de Steeg and Zöbisch (1999) revealed that the irrigated soils showed levels of soil salinity which are at the limit of the salt tolerance of most crops (Table 1). The highest accumulation of salts was at 40-60 cm depth, i.e., within the root zone of most irrigated crops. The differences between rainfed fields and irrigated fields are striking, considering that irrigation has only been practised for a relatively short period. The expected potential reduction of crop yields for barley, wheat, and cotton, due to salt accumulation in the soil, are given in Table 2. The figures show that the irrigated soils in the Valley are approaching the limits of salt tolerance of the grown crops, and demonstrate clearly the degradation potential of irrigation in the area.

Table 1. Range of soil-salinity characteristics in rainfed and irrigated fields.

	Soil Depth	Electrical Conductivity, EC ¹		
		Min	Mean	Max
	-----cm-----	-----dS m ⁻¹ -----		
Rainfed	0-20	0.1	0.3	0.4
	40-60	0.7	1.1	1.5
	80-100	0.9	3.3	5.6
Irrigated	0-20	0.1	8.0	17.3
	40-60	2.4	10.3	16.4
	80-100	3.9	9.3	19.7

¹values determined in the saturation extract. Source: (Van de Steeg and Zöbisch, 1999).

Table 2. Salinity rating for irrigation water and yield decrease for irrigated barley, wheat and cotton¹.

Irrigation Water Salinity-Rating	EC -dS m ⁻¹ -	Crop	Potential Yield Reduction	
			25% at EC	50% at EC
Not saline	< 4		--- (dS m ⁻¹)---	
Slightly saline	4-8	Barley	13	18
Moderately saline	8-15	Cotton	13	17
Strongly saline	> 15	Wheat	10	15

¹(modified after Richards, 1954, and Landon, 1996).

CONCLUSIONS AND RECOMMENDATIONS

Since the introduction of irrigation in the Valley, the groundwater resources have deteriorated, both in quantity and quality. The development of irrigation has shown to be inappropriate and detrimental to the soils in the area. If this development continues, large parts of the Valley will be rendered unproductive due to salinity. However, the farmers in the Valley are under great pressure to intensify production in order to make ends meet. Regulatory arrangements will assist in the better management of the water resources, but they will not completely prevent more wells to be drilled before the entire aquifer will have turned saline. The pressure on the land and water resources in the Valley is high.

The change of crops and cropping patterns is an option towards a more intensified, but also water-saving, land use. Permanent crops, such as fruit trees and shrubs, would increase the water-use efficiency and thus reduce water consumption. The choice of change has to be made attractive to the farmers through incentives that help make the necessary investments and assist in the marketing of new crops. Appropriate groundwater use, and conservation of the water resources, will only function if it pays for the farmers.

The introduction of more appropriate irrigation methods and management practices will probably contribute most significantly to a general saving of water. However, the change of irrigation methods will require heavy investments. Public agencies are required to provide credit to farmers at acceptable terms.

Another feasible way could be the costing of water, which, at present, is free of charge. *Suitable ways of valuing the water and charge water fees could contribute to a more careful use.* These regulatory arrangements cannot be taken without consulting and close cooperation with the farmers of Khanasser Valley. Therefore, research appropriate ways of on-farm irrigation-water management is recommended to develop systems and/or methods, which result in sustainable groundwater use and are supported by the farmers.

REFERENCES

Abrol, I.P., J.S.P. Yadav, and F.I. Massoud. 1988. Salt-affected soils and their management. *FAO Soils Bulletin 39*. FAO, Rome. Italy.

ACSAD. 1984. *Water resources map of the Arab countries*. The Arab Center for the Studies of Arid

Zones and Dry Lands, Damascus, Syria.

Appelo, C.A.J., and D. Postma. 1993. *Geochemistry, groundwater and pollution*. A.A. Balkema, Rotterdam, The Netherlands.

Hoogeveen, R.J.A. and M. Zöbisch. 1999. Well inventory and groundwater in the Khanasser Valley, Syria. *Report on a field study in northwestern Syria*. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. *Mimeo*. 58 p.

Landon, J. R. (Ed.). 1996. *Booker Tropical Soil Manual*. Addison Wesley Longman Ltd., London, UK.

Louis Berger International. 1982. Land classification and soil survey of the Syrian Arab Republic. Volume 2 (Reconnaissance Soil Survey of Syria, 1:500,000). Louis Berger International Inc., Remote Sensing Institute of South Dakota University, and United States Agency for International Development, Washington DC, USA

Nielsen, T.L. 1999. Land-use inventory for the Khanasser Valley, Syria. *Report on a field study in northwestern Syria*. *Mimeo*. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria

Richards, L.A. (Ed.). 1954. Diagnosis and improvement of saline and alkali soils. *Agriculture Handbook No. 60*. Agricultural Research Service, United States Department of Agriculture, Washington DC, USA

Skogerboe, G. 1991. Soil and water management of irrigated lands. In: J. Skujinš (Ed.) *Semiarid Lands and Deserts - Soil Resource and Reclamation*. Marcel Dekker Inc., New York, 605-632.

Soumi, G. 1991. Supplemental irrigation systems of the Syrian Arab Republic (SAR). In E.R. Perrier and A.B. Salkini (Ed.). Supplemental irrigation in the Near East and North Africa, *Proc. workshop on "Regional Consultation on Supplemental Irrigation"*, p. 497-511. ICARDA and FAO, 7-9 Dec. 1987, Rabat, Morocco. Kluwer Academic Publishers. Dordrecht.

Stein, T. 1998. Erarbeitung und Überprüfung von Entwurfskriterien für Gefäßbewässerungsanlagen. Supplement 66, *Der Tropenlandwirt - J. Agriculture in the Tropics and Subtropics*, Witzenhausen, Germany

- Stuyfzand, P.J. 1993. Hydrochemistry and hydrology of the coastal dune area of the western Netherlands. KIWA N.V. Research and Consultancy Division, Nieuwegein, The Netherlands.
- Szabolcs, I. 1998. Salt buildup as a factor of soil degradation. *In* Methods for Assessment of Soil Degradation. *Advances in Soil Science*. R Lal et al. (Ed), p. 253-264. CRC Press, New York.
- Technoexport, 1964. The geological map of Syria, 1:200.000, and explanatory notes. Syrian Arab Republic Ministry of Industry Department of Geological and Mineral Research, Damascus.
- Van de Steeg, J.A., and M. Zöbisch. 1999. Effects of saline irrigation water on the biomass production of irrigated field crops and salt accumulation in the root zone. *Progress report* on a field study in Khanasser Valley, northern Syria. International Center for Agricultural Research in the Dry Areas, (ICARDA), Aleppo, Syria. *Mimeo*
- Wolff, P. 1997. The problem of sustainability of irrigation systems. *Z. f. Kulturtechnik und Landentwicklung* 38, 54-57.

Wadi Hydrology for Sustainable Dryland Development

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ABSTRACT

With increasing population and limited water resources in the Arab region, the water issue is gaining increasing importance every day. This paper addresses *wadi* hydrology, as an important, though often neglected component of the water budget of the region. First, basic characteristics of arid and semi-arid zones are presented. Then, the water scarcity problem in the Arab region is addressed. Wadi water flows, though intermittent and rare, are introduced as a viable source of high-quality fresh water. The major scientific, technological, and managerial constraints and deficiencies in the region, which handicap the full utilization of this resource, are addressed. UNESCO's International Hydrological Program (IHP) has been overviewed, and the most recent activities in the field of *wadi* hydrology, and plans of action to overcome these deficiencies, are presented.

INTRODUCTION

Countries of the Arab region are confronted with several water problems due to both climatic conditions and socio-economic factors. From an eco-climatic point of view, most of the region extends across semi-arid, arid, and hyper-arid zones. The semi-arid belts have been particularly affected by cycles of drought and desertification in the past decades. Socio-economically, the region is characterized by a fast increasing population, which has resulted in a sharp decline of the per capita availability of water, from about 2200 m³ per year to less than 1000 m³ per year within the past 25 years.

In response to these concerns, many countries have adopted policies for the sustainable management development and efficient utilization of their water resources. However, due to increasing water scarcity and reduced per capita availability, many countries have recognized the urgent need to secure and utilize new supplies of water in order to sustain a minimum resource base. For many countries, the development and efficient utilization of the renewable sources of water in *wadis* is the only optimal solution for addressing water shortage problems. The efficiency of harnessing water from *wadis* depends on the understanding and knowledge regarding the qualitative and quantitative hydrology and water resource potential of *wadi* systems.

Wadi is the name given to an ephemeral water-course in the Arab region, yet it is increasingly recognized as an international name used in most

hydrological publications all over the world. Despite its important role as a vital source of water in many Arab countries, as well as other arid areas of the world, catastrophic flash floods occurring in *wadis* represent a major threat to communities living close to these *wadis*. Furthermore, the scientific understanding and knowledge of its hydrological processes are rather poor in most of these countries. The current IHP-V 'Wadi Hydrology' action aims mainly to enhance the knowledge and understanding on *wadi* systems, and to develop the human and institutional capacities needed for the sustainable management of *wadis* and their water resources in arid and semi-arid areas.

This paper presents *wadi* water flows as a viable source of high-quality fresh water for arid and semiarid zones. First, basic characteristics of arid and semiarid regions are presented. The water scarcity problem in the Arab region, representing one of the major arid regions in the world, is briefly overviewed. Then, major aspects related to sustainable management of *wadi* systems are discussed. UNESCO's IHP program is introduced and the most recent activities and plans of action in the field of Wadi Hydrology are presented.

BASIC CHARACTERISTICS OF ARID AND SEMI-ARID ZONES

General

Arid and semi-arid zones refer to those regions in the world where dry climates prevail. Arid lands can be mainly found in Northern Africa, West and Central Asia, Southwestern Africa, Australia, and on the American continents in Southwestern USA, Mexico, Peru, and Chile. The term aridity, however, is ambiguous with various definitions having evolved, originating from different backgrounds such as climate, soil, vegetation, human settlement, land use, etc.

Definitions of arid lands can generally be based on two different approaches, either of descriptive nature, or of quantitative character based on measurable parameters. The descriptive approaches focus on the literal meaning of the word "desert". Approximately one third of the earth's surface is actually desert, with almost as many definitions of desert as there are deserts in the world. Heathcote (1983) has listed definitions that evolved through the period 1225 to 1968. Generally, the term desert is characterized by low annual rainfall and a potential evapotranspiration that exceeds rainfall by far. Deserts, therefore, support only sparse vegetation and small populations of people and animals. Other climatic parameters such as temperature can vary

widely, as do the geologic features to be found in deserts.

The most known quantitative definitions of arid climates have been based upon annual precipitation in relation to evapotranspiration, annual rainfall distribution, and average temperatures. Meigs' (1953) contribution, based upon the work of Thornthwaite, as well as to some extent on Köppen, is somehow widely accepted. Meigs divides arid regions of the world into three categories: *extremely arid lands*, *arid lands*, and *semi-arid lands*. Extremely arid lands have at least 12 consecutive months without rainfall, arid lands have less than 250 mm of annual rainfall, and semi-arid lands have a mean annual precipitation of between 250 and 500 mm. Arid and extremely arid land are usually referred to as deserts, while semi-arid grasslands are generally called steppes.

Typical temperatures in the arid regions vary widely. In the Arab countries, for example, average daily temperatures of 5° C or less are experienced in January in Morocco and Lebanon in mountainous areas along the Mediterranean coast. Average winter temperatures increase to 15 and 20° C traveling inland. In summer, temperatures in the coastal areas are between 20 and 30° C, while inland temperatures reach much higher levels. Temperatures in excess of 50° C have been recorded in some regions of the Great Desert, as well as some parts of the Arabian Peninsula and Iraq. Daily temperature fluctuations are considerable in the desert environment, where, especially in the winter season, night temperatures can drop as low as 0° C (UNESCO/ACSAD/IHE, 1988).

Hydrological Characteristics

While arid and semi-arid lands are usually classified by their average annual rainfall, ranging from 500 mm in the sub-humid zone to less than 25 mm in the extreme arid zone, the most striking hydrological characteristic of the arid and semi-arid zones is not only the low amount of rainfall, but the variability, both in time and in space, of the rainfall occurrences. A typical rainstorm in a desert is usually of *short duration*, *high intensity*, and *occurs locally*. Periods up to several years without significant rainfalls are common.

Permanent surface water resources are limited in the arid and semi-arid zones, and confined to few well-known international rivers, shared by two or more states. Typical examples are the Nile, Tigris, Euphrates, and Indus, which originate from catchment's areas with higher rainfall. In addition to those few perennial rivers that traverse a number of arid and semi-arid locations, a greater number of ephemeral streams (called *wadis* in the Arab region) with wider geographical distribution, exist and serve as the most important source of water supply in the arid and semi-arid regions around the world. These seasonal rivers are characterized by sharp flow fluctuations, and periods of drought sometimes exceeding eight months, and even several years in some regions (Al-Eryani, 1997).

Therefore, the lack of permanent surface water resources in most parts of the arid and semi-arid zones, has led to greater dependence on the scarce precipitation, and consequently to the development of ingenious methods of water harvesting in many parts of the arid and semi-arid world. Famous examples are the "fog harvesting" in the Andes Mountains, Hafirs in Sudan, and various floodwater harvesting and management techniques in different countries of North Africa and the Arabian Peninsula (Khouri et al., 1995).

More on the characteristics of rainfall processes and their relation to evaporation and evapotranspiration, infiltration and runoff is given in the sections below with emphasis on the Arab region. Needless to say, these characteristics would follow similar trends in other arid and semi-arid areas of the world.

Evaporation and Evapotranspiration

Evaporation in arid and semi-arid zones is high due to high temperatures, low relative humidity, and the abundance of heat energy resulting from net solar radiation. In the Arab countries, for example, evaporation from free water surfaces along the southern and eastern coasts of the Mediterranean Sea could be well below 1000 mm/year. This value increases inland to about 2000 mm/year, while in the desert areas of North Africa evaporation reaches 3000 mm/year. Figures from the Arabian Peninsula indicate potential evaporation of around 2500 mm/year (Khouri et al., 1995).

Evaporation can be determined through direct measurements, by using empirical formulas built on climatic observations, or by utilizing evaporimeter measurements as indices to evapotranspiration. The lack or poor quality of climatic data can form problems in using some of these methods in many of the arid zones. The siting of weather stations and the selection of the most suitable method can also affect the results obtained from these methods. Further impediments are vagueness in the definitions of aridity, shortage in climatic and direct measurements data, little knowledge on the effect of siting and advection in climatic measurements, and the controversial definitions of evapotranspiration terms, i.e., potential, reference, crop, etc (Salih, 1988).

Rainfall Distribution and Characteristics

Variation and distribution of rainfall in arid countries are reviewed below through a few selected examples from the Arab region. The northern parts of the Arab region are exposed during winter to a number from low atmospheric pressure zones, causing cold fronts of Siberia and the Atlantic Ocean to pass over the Mediterranean Sea, where they are saturated with humidity, and consequently cause rainfall. Progressively, the amount of rainfall diminishes as the fronts pass over the mountain ranges of the coasts and become meager over Jordan, North Iraq, and Saudi Arabia. Similarly, several tens of kilometers inland in

Libya and Egypt, rainfall disappears. In the southern Arab states, on the other hand, high atmospheric pressures concentrate over the Indian Ocean during summer, and the seasonal monsoon winds cause saturated air masses to pass over the coasts of Somalia and the Arabian Sea. Rainfall occurs on the slopes of the mountains along the coasts, without reaching further inland. Thus, the mountainous ranges on the Mediterranean Sea, the Red Sea, and the Atlantic Ocean play a major role in the rainfall distribution over the Arab region.

In addition to the orographic effect, a number of Arab states in the east, such as Lebanon, Syria, Iraq, Jordan and the north of Saudi Arabia, receive rainfall during spring due to frontal cyclones. These rains are characterized by short precipitation periods ranging between a few minutes and an hour or more, and by high intensities reaching 100 mm/hour, resulting in high, and sometimes destructive, flood waves.

In reviewing recent studies, Khouri (1997) reports that the total average annual precipitation over the Arab states is being estimated at 2605 billion m³. However, as is shown in Table 1, more than half of the total area of 14,232,000 km² of the Arab countries, receives less than 100 mm annually, and consequently only 14% of the total annual rainfall. Less than 29% of the total precipitation falls in about 30% of the area with an average annual rainfall between 100 and 300 mm. More than 40% of the total rainfall in the Arab countries is, however, received outside the arid and semi-arid zones, with average rainfall rates of 500 mm and more.

Table 1. Rainfall distribution over the Arab region.

Rainfall Range	Area	Quantity	Rainfall
	-----%-----		--10 ⁹ m ³ /year--
< 100 mm	52	14.1	367
100 - 200 mm	22	17.8	464
200 - 300 mm	8	10.8	281
300 - 500 mm	7	15.0	391
> 500 mm	11	42.3	1102
Total	100	100	2605

Source: ACSAD (1997).

Taking the total amount of rainfall divided by the total area, the average annual rainfall over the Arab states does not exceed 180 mm. It is unfortunate that only 200 billion m³ of the total amount of rainfall received is actually accounted for as renewable surface water and groundwater sources (UNESCO, ACSAD, IHE, 1988). Therefore, a large untapped amount of rainwater is being lost annually and could partially be harvested if better managerial techniques were developed and adopted.

Knowledge of the characteristics of rainfall is the most important climatic parameter used for estimating average and maximum flows in *wadis*. In moderate climatic conditions, average annual precipitation has a

standard deviation of 10 to 20%. With a 95% probability, i.e., 19 out of 20 years, the single value ranges between 75 and 125%. Variability is, however, much greater under arid and semi-arid climatic conditions. The range of minimum and maximum annual precipitation exceeds by far the figures of the temperate climates, while the probable distribution diverges more from the uniform distribution. In those areas, where the average annual rainfall is in the range of 200 to 300 mm, the single value ranges between 40 and 200% (95% probability). This becomes 30 to 350% for areas with an average annual rainfall below 100 mm. These figures show that the coefficient of variation for the annual precipitation at a certain place is inversely proportional to the average annual rainfall. Thus, it is obvious that the drier regions can experience several years without rainfall.

Rainfall-Runoff Processes

When rain falls, a portion of it is retained as "surface retention", which comprises interception by vegetation and depression storage; another portion serves to increase the soil moisture, and part will infiltrate into the soil recharging the groundwater layers. Runoff develops only when the rainfall intensity exceeds the infiltration capacity of the soil, which depends on many factors such as soil type, moisture content, organic matter, and vegetation cover. Typically in arid and semi-arid areas, the impact of rainfall on bare soil leads to soil crusting, which has an adverse effect on the infiltration capacity. Surface runoff, however, occurs at low rainfall intensities, due to the presence of this surface crust (Abu-Awwad and Shatanawi, 1997).

Direct runoff is comprised of surface runoff (overland flow) and interflow, while stream flow consists of both surface runoff and groundwater base-flow. Since recharge is low in arid zones compared with temperate regions, groundwater base flow into *wadis* usually constitutes a minor proportion of the total flow. Direct runoff dominates the cumulative runoff in semi-arid catchments.

The combined effects of the presence of a surface crust, coupled with high intensity and short-duration convective rainfall, typical in arid and semi-arid areas, leads to extensive overland flow. Converging into the *wadi* channels, this results in flood flows to be generated. However, due to the spottiness of the spatial rainfall, the generated runoff is most likely to be localized in space (Wheater, 1997).

Conventional analysis of rainfall-runoff relationships in arid and semi-arid regions is difficult. Rain-gauge networks, set up according to conventional densities, do not register all rainfall, due to the spottiness of the spatial rainfall pattern. Combined with the effect of flood transmission losses, it therefore can occur that a flood is observed without measuring significant rainfall in any of the sites where a gauge is located. Wheeler (1997) quotes previous studies in Wadi Ghat in Saudi Arabia, where runoff coefficients ranged from

5.9 to 79.8%: the greatest runoff volume was generated by the smallest observed rainfall.

Wadi bed infiltration not only has an important effect on flood propagation, but also provides recharge to alluvial aquifers. Comparing distributed infiltration from rainfall (soil surface) with *wadi* bed infiltration,

sub-regions and individual countries. However, even if one hypothetically accepts the highest values of renewable regional resource indicated above as correct, the Arab region currently still suffers from a great scarcity in its per capita annual water resources; and the problem is expected to increase drastically with time.

Table 2. Total water resources of the Arab region.

Reference	Renewable Water Resources			Non-Renewable Groundwater
	Surface Flow	Groundwater Recharge	Total	
	-----10 ⁹ m ³ /year-----			-10 ⁹ m ³ -
Rostas, 1988	295	41	336	14215
Khour, 1990	282	35	317	13498
ALECSO, 1992	307	45	352	7700
Saad, 1993	307	40	347	19573
Abu Zeid, 1995	352	-	-	-
ACSAD, 1994 ¹	295	45	340	-
Khour, 1995	-	-	300	-
Population Action Inter., 1995	-	-	405	-
Gleick, 1993	-	-	411	-
ACSAD, 1997	225	39	264	-
Average	306	41	351	13745
Highest Variation from Average	24%	15%	21%	44%

¹Source: Khour (1995), Salih (1999).

Wheater (1997) points out that soil moisture observations from SW Saudi Arabia indicate that distributed infiltration of catchments soils is limited and that increased near surface soil moisture levels are subsequently depleted by evaporation. Therefore, *wadi* bed infiltration seems to play a dominant role in groundwater recharge. The characteristics of the resulting groundwater resource will depend on the underlying geology, but bed infiltration may generate shallow water-tables within a few meters of the surface, which can sustain supplies to nomadic people for a few months (as in the Hesse of the north of South Yemen), or recharge substantial alluvial aquifers with potential for continuous supply of major towns - as in northern Oman and SW Saudi Arabia (Wheater, 1997).

ARAB REGION WATER SCARCITY

In spite of the voluminous reports and papers written by authoritative sources, it is unfortunate that a wide range of variation is still found in the numerical values indicating the water budget of the Arab region, its sub-regions and the individual countries. As an example of such variations, Table 1 indicates the numerical values of the total volume of traditional renewable and non-renewable water resources at the regional level. The maximum variations from the average value range from 44% in the non-renewable case to 15% in the renewable sources. The extents of these variations are, certainly, much higher in going down to the levels of the

Salih (1994) has clearly demonstrated the uneven distribution in the availability of water resources between the various regions of the World, indicating that the worldwide lowest per capita availability lies within the Arab region, which, unfortunately, has also the highest rate of worldwide annual per capita reduction in these resources. This critical situation has led to current speculations of ultimate water conflicts and confrontations in this region. These hasty conclusions are reached, basically through subjective definitions of "scarcity limits", using worldwide yardsticks that are usually based only on conventional renewable water resources.

The available information in the quoted literature has been utilized in Table 3 to analyze, in a broad regional manner, the future of the per capita renewable water resources. All the numbers of the base year 1990, as well as the indicators for future forecasts, are selected, based on the author's judgment, from ALECSO (1992) report on "Detailed Program for the Preparation of Arab Water Security". A total of 264 × 10⁹m³/year for the renewable water resources was utilized based on Khour (1997), being the most conservative estimate.

No doubt, all of the values in Table 3 are subject to the same limitations of accuracy mentioned previously and would hence represent only order of magnitudes demonstrating broadly the actual status of the issue. Considering the above limitations and the assumptions

in the remarks column, it is obvious that the regional per capita annual water resources of 1.17 thousands cubic meters in 1990 is much lower than the average corresponding value for the world, estimated by Serageldin (1995) as 7.40 thousands cubic meters. It is also demonstrated in the Table that the year 1995 marks a decline of the per capita's share to less than the internationally assumed scarcity critical limit of 1000 m³, while by the year 2000 the regional water demand will hardly equal the available renewable resources. The picture will look more critical if viewed at the country's level in considering deterioration in quality, annual supply variations as well as problems related to share resources.

appreciable loss of life and property. The amount of water generated in these floods can, however, be considerable. Floods in Upper Egypt during the period of 12-17 November 1996, for example, contributed 154.5 million m³ to the river Nile alone. This amount is equivalent to the average daily water release from the High Aswan Dam to satisfy Egypt's daily water needs (Abu Zeid, 1997).

Conventional flood-design practices often include costly structures, such as flood mitigation reservoirs, retarding dams, levees, floodwalls, and floodways. The aim of these structures is mainly re-routing of the precious water source and, hence, wasting the floodwater. However, a better approach to floods is to try to

Table 3. Water budget of the Arab region up to 2030.

Year	1990	2000	2010	2030	Remarks
Parameter					
Population, millions	226	304	408	758	Using a growth rate of 3% per year
		-----10 ⁹ m ³ /year-----			
Renewable Water Resources	264	264	264	264	Using Khouri's (1997) as a conservative value
Water Demand	200	269	362	671	1990's base demands were averaged from wide sources in the literature (1990's demand) Rate is assumed for other years.
Balance of Water Budget	64	-5	-98	-407	Year 2000 represents the critical period of full utilization of resources.
		-----10 ³ m ³ /year-----			
Per Capita Water Resources	1.17	0.87	0.65	0.35	Mid nineties represented the beginning of scarcity

Source: Salih (1999).

On the positive side, however, are the opportunities provided through non-conventional resources such as desalination and re-use as well as current appreciation of the need for strict demand-management policies. As is shown below, *wadi* water flows, though intermittent and rare, can present a viable source to augment the scarce water resources in many countries of the region.

SUSTAINABLE MANAGEMENT OF WADI SYSTEMS

As pointed out in the previous sections, better knowledge of the hydrological processes is a mandatory prerequisite for sound water resources management in *wadis*. Some other aspects relevant to water resources management in *wadis* are highlighted below.

Technical Aspects

Floods are among the most damaging and high-ranking natural disasters that occur every year in various parts of the arid and semi-arid regions, including the Arab World. It is ironic that in countries that usually suffer from severe water shortage, floods are responsible for

mitigate the effects of the flood while at the same time aiming to maximize the benefits from the valuable floodwater. Various techniques are available; floodwater spreading, an easy and economical method of flood damage mitigation, in which flood water is treated as a scarce resource, is one of them.

That floodwater-spreading systems can mitigate the damage of floods is shown in the case study of the Gareh Bygone plain in Iran (Kowsar, 1997). During an exceptional event, between 2-7 December 1986, some localities in Southern and Central Iran received nearly three times their mean annual precipitation, causing 424 deaths and major financial losses. However, in the study area, where floodwater spreading was practised, 1.5 times the mean annual precipitation inflicted damages upon the floodwater spreading systems amounting to only 2.5% of the losses that would have occurred had it not been mitigated by the systems. Although floodwater-spreading systems are usually designed for a return period of 15 years, the damages to the systems, in this event with a recurrence interval of more than 100 years, was surprisingly low.

Floodwater harvesting and spreading has a long tradition in the Arab World, as has been described in Khouri et al. (1995). Traditional methods of floodwater use for agricultural purposes, in micro-catchment's systems, macro-catchment's systems and spate irrigation, until today, play an important role in the water resources management in the Arab region and a growing interest in further development and reviving of harvesting and spreading methods exists. One of the techniques that have been receiving a lot of attention is artificial recharge to groundwater, through the construction of retaining dams in *wadis*, capturing especially the flash floods. The utilization of this technique is more obvious in the Gulf countries where many dams have been constructed for the purpose of artificial recharge and flood control.

Socio-Economic Aspects

Sound water-resources management should be based upon the social and economic circumstances existing within the boundaries of any water project. Although the importance of this statement is stressed in many reports, few specific cases can be found where the socio-economic dimension has been given its proper share during the planning, design, implementation, and management of such projects. The FAO (1994), in the expert meeting on water harvesting in Cairo in 1993, noted that *"during the planning phase of water harvesting project, often insufficient attention is given to social and economic aspects, such as land tenure, unemployment and involvement of beneficiaries. This has turned out to be a major constraint in water harvesting projects"*. The meeting recommended *"water harvesting projects should be planned, designed and implemented by multi-disciplinary team of experts in order to ensure that technical, social, economic and environmental aspects are adequately covered"*. The same can be said for water resources management; an integrated approach is highly needed right from the planning phases, through the implementation and operation phases, and including evaluation and monitoring.

Of special importance is the evaluation of the social and economic effects and impacts on water resources projects; this is essential for examining what the projects can do for the population and development of an area, and to continuously learn from these experiences. A good example can be shown from the beneficial effects of a water spreading project in Iran and its effect on emigration, where it has been described by Movahed (1997), in the Gareh Bygone area in Iran, where water is scarce, the introduction of floodwater spreading has clearly changed the future perspective of the community to the extent that mobility and migration to urban area has decreased.

Environmental Aspects

There is no success for any managerial plan in *wadis* if the environmental aspects are not given their proper role. The importance of the environmental dimension

has now been well recognized as of great influence on all elements of the hydrological cycle. In turn, terms like environmental hydrology, eco-hydrology, and/or comparative hydrology are increasingly receiving global recognition. The effects of quality aspects - chemical, biological, and physical - of the components of the hydrological cycle, can not at all be neglected. Real examples are the problems of acid rain and its effects on the soil and water resources in industrialized countries.

It is, therefore, increasingly and globally demanded to conduct environmental impact assessment (EIA) studies as part and parcel of all processes related to the planning, implementation and operation of water projects. This is especially important under arid conditions and in environments where its absence could lead to quick deterioration of the quality of surface and groundwater. It is unfortunate, even now, that many examples of untreatable contamination of critically important alluvial aquifers have been reported in many *wadis* in the Arab region. These catastrophes would not have occurred if the EIA concept was considered at the planning and implementation stages of these utilizations.

Institutional and Legal Issues

The institutional and legal aspects represent an important component of any management plan for *wadis*. Institutional framework and ownership issues are complex and diverse issues throughout the Arab region and need to be addressed accordingly in the planning phase of any project. Historically, legal aspects concerning the use of water on *wadis* have received great attention and the management of *wadi* water resources has been well accepted ever since and even before the introduction of Islamic law which institutionalized regulations such as the rights of upstream owners to use a given amount of water for their needs, leaving sufficient water for the next user along the course of a *wadi*. Current legislation in the Arab countries, however, mainly address the legal aspects of perennial rivers, as was clearly stated during a meeting on the legal aspects of water organized by ESCWA in Jordan (1996). It was felt in the conclusions of this meeting that there is a need for a regional initiative to develop a legal framework that addresses the specific problems of *wadis* and groundwater.

UNESCO'S INTEGRATED HYDROLOGICAL PROGRAM

Goals and Objectives

The general objectives of the IHP were set to improve the scientific and technological basis for the development of principal methods and techniques as well as providing the human resources base necessary for the rational development and management of water resources. Since the inception of the International Hydrological Decade (IHD) in 1965, and later the IHP

in 1975, great progress has been achieved regarding methodologies for water resources and management as well as in capacity-building in the water sector. Notwithstanding the attained achievements, the general objectives, unfortunately remain valid, but perhaps with some changes in emphasis. The main components of these changes include the current emphasis given to water resources management for sustainable development and the adaptation of hydrological sciences to cope with the anticipated climate change and the preservation of the environment.

Structure and Implementation

The IHP is planned, executed, coordinated, and monitored at global, regional, sub-regional and national levels. This is accomplished through 140 national IHP committees, the 36 members of the Intergovernmental Council (IC) of the IHP and its Bureau, committees, working groups, rapporteurs, Secretariat in Paris and six regional hydrologists, well distributed in the regions of the world. IHP programs are generally executed in close cooperation and great harmony with related UNESCO environmental programs (MAB, IGCP, IOC, etc.), other United Nations specialized organizations (WMO, FAO, WHO, UNEP, IAEA, ESCWA, etc.), regional organizations (ACSAD, ALECSO, etc.), non-governmental scientific organization (IAHS, IAH, IAHR, IWRA, etc.) and research and academic circles. It remains to be mentioned that the finances of the IHP projects are provided through UNESCO's regular and participation budgets, country's own resources, as well as extra-budgetary sources obtained from various funding agencies (UNDP, WB, UNEP, etc.)

Main Themes for the Current Cycle

In general, IHP-V (1996-2001) plans to stimulate a stronger interrelation between scientific research, application, and education. The emphasis should be on environmentally sound integrated water resources planning and management supported by scientifically proven methodologies. Within these major issues, eight themes, given below, have been identified as a support structure for the whole Program. They cut across different hydrological scales and different climatic regions, but have integrated water management in a vulnerable environment as a common issue. The proposed themes are seen as cornerstones within which projects could be flexibly implemented. Due to the special importance of water problems in the humid tropics and the arid/semi-arid zones, as well as in urban areas, these regions have gained increased attention.

The eight themes are:

- Global hydrological and biochemical processes.
- Eco-hydrological processes in the surficial zone.
- Groundwater resources at risk.
- Strategies for water resources management in emergency and conflicting situations.
- Integrated water resources management in arid and semi-arid zones.
- Humid tropics hydrology and water management.
- Integrated urban water management.
- Transfer of knowledge, information, and technology.

Any of these themes is divided into projects, which transform the theme into a practical experience with all its dimensions. To avoid a purely hierarchical structure of the IHP-V program, any theme should emphasize both methodological aspects as well as a process for knowledge transfer. All must include interactions in the biotic and abiotic environments as well as in decision-making. The products should be considered as the outcome of the worldwide efforts of member states, regional and international organizations. UNESCO, while conducting a large number of activities itself, will coordinate all IHP-related activities through the Intergovernmental Council of IHP-regardless of the method of implementation.

UNESCO's Contribution to Wadi Hydrology

With the increased pressure on conventional water resources and a growing demand due to major population growth throughout this century, the need for better knowledge and management of scarce water resources in arid and semi-arid areas is increasingly being recognized. *'Integrated water resources management in arid and semi-arid zones'* is, therefore, a logical outcome as a major theme of the fifth cycle of the International Hydrological Program (IHP-V) of UNESCO. It coincides very much with the initiative of the participants of the Sixth Regional Meeting of the IHP committees of Arab Countries, held in Jordan in December 1995, where a special project on 'Wadi Hydrology' has been suggested. This is in line with UNESCO Cairo Office's selection of rainfall water management as a concentration area for its activities in the region. Besides the initiative for a project on Wadi Hydrology, a Regional Network on Wadi Hydrology was formed, as described below.

Regional Network on Wadi Hydrology

After the meeting in Jordan, the idea of a project on Wadi Hydrology was unanimously endorsed in the recommendations of the UNESCO/NWRC/ACSAD Workshop on 'Wadi Hydrology' held in Cairo on 5-6 June 1996. During this particular workshop, a network on wadi hydrology was created, with ACSAD serving as its regional coordinator. Consequently, a draft resolution on Wadi Hydrology was approved and subsequently submitted during the 12th IHP Intergovernmental Council meeting of September 1996, where it was accepted and endorsed by the Council. Wadi hydrology as a regional priority has been endorsed and confirmed again by the participants of the 7th Regional Meeting of the IHP committees of the Arab region, held in

Morocco in September 1997. As a result of these initiatives, Wadi hydrology has been incorporated into the 1998/1999 work plan of the International Hydrological Program of UNESCO as a global action under the coordination of the Regional Hydrologist at UNESCO Cairo Office.

Objectives of the Regional Network

UNESCO Cairo Office's regional program on "Wadi Hydrology", under Theme 5 of the current cycle of the International Hydrological Program, has the following development objectives:

- Improve the understanding and knowledge of the hydrological processes in arid and semi-arid zones with emphasis on Wadi Hydrology.
- Develop the concept of integrated and sustainable development and management of *wadi* systems and improve methodologies and education on coping with water scarcity in dry regions.
- More specifically the project aims towards.
- Improving and consolidating the knowledge on the physical processes of Wadi Hydrology through research and development;
- Enhancing the water resources development and management capabilities in Wadi systems through development of approaches and cost-effective techniques for the integrated development and management of *wadi* systems.
- Strengthening human resources and institutions in the region through training and capacity-building activities at various levels.

Network Structure

To achieve these objectives a regional network has been established, with the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) as its coordinator. The Network Secretariat is composed of the founding organizations: UNESCO Cairo Office, ALECSO, and ACSAD. The general assembly is constituted entirely of Arab IHP Committees, and meets bi-annually. A Steering Committee meets regularly to discuss network activities, and is composed of focal Network activities include representatives from funding organizations, experimental *wadis*, and regular training courses.

Training

The following courses are organized regularly through the network:

- Regional Short Course on "Hydraulic Engineering for Water Harvesting in Arid and Semi-Arid Environment", (Hydraulic Research Institute of Egypt and the International Institute for Infrastructural, Hydraulic and Environmental Engineering of the Netherlands).
- International Course on Wadi Hydrology, Amman, Jordan (Water and Environment Research and Study Center of the University of Jordan).

- Various Regional Workshops on Wadi Hydrological Networks (Damascus, Syria, ACSAD, UNESCO, and WMO).

Research Program

Research of the Network in selected representative Wadis covers the following areas: hydrological processes under semi-arid conditions; rainfall-runoff models; development of water resources through water harvesting, hill reservoirs, and artificial recharge; and integrated water-resources development.

The following representative Wadis have been selected in the Arab region: Egypt - Wadi Arabi, Wadi El Firan, Syria - Wadi El Abiad (the White Wadi) Wadi Sindiana, Tunisia - Wadi Marg El Leil, Morocco - Wadi Maasa, Sudan - Wadi Al-Owaiteeb, Wadi Abu Habil, Jordan - Wadi Hassan (in the Azrak basin), Palestine - Wadi Gaza, and Yemen - Wadi Zabeed.

CONCLUDING REMARKS

The scarcity of water resources in arid and semi-arid regions is becoming a serious problem threatening future economic developments of many states. Therefore, there is an urgent need for the proper management and utilization of all possible conventional and non-conventional water resources. Wadi water flow, though intermittent and rare, is considered as a viable source of fresh water for many countries of arid regions. Major scientific, technological, and managerial constraints and deficiencies, which handicap the full utilization of this resource, have been addressed. UNESCO's water program has recognized the importance of water resources management in arid zones since 1950. Its concern and contribution towards enhancing the knowledge base and human resources development is continually growing through its International Hydrological Decade and the various cycles of the International Program. Contributions of UNESCO's IHP program to the field of wadi hydrology have been presented.

REFERENCES

- Abu-Awwad, A.M., and M. Shatanawi, 1997. Water harvesting and infiltration in arid areas affected by surface crust: Examples from Jordan. *J. Arid Enviro.* 37(3): 443-452.
- Abu Zeid, K. 1997. Floods and watershed analysis, in: *CEDARE Chronicle* March/April 1997.
- Abu Zeid, M. 1993. Evaluation of non-conventional water resources in the Arab States, *Unpublished report* prepared for ACSAD, June 1993, in Arabic.
- Abu Zeid M., 1995, Problems in water resources management in the Arab World, *Proc. "Sixth Regional Meeting of the Arab IHP Committees"*, Amman, Jordan, 3-6 Dec. 1995.
- ACSAD, 1997. Water resources and their utilization in the Arab region, *In: Second Symposium on Water Resources and their Utilization in the Arab Region*,

- AFESD/ACSAD, 8-10 March 1997, Kuwait, (in Arabic).
- Al-Eryani, M. 1996. Wadi systems: hydro-geological characteristics and implications for water resources management. *Proc. "UNESCO/NWRC/ACSAD Workshops on Wadi Hydrology"*, Cairo Egypt, 3-6 June 1996. IHP-V, Technical Documents in Hydrology, No. 1, UCO.
- Heathcote, R. 1983. The arid lands: their use and abuse. Longman: London and New York, pp 12-21.
- ALECSO, 1992. Detailed program for the preparation of Arab water security. Tunis, Tunisia.
- ESCWA, 1996. *Proc. Expert Group Meeting on Water Legislation in the ESCWA Region*, Amman, 24-26 Nov. 1996, Economic and Social Commission for Western Asia, United Nations Economic and Social Council.
- FAO, 1994. Water harvesting for improved agricultural production. *Proc. FAO Expert Consultation*, Cairo, Egypt. 21-25 Nov. 1993, *Water Reports* 3, Rome.
- Gleick, P.H. 1993. Water in crisis. Oxford University Press, Oxford.
- International Conference on Water and the Environment: Development Issues for the 21st Century, 1992, The Dublin Statement and Report of the Conference, 26-31, January, Dublin, Ireland.
- Khoury, J. 1990. Water resources assessment activities in the Arab region, a paper submitted to UNESCO/WMO meeting in July 1990, Geneva, Switzerland, ACSAD, Damascus, Syria.
- Khoury, J. 1995. Water resources assessment in the Arab region. *Proc. Sixth Regional Meeting of the IHP Committees of the Arab Region*, (under publication), Amman, Jordan, 3-6 Dec., 1995.
- Khoury, J., A. Amer, and A. Salih (Ed). 1995. Rainfall water management in the Arab region, State of the art report, UNESCO/ROSTAS, Cairo.
- Meigs, P. 1953. World distribution of arid and semi-arid homoclimates. *UNESCO Arid Zones Research*, Series No. 1, Arid Zone Hydrology.
- Movahed, K. 1997. The effects of floodwater spreading project on population mobility in the Gareh Bygone Plain. *In: Proc. 8th International Conference on Rainwater Catchment's Systems*, April 25-29, 1997, Tehran, I.R. Iran, p. 144-151.
- Population Action International, 1995. Sustaining water: an update, United Nations Population Division, UN, New York.
- ROSTAS-UNESCO/ACSAD/IHE, 1993. Water resources assessment in the Arab region, 1988, partially updated and translated to English version, ROSTAS/UNESCO.
- Saad, K.F. 1993. Evaluation of groundwater resources in the Arab States, (*unpublished report*). Prepared for ACSAD, June 1993, in Arabic.
- Salih, A.M.A. 1994. Water scarcity in the Arab region: options for survival. *Proc. 8th conference of the Islamic Academy of Science*, 5-9 Dec. 1994, Khartoum, Sudan.
- Salih, A.M.A., and A.G. Ali. 1992. Water scarcity and sustainable development, *Nature and Resources*, 28(1): 44-48.
- Salih, A.M.A. 1999. UNESCO's IHP Programs and Wadi Hydrology. Fourth Gulf Water Conference, Bahrain, 13-18 Feb. 1999.
- Salih, A.M.A. 1988. Arid lands: evapotranspiration under extremely arid climates, *In Water Resources Environmental, Civil Engineering Practice*, 10: 305-324.
- Salih, A.M.A., and T. Al-Fara. 1983. Old systems of irrigation in the Kingdom of Saudi Arabia. *In: International Conference of the History of Arab Sciences (Irrigation, Botany and Agriculture)*, Kuwait, Dec. 1983.
- Salih, A.M.A., and U. Sendil. 1984. Evapotranspiration under extremely arid climates, *J. Irrigation and Drainage Eng.* 110(3): 289-303.
- Sendil, U., and A.M.A. Salih. 1984. Hydrology of an arid watershed in Saudi Arabia. *In: Proc. Fourth Congress of APD-IAHR*, 11-13 Sept. 1984, Thailand.
- Serageldin, I. 1995. Toward sustainable management of water resources. The World Bank, Washington D.C.
- The Delft Declaration, 1991. *Proc. UNDP Symp. on "A Strategy for Water Sector Capacity Building"*, Delft, 3-5 June, 1991, The Netherlands.
- UNESCO/ACSAD/IHE, 1988. Water resources assessment in the Arab region. UCO, Egypt.
- Wheater, H.S., A.P. Butler, E.J. Stewart, and G.S. Hamilton. 1991. A multivariate spatial-temporal model of rainfall in SW Saudi Arabia. I. Data characteristics and model formulation, *J. Hydrology*, 125: 175-199.
- Wheater, H.S. 1997. Wadi hydrology: process response and management implications. *In: Proc. UNESCO/NWRC/ACSAD Workshops on 'Wadi Hydrology' and 'Groundwater Protection'*, Cairo, Egypt 3-6 June 1996, IHP-VI *Technical Documents in Hydrology*/ No. 1, UNESCO Cairo Office, p. 1-13.

Agricultural Water Management in the Arabian Peninsula

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ABSTRACT

Most of the Arabian Peninsula (AP) is characterized by high potential crop water use and low precipitation. Agriculture accounts for by far the largest share of water use in the AP, and in many places water is being used faster than it is being renewed. Much of the AP is rangeland which has been degraded to various degrees by overgrazing. The large animal population is supported by irrigated or imported fodder, resulting in a large part of the water consumed by agriculture supporting irrigated forages, commonly alfalfa and Rhodes grass. The water use efficiencies of these irrigated forages may be lower than those of indigenous species. The ICARDA Arabian Peninsula Regional Program is coordinating studies conducted by the countries of the AP to determine the water use efficiencies of commonly grown forages and mixtures of these forages. These data will be compared to equivalent data from indigenous species whose seeds have been harvested on collection missions in the region.

In situ studies are also underway to determine water use of naturally occurring indigenous species. If the water-use efficiency of indigenous forages is sufficiently high, particularly under low water conditions, it may be possible to begin substituting them for Rhodes grass and alfalfa. There is also considerable scope for improving on-farm water management through training programs and the application of available technologies, such as irrigation scheduling and water measurement. Work is also being conducted on developing protected agriculture within the region to maximize water use efficiency and minimize potential contamination of the produce, and soil and water by agricultural chemicals.

INTRODUCTION

The Arabian Peninsula (AP), comprising the countries of Saudi Arabia, Kuwait, Bahrain, Qatar, United Arab Emirates, Oman, and Yemen, is characterized by low rainfall, high summer temperatures, and limited renewable water resources. Annual precipitation is usually much less than potential crop water use so that, with few exceptions, all arable crop production requires irrigation. The absence of any major surface water sources requires dependence on groundwater for irrigation, which receives limited recharge due to low precipitation.

The renewable supply of water per capita is amongst the lowest in the world. For example, some parts of the Republic of Yemen receive more rainfall than anywhere else in the AP. The mountainous areas

can receive 500 to 1000 mm per year and more, which is sufficient for rainfed agriculture. However, the average renewable water resource for the entire country is still only 150 m³ per person per year, with an uneven distribution such that 90% of Yemen's population has less than 90 m³ per person per year. As another example, the renewable water resource for the United Arab Emirates, which has an average annual rainfall of 100 mm per year, has been estimated at 79 m³ per person per year. Large areas of the AP receive annual precipitation of 50 mm or less. These values for renewable water per capita are some of the lowest in the world. To place them in context using values published by the World Bank, the average worldwide renewable water supply is 7500 m³ per person per year, and the average for the entire Middle East and North Africa is 1250 m³ per person per year.

Historically, some irrigation systems developed or adopted in the AP were sustainable, and some of them are still in use such as the Aflaj (singular: *Falaj*) in Oman, and spate irrigation in Yemen. However, these systems do not account for much of the current irrigated land total. They are important, however, as a potential source of indigenous knowledge.

RECENT TRENDS

In common with other arid regions, most of the annual water consumption in the Arabian Peninsula supports irrigated agriculture. The irrigated area has increased significantly in recent years as population and income have increased. A substantial part of the irrigated area produces perennial forages such as alfalfa (*Medicago sativa*) and Rhodes grass (*Chloris gayana*) to fully or partially support an increasing livestock population. The annual irrigated area of the Arabian Peninsula, which has more than doubled since 1980, while the annual irrigated area per person, which has not changed substantially because population and irrigated area have increased at about the same rate.

The rural population has not changed substantially because, although it has decreased in the Gulf Cooperation Council (GCC) states (all the countries except Yemen), it has been matched by an increase in Yemen. On the other hand, the urban population has more than doubled in the same period, with all countries showing large increases. Goats, sheep, and camels have increased substantially. The increased population of these animals, most of which depend at least partially on natural rangeland, has caused significant degradation of rangeland resources (Ferguson et al., 1999). The cattle population, which is much more dependent on irrigated forage crops, has also increased, but at a

slower rate. This livestock population increase has been made possible by the increased area of irrigated forage crops.

Problem Description

The large increase in irrigation has resulted in unsustainable water use. For example, total water withdrawal (including desalination) in the United Arab Emirates in 1995 was 2108 million m³/year, of which 1408 M m³/year was used for agriculture. The total renewable water resource was estimated at 150 M m³/year, so that agriculture alone used over nine times the renewable supply. These figures for the UAE are typical of much of the AP. Renewable water scarcity prevails throughout the peninsula.

Maintaining full irrigation, however, requires large volumes of water, especially for perennial crops such as alfalfa and Rhodes grass. Potential crop water requirements have to be met during the long hot summer period if water stress is to be avoided. The large difference between water consumption and renewal is provided by groundwater from aquifers with little or no recharge and desalination. While there may be differences in estimates of water resources and consumption within a country and over time, there is no doubt that, they are currently being mined at an alarming rate throughout the AP.

Consequences of Excess Water Use

Continued use of groundwater for irrigation to meet agricultural production targets has led to declining water levels and saline intrusion in many areas. An example is the Al-Dhaid area in the Sharjah Emirate of UAE. Groundwater levels there have declined from about 40 m to 300 m in little more than a decade. At the same time, salinity has increased more than four-fold. The expansion of irrigation in this area has also caused the traditional *falaj* system, upon which the area used to depend, to cease operation because the groundwater level has declined to below the level of the mother well. Abandoned farms are now common in the area.

Another example is Al-Batinah region in northern Oman, an important agricultural area between the Hajar Mountains and the sea that historically depended on *aflaj* exploiting runoff or groundwater originating in the adjoining mountains, and on wells that used animal power to raise water from shallow water tables. Date palm and other fruit trees such as lime, mango, and banana were grown along with vegetables and fodder crops. Average annual potential evapotranspiration has been estimated to be about 1800 mm, while annual precipitation averages about 80 mm (Mini. Agric. & Fisheries, 1996).

In recent times, groundwater in Al-Batinah has been exploited by a large number of new wells with mechanical pumps. Over 80% of the irrigated land in the South Batinah currently produces perennial crops, primarily fruit trees and fodder. Alfalfa and Rhodes grass account

for about 90% of the irrigated forage area. Maintaining perennial crops such as these under full irrigation requires very large amounts of water, particularly during the summer months when crop water use is very high. The increase in the irrigated area and over-exploitation of the groundwater has led to saline intrusion in many areas resulting in salinity and abandonment of farms, particularly near the coast. Even date palm, which is indigenous to the Peninsula because of its heat and salinity tolerance, has not been able to survive in the worst affected areas. Studies conducted in the region (Mini. Agric. & Fisheries, 1996) estimate the annual groundwater deficit to be at least 60 million m³. This has contributed to the abandonment of farms comprising about 10% of the total farmed area.

Irrigation Requirements

In most areas of the AP, the difference between precipitation and potential evapotranspiration is large. For example, annual potential evapotranspiration for perennial crops in many areas of the Kingdom of Saudi Arabia is over 2,400 mm, which requires over 24,000 m³ of water per hectare. A large amount of this is required to maintain full evapotranspiration during the hot and dry summer months. Alfalfa grown in northern Saudi Arabia requires an average total of 24,600 m³ of water per hectare to meet crop water use (Al-Zeid et al., 1988). Over 68% of this total is required during the six months from April to September. For date palm, the total annual requirement is 17,200 m³ of water per hectare, of which 72% is used during the same six-month period. During the three peak water use months of June, July, and August, alfalfa requires 38% of the annual total, while date palm requires 41%. Irrigation in this region depends almost entirely on fossil groundwater with negligible recharge. In addition, the actual water applied is significantly more than crop water requirements because of inefficiencies in water application and management.

POTENTIAL SOLUTIONS

It is clear that, if the current trends continue, the result will be exhaustion of water resources and devastation of rangeland and soil resources. Apart from the environmental destruction and loss of heritage, the economic and social consequences of such an outcome are enormous. Solutions appropriate to the region must be developed to restore sustainability of water use before it is too late.

In general, it will require an increase in water supply or a decrease in consumption (or a combination of both) in order to restore balance to agricultural water use.

Increasing Water Supply

Possible sources include: brackish or marginal groundwater, desalination, undiscovered or unexploited groundwater resources, importation from sources outside the region, capture and storage of surface water

that would otherwise flow into the sea, and increasing precipitation.

Some of these solutions may not be possible with current technology. For example, cloud-seeding as a means of increasing precipitation has not proved effective so far. Similarly, the discovery of significant new groundwater resources cannot be relied on, and, if discovered, would likely be fossil reserves that are not recharged. The discovery of such resources would not be a solution, but would provide more time to develop one.

There is still some scope to capture and store, either at the surface or by aquifer recharge, runoff from storm events that would otherwise have flowed into the sea. However, the construction of the infrastructure needed, such as dams, is expensive, particularly considering the low rainfall amounts and number of events generating significant runoff. The cost per cubic meter of water is therefore likely to be high if all the costs are included at their true market value. Similarly, importation of water from outside the region, while technically feasible, is expensive and may not be economically viable when compared with the cost of simply importing the food.

Perhaps the most renewable source of water in the region is *desalination*, although currently the high cost per cubic meter, at market prices, eliminates this as an economically viable source for open-field agriculture. The production of high-value crops under protected agriculture may justify the use of desalinated water. Future advances in technology may bring the cost down sufficiently to economically justify using desalinated water for irrigated agriculture, particularly considering the regions fossil energy and solar energy resources.

There is, however, sometimes an imbalance between the supply of desalinated water and the demand for it. Because there is usually little storage in the system, any excess supply is often discharged back to the sea. This imbalance is particularly true when considering treated wastewater. Municipalities often generate treated sewage effluent and use it for landscaping needs. However, the production rate of treated sewage effluent is fairly constant throughout the year compared with the water requirements of landscaping. If the area of landscaping is sufficient to take all the production during the peak summer months, there will be a surplus in winter when water requirements are much lower. The winter excess is therefore sometimes discharged to the sea or other open water bodies where it is not beneficially used. This water does represent a resource which could be used by agriculture, although its seasonal nature presents challenges.

Reducing Water Demand

Possibilities include: reducing the irrigated area, improving on-farm irrigation distribution, scheduling, and management, protected agriculture, crops with higher water use efficiency, and deficit irrigation.

While reducing the irrigated area is often an economic, political, or social decision, there is considerable scope for saving water in the other categories. The Arabian Peninsula Regional Program (APRP) of ICARDA is actively involved in many of them.

APRP Activities

The program is currently focused on irrigated forage production. Trials are being conducted by the national agricultural research systems at various locations in the peninsula to determine the WUE of the main forage crops and their mixtures. Much of the work is on alfalfa and Rhodes grass. However, one of the primary objectives is to develop new production systems more suited to the region. To this end, the use of indigenous desert species as replacements for current forage crops is being investigated (Ferguson et al., 1999).

A Potential Model?

Ferguson et al. (1998) have identified promising indigenous forage species for further study in semi-intensive systems under deficit irrigation. We feel that a system based on indigenous species, rather than the conventional species currently dominating production systems, could use far less water than current systems because they may inherently have greater production per unit volume of water under full or deficit irrigation, and because they are able to withstand long periods of water stress. Irrigation during the summer may be substantially reduced or even eliminated without causing the death of the crop, as is currently the case with conventional species.

The model envisages irrigation during the winter, perhaps making use of any excess treated sewage effluent which would otherwise be wasted. Maximum use would be made of any rainfall. The goal could be deficit rather than full irrigation because the crop would be able to withstand water stress. The important criterion would be production per unit volume of water, which is the most limited input, rather than production per unit land area which is the commonly used criterion. Production per unit land area would likely be lower than conventional systems under full irrigation, but higher per unit water volume. For forage crops, production should perhaps be measured in terms of the amount of animal products per unit water volume, which would take into account the quality of the forage as well as its quantity. Another benefit for a production system based on indigenous species may be greater flexibility. For example, missed irrigations may not cause major damage. However, good salinity management would be very important, as leaching would be reduced. It would furthermore be flexible.

Examples of such a model are given in Fig. 1. The data for potential crop water requirement (ET_0) and rainfall are from Saudi Arabia (Al-Zeid et al., 1988). Irrigation amounts can be specified in any way, such as fixed quantities or based on a single or variable

percentage of ET_0 . In a conventional system under full irrigation, the goal would be to supply 100% of ET_0 , while in this model the percentage would be much lower, as shown. Rainfall would contribute to crop water requirements in a more important way than under full irrigation. In this illustration, irrigation is a higher percentage of ET_0 during the winter than during the summer, so that, in combination with rainfall, it provides a fairly high percentage of ET_0 in winter. Figure 1 (bottom) shows the cumulative water use under this model compared with full irrigation. It is substantially less.

There are much data needed before such a model can be experimentally tried. One of the most important gaps in knowledge is the production of indigenous species as a function of irrigation amount and timing. APRP has taken steps to collect these data by establishing irrigated plots both *in situ* and under experiment station conditions. These plots are located in Sharjah Emirate, UAE.

Ministry of Agriculture and Fisheries (Central Region) facilities. Seeds of three priority species (*Cenchrus ciliaris*, *Coelachyrum piercii*, and *Lasirus scindicus*) were collected from the desert and planted under a line-source sprinkler system in which the amount of applied water decreases with distance from the line. These species are being compared with conventional species (*Chloris gayana* and *Panicum maximum*). TDR is similarly being used to monitor soil water content. Yield response and water use efficiency will be measured.

It is too early to judge whether our proposed model will be useful as an alternative to current systems. However, we feel it is an important and timely step in the right direction. Restoring greater sustainability to this unique region will require considerable research effort. We hope the ongoing APRP work in rangeland, irrigated forages, and protected agriculture will be decisive in developing appropriate solutions before it is too late.

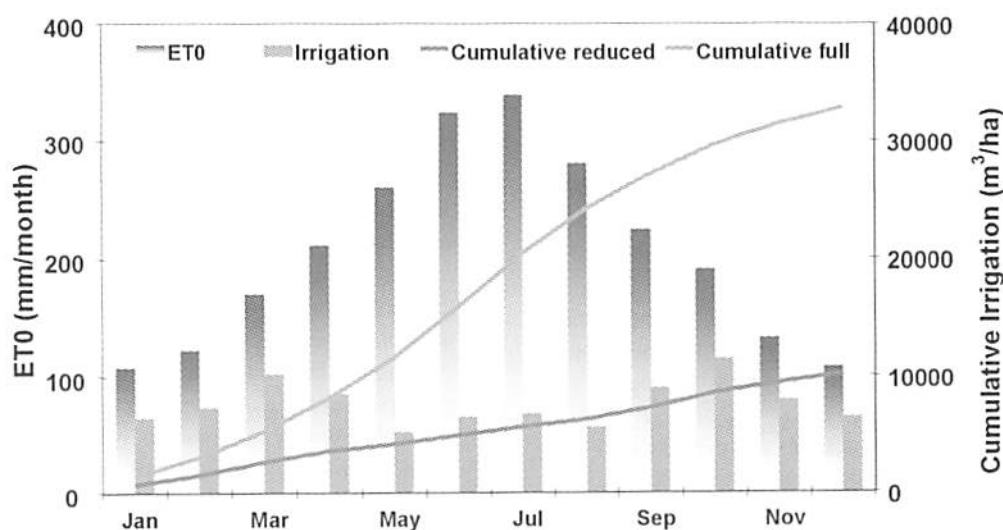


Fig. 1. Example of a model for deficit irrigation of indigenous forage species. Potential crop water use (ET_0) and rainfall are shown with irrigation as a variable percentage of ET_0 (top), and cumulative water use for full irrigation and with the deficit model (bottom).

The *in situ* work is being conducted at the Desert Park, which has been protected from grazing for a number of years. Small plots have been established in an area containing several naturally occurring species of interest. The plots are being irrigated using a drip system. Soil water content is being monitored using a Time Domain Reflectometry (TDR) system based on access tubes such as are used with a neutron probe. An automatic weather station has been installed on the site to measure the weather parameters necessary to estimate ET_0 . Changes in measured total soil water content over time will be used to estimate actual water use, which can then be related to standard estimates of ET_0 .

The experiment station research is being conducted at Al-Dhaid, about 15 km from the Desert Park, at

REFERENCES

- Al-Zeid, A.A., E.U. Quintana, M.I. Abu Khate, M.N. Nimah, F.H. Al-Samerai, and I.I. Bashour. 1988. Guide for crop irrigation requirements in the Kingdom of Saudi Arabia. Mini. Agric. & Water, Riyadh.
- Ferguson, M.E., I. McCann, and G. Manners. 1998. Less water, more grazing. Caravan 8: 9-11.
- Ferguson, M.F., A. Saleh, A. Hassan, G. Al-Hadrami I. McCann, and J.M. Peacock. 1999. Desert forages of the Arabian Peninsula: a solution for sustainable rangeland production in the 21st Century? 6th Int. Conf. on the Development of Dry Lands, Cairo, Egypt.
- Ministry of Agriculture and Fisheries. 1996. South Batinah Integrated Study. Sultanate of Oman.

Developing Water-Saving Techniques and Efficient Agriculture under Rainfall Harvesting in China

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ABSTRACT

Rainwater is a major water resource of agriculture production in Loess Plateau. The erratic rainfall often causes frequent crop failures. However, favorable conditions provide the probability in time and space to collect excess monsoon rainwater into the soil or in cisterns for limited supplementary irrigation during the dry spell. Therefore, many ways to concentrate runoff in soil have been found and used since ancient times: (1) transforming topography for cutting runoff; (2) ploughing and raking soil to retain water; (3) increasing cover to reduce the loss of soil moisture and improve water-use efficiency; (4) forming suitable crop patterns and increasing input of fertilizer to improve water-use efficiency; and (5) internal seeding and rotation of crops to reduce runoff.

In recent years, the newly developing water harvesting system in China took a new look for agricultural production in dryland. It uses *rooftops, asphalt pavement, earthen roads, natural soil surfaces, and artificial catchments* to harvest rainfall, and store it in cellars for supplementary irrigation in the field or for developing small-scale yard economy. Moreover, combined with drip irrigation, harvested rainwater can be used in greenhouse to grow rare flowers or other valuable crops. Small-scale rainwater harvesting projects have spread in the Loess Plateau. Limited by fragile eco-environments, and a properly designed rainwater-harvesting system that is suitable to use at a large scale has been in the experimental stage, some key technical problems (such as catchment's materials, water quality protection, and high efficiency of water-use) need to be solved.

INTRODUCTION

Drought is the main constraint that restricts the sustainable agricultural development in the arid and semi-arid regions of the northern China. The total water amount in northern area is only 14.4% of the whole country, but farmland area and population account for 58.3 and 43.2%, respectively. During the last decade, an average area of 20-26.6 million ha in the whole of China was struck by drought annually. The grain reduction caused by drought and shortage of water has reached 25 million tons. Rainwater is a major water resource of agricultural production in dry areas. The mean annual rainfall over the whole Loess Plateau is 443 mm; the total amount is 275.7 billion m³, which is about 9.2 times of annual consumption of surface and groundwater

together (Huang, 1998). But rainfall is poorly distributed in time and space, and is not often in accordance with crop growth stages, i.e., 70% of rainfall occurs between June and September, and the inter-annual variability is 0.25-0.35. In addition, 70-80% of rainfall is lost as evaporation and runoff, causing serious soil and water loss. The water erosion modulus is over 5000 tons km⁻² ha⁻¹. The eco-environment is immersed in a vicious cycle due to soil deterioration, drought aggravation, population pressure, and overgrazing. Poverty of the people living in the upper and middle reaches of the Yellow River has increased.

The rainwater-use efficiency (RUE) is only 4.5-6.0 kg mm⁻¹ ha⁻¹, and yield drops approximately 67-75% due to water stress. So, an increase in quantity of water available to crops in the arid and semi-arid regions can lead to an improvement of the reliability of production as well as of the level of production. Characterized by high intensity rainfall, crusted soil, up-down topography, large areas in semi-arid zones have a considerable potential to collect rainfall. Therefore, many ways to conserve rainwater have been found and used since ancient times. The objectives of this paper are to review techniques and development on rainwater utilization in Loess Plateau region of China and discuss the current status and problems existed in the rainfall utilization.

RAINWATER MANAGEMENT

Changing Topography: Cutting Runoff

This practice includes construction of terrace, leveling gully, and fish-scale pits along hillsides. In regions with rainfall of 450-550 mm, level terraces can catch 35-100 mm runoff per year, reversed-slope terraces 25-65 mm, and level gullies 15-57 mm compared to sloping fields.

Tillage Practice

Ploughing and raking is a traditional way to get rainwater into soil in the Loess Plateau. Soil moisture storage could increase by 5.9-7.5 mm in the 0-30 cm soil layer and about 30 mm in 0-200 cm soil layer by deep ploughing of 30 cm compared to shallow plough depth of 20 cm. Contour cultivation could intercept 19.2-39% of runoff and reduce 31.2-67% of soil loss in comparison with conventional cultivation method. Basin tillage could catch 71-98% of runoff and decrease 84-99% of soil loss. Strip-cropping could retain 60% of runoff and decrease 66% of soil loss. Crop rotation could harvest 60% of runoff and reduce 65-68% of soil loss.

Ground-hole tillage is a new practice in the Loess Plateau, whereby a sloping field was formed in a pattern of 25-cm ridges and 25-cm furrows alternately along contour, then a diameter of 5 cm hole with a depth of 35 cm was drilled in the furrows 25 cm apart for runoff infiltration. The crops were grown in the furrows. The study showed that this method could bring about an increase of 54.8 mm water in 0-200 cm soil layer and 27.7% wheat yield, and a reduction of 52.8% of surface runoff and 53.5% of soil eroded in comparison with the conventional cultivation (Zhang et al., 1994).

Another ridge and furrow method of *in-situ* rainwater conservation system consists of ridges and furrows alternately in the dry flat field. The ridges, covered with plastic film served as rainwater harvesting zone for concentrating rainfall and furrows as the planting zone. The ratio between ridge and furrow depends on rainfall characteristics and water requirement of crop. For corn, 60-cm wide ridge and 60-cm wide furrow is recommended under a mean annual rainfall of 250-300 mm. By this treatment, soil moisture storage in the planting zone could increase 57.4-272.7 mm in 0-200 cm soil layer, yield 20-332%, and water-use efficiency 40-99%.

Mulching

Plastic film cover could decrease 30.8 mm soil evaporation, and increase 10-12 mm water in the upper 20 cm soil. Straw covers could bring about an evaporation reduction of 12-42 mm and increase of 27.5 mm moisture before crop sowing. Gravel mulch is a traditional way to conserve rainfall in the soil, and has been used by farmers in the western Loess Plateau for over 300 years. It could increase soil moisture by 4-8% (in weight) as compared to the bare soil (Table 1).

Rainwater Harvesting Management

Rainwater harvesting is an old technique in China. Various forms of water harvesting have been used traditionally throughout the centuries. One very old, but still common, flood diversion technique is called "warping" (harvesting water as well as sediment) and has been extensively applied in China's loess areas since the dynasty of Spring and Autumn War (2700 years ago). In Dongzhiyuan of Gansu Province and north of Weihe River, Shanxi Province, rainwater cistern wells and jars, as well as ponds, have existed since the Ming Dynasty (620 years ago). But a growing awareness of its potential for improving crop production arose in the 1980s, with the widespread droughts followed by serious shortage of drinking water and crop failure.

In September 1995, the 7th International Conference on Rainwater Use was held in Beijing. In September 1996, the 1st Chinese Rainfall use and East Asia International Meeting was held in Lanzhou, Gansu Province. In September 1998, the International Symposium and 2nd Chinese National Conference on Rainwater Utilization was held in Suzhou, Jiangsu Province, China. These made rainwater utilization research a high priority China.

The practice of rainwater harvesting was extensive and developed rapidly in the Loess Plateau, and formed a special agricultural model. In Gansu, Inner Mogolia, Shanxi, and Ningxia Province, building water cellars has become a movement organized by the Government. Gansu carried out "121 Rainwater Harvesting Project" that means one family established 100-m² rainwater catchment with concrete in courtyard and rooftops, built two water cellars and irrigated about one mu (0.067 ha) cash crop. This plan has made obvious benefit and shown great promise in alleviating the water and

Table 1. Influence of gravel mulch on soil moisture content.

Depth	Gravel Mulch				Bare Field
	New, 2 - 7 years	Younger, 15 - 30 years	Older, 60 years	Oldest, 100 years	
-cm-	-----% in weight-----				
0-20	19.4	19.6	18.1	14.2	11.0
20-50	18.8	17.5	14.8	13.4	9.5
50-100	15.2	15.5	13.5	12.3	8.0

Source: Luo Huanxin, 1991.

Increasing Phosphate Fertilizer

Phosphate fertilizer has a relatively powerful function of stimulating roots to absorb water. The results of experiments showed that the root length of wheat reached 233 cm in P-fertilized fields, 47 cm longer than that of fields fertilized with nitrogen alone. The capacity of absorbing water of such soil increased 6.4 and 5.8% in 100-150 cm soil layers and 150-200 cm layers, respectively.

food problem of dryland. Up to now, 91 M new water cellars have been built, with storage capacity amounts to some 3500 M m³. About 14 M ha farmland has been supplementary irrigated by harvested rainwater.

Rainwater Harvesting System

Water harvesting system can be defined as artificial methods for collecting and storing precipitation until it can be used for watering livestock, small-scale subsistence farming and domestic use (Brooks et al., 1991).

These systems include a *catchment's area*, usually prepared to improve runoff efficiency, a *storage facility* for the harvested water, unless the water is to be immediately concentrated in the soil profile, and a *water distribution* scheme to use harvested water efficiently.

Catchment

The particular surface treatment selected for runoff inducement will depend, in large part, upon the rainfall parameters, cost, and availability of materials and labor. The popular treatments in China include *mechanical treatment* (smoothing and compacting) and *surface binding materials* (cementing and sealing). The runoff water was often collected from rooftops, concrete treated courtyard, asphalt paved and unpaved road, and cleared and smoothed hillside areas. With financial support from the government, one family established 100 m² of concrete catchment, adding 50 m² from rooftops, 40 m³ of runoff could be collected in average year in Gansu Province.

The concrete treatment cannot be spread on a large scale on hillslopes due to high cost and environmental problems. Cost of 1 m² concrete collecting area is about 5 yuan. Other surface treatments, including chemical and covering, are in the experimental stage. The average runoff efficiency and cost of different materials are listed in Table 2.

pacted soil surface produce water at low cost and have low runoff efficiency.

The criterion of rainfall catchment is hard to make, it is often location-specific and should be based on the whole environmental conservation value. An integrated approach with ecological effects and economic benefits must be taken. Generally, all the surface treatments destroy or prevent development of the natural vegetation cover, thus unavoidably influencing the water cycle and bringing about environmental degradation if widespread. Environment in the Loess Plateau is fragile, and preserving some vegetation is necessary indeed. Loess Plateau is situated in upper and middle reaches of the Yellow River, and in recent years; the flow time of the Yellow River has become longer. So the relationship between rainwater harvesting and ecological environment is a new subject to resolve in Loess Plateau.

Water Storage

Basically, there are three types of storage: the soil profile, evacuated pond and cellar or well, and tank or cistern containers. The popular water-storage pattern is evacuated cellars, which are treated with cement or traditional red clay soil in Loess Plateau. The shapes of the water cellar are vase-like, ball-like, and column-like, the diameters ranging from 2-4 m and depth 4-5

Table 2. Average runoff efficiency¹ and cost of different catchment materials².

Material	Thickness ---cm---	Runoff Efficiency ----%----	Cost ---Yuan/m ² ---
Compacted surface of red clay and loess mixture	3-5	50	0.3
Compacted loess soil surface	3-5	27	0.25
Compacted surface of cement and loess mixture	3-5	46	3.64
Gravel-covered plastic film	3 - 5	65	1.78
Plastic film covered by straw and muddy mixture	10 - 15	40	0.60
Plastic film		90	0.5
Asphalt sheeting		79	2.9
Tile		38.5	3.0
Concrete	5	75	4.8
Crusted surface		12.3	0

¹Slope degree = 10°. ²(P=75%, 1 yuan= about US \$0.12).

From the study, plastic film had a high runoff efficiency and low cost, but it could not resist weathering and damage by wind. It could last only 5 months. A moveable plastic film (0.08 mm thick) catchment is recommended to use in the rainy period in the field or yard. Gravel-covered plastic sheeting is also desirable if pebble materials are available. It can resist radiation and last 12 months. Runoff from asphalt sheeting was black colored and full of foam, and may be toxic to human health, as well as high cost. Smoothed and com-

m. The volume is 15-60 m³ depending on cellar type and water requirement. The evaporation from such cellar is negligible, only 0.1 mm/day. A volume of 20-30 m³ cellar cost 1200 yuan, including labor cost of 500 yuan in most cases. The cellars are often situated around yards to collect runoff from rooftops, courtyard for domestic use, livestock watering, or limited irrigation. Also, they are distributed in fields near both sides of paved and unpaved road to store runoff for irrigation purpose.

Water Quality

Water collected from a catchment can contain organisms and water-soluble impurities from windblown dust deposited on the surface, chemical pollutant directly from the treatment, and weathering by-product created by deterioration in sunlight and heat into water-soluble products. Animal feces can be a source of bacterial and viral contamination (Brooks et al., 1991). In China, many water-harvesting systems have no filters before runoff enters cisterns except a silt trap. Usually, these systems were poorly maintained and prone to fecal contamination. Coliforms were detected in some water samples from cellars. So the rainwater catchment should be often cleaned and some simple filters are needed in most cases if the water is for human consumption.

CONCLUSION

Rainwater harvesting indeed offers a method of effectively developing the surface water resources of arid and semi-arid regions. It shows great promise in alleviating drinking water and food problems to some extent in dry year in the Loess Plateau. Small-scale (family unit) rainwater harvesting project have spread in the Loess Plateau. Limited by fragile eco-environment, a properly designed rainwater harvesting system that is suitable to use in large scale has been in the experimental stage, some key technical problems (such as catchment materials, water quality protection, and high efficiency of water-use) need to be solved.

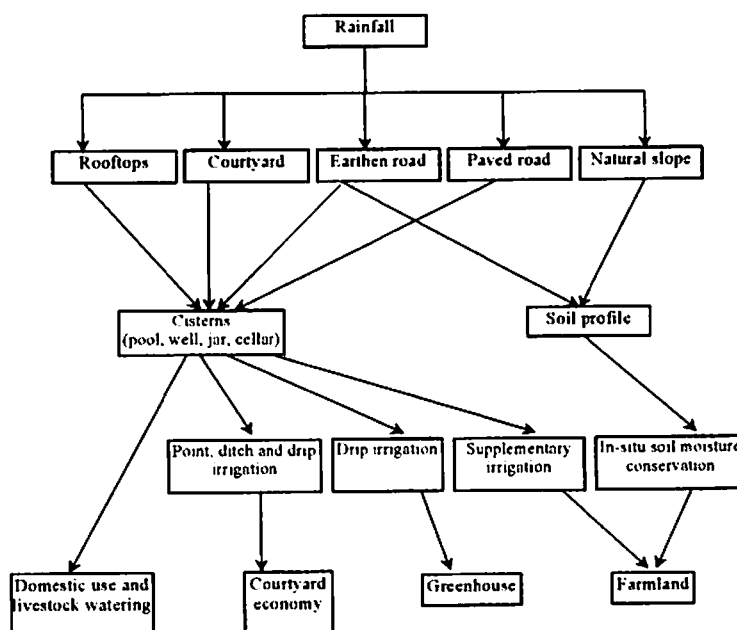


Fig. 1. Schematic diagram of rainfall utilization of rainwater harvesting system.

Harvested Rainfall Utilization

Rainfall harvesting can alleviate drought in dry periods. The rainfall utilization approach of rainfall harvesting in Loess Plateau is shown in Fig. 1. Harvested water is mainly used as supplementary irrigation in dry spells and at critical stages of crop growth. In general, farmland is supplementary irrigated about 1-2 times with $150-225 \text{ m}^3 \text{ ha}^{-1}$ each time. Patterns of harvested water utilization may be divided into three types: *courtyard economy*, *greenhouse*, and *farmland*. For crop production in farmland, water-harvesting system should be combined with *in-situ* soil moisture conservation measures. For greenhouse management, rainwater-harvesting system should be incorporated with drip irrigation to grow flowers or valuable vegetable. For courtyard economy, the irrigation methods selected depended on local conditions and economy. It is suitable to develop vegetable, fruit, and cash crop.

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REFERENCES

- Brooks, K.N., P.F. Ffolliott, and H.M. Gregersen. 1991. Hydrology and the management of watersheds. Iowa State University Press, AMES, IA, USA.
- Zhanbin, H. 1998. Model of rainwater-harvesting agriculture in Loess Plateau of China. Zhang, G., et al. (Ed) *In: International symposium and 2nd Chinese National Conference on Rainwater Utilization*. Xuzhou, Jiangsu Province, China.
- Luo, H. 1991. Drought resistance role of pebble-mulched lands and its tillage in Beijing Prefecture. *Agric. Res. Arid Areas*, 1: 37-45.
- Zhang, D., J. Wang, and Z. Xu. 1994. Tillage technique of water harvest and storage on rainfed sloping farmlands. *Agric. Res. Arid Areas*, 12(4): 31-36.

Sustainable Development of Irrigated Agriculture in the Uzbek Part of the Hungarian Steppe

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ABSTRACT

Hungarian Steppe is vast intermountain plain, situated on the left bank of the Syr Darya river in its middle reaches. The total area of the Hungarian Steppe is 850,000 hectares, including the Uzbek part relating administratively to Syr Darya Oblast, has an irrigated area of 286,770 ha. The main plateau of the Steppe was not irrigated in ancient times. Only after conquering of Turkestan by Russia in the 1890s, its irrigation began. By 1917, the area of irrigated lands reached 34,500 ha. Land development for irrigation without any drainage led to rising of groundwaters and intensive secondary salinization of soils, whose reclamation required substantial efforts, means, and time.

The precipitation here is 202-425 mm a year, their maximum is recorded in winter-spring months; in summer and autumn there is almost no rain. Average summer temperature is 27.8°C (maximum 47°C); in winter, it decreases to -27°C. A very low air relative humidity and strong winds in a summer period cause a strong evaporation from the soil surface reaching 1500 mm a year, which 4-7 times higher than the total rainfall. A relative humidity of air in summer fluctuates from 25 to 40%.

The territory considered is situated on the I, II, and III terraces of the Syr Darya River and on a peripheral part of debris cones of the Turkestan Range in alluvial plains. Land is irrigated from the Syr Darya River by the systems of big main canals, Dustlik and the Sarkisov South-Golodnostep canal.

INTRODUCTION

In terms of lithological conditions, from the surface there are loamy sands, and loam and clay deposits with depth 1.5-45 m (mainly 15-30 m), lower one or two, more rare three layers of gravel-sand and sand deposits with depth from 5-10 m to 80 m and more. Hydrologically, the irrigated land is characterized with rather poor drainage conditions and toward the north; natural drainage conditions are practically absent.

Water-salt regime has a predominant role in forming thermal, nutritious, and microbiological conditions of soils, i.e., soil fertility. Many experimental relationships between crops yield and water-salt conditions of soils were defined.

At the end of the 60's, in the Hungarian Steppe an intensive construction of progressive types of drainage (vertical and deep subsurface horizontal drainage)

began to control soil salinization. A construction of vertical drainage was started in difficult hydrological conditions of the old zone of irrigation to increase the capacity of existing open horizontal drainage. Construction of subsurface horizontal drainage was started widely in the new zone of irrigation of the Hungarian Steppe.

Many years' experimental-industrial research in various natural-agricultural conditions of Uzbekistan and in other republics of Central Asia showed that the systems of progressive drainage, with appropriate water availability, can create conditions for rapid soil desalinization and raise their productivity. Materials of experimental-industrial research by SANIIRI in the Hungarian Steppe are given as an example in Table 1. SANIIRI's research has proven that the progressive type of drainage chosen allows to raise land use ratio by 8-12%, water saving can be up to 10-20% due to reduction of tail escapes, and 15-40% due to optimal soil moisture conditions.

With a huge construction of drainage systems, sufficient water availability during vegetation and dormant periods, a relatively rapid desalinization of lands had been achieved, as well as decrease of groundwater-table down to 2.5-3 m and increase of crop yields. It was occurred with the coefficient of leaching conditions equal (in annual context)

$$\frac{\sum B + O_c}{\sum U + T} = 1.15 - 1.3$$

Where: B ≡ "net" field water supply; O_c ≡ rainfall; U + T - evapotranspiration.

The drainage modulus of the old irrigated zone were 4.5-5.5 t/cm/ha with efficiency of irrigation systems equal 0.69-0.70, whereas in the new irrigated zone it was 2.5-3.2 t/cm/ha with the efficiency of irrigation systems equal 0.77-0.80.

In the old irrigated zone of the Hungarian Steppe, these processes took place during 1974-'80, and in the new zone of irrigation during 1990-'93. Average yield of the main crop during these years on big massifs reached 2.5-3.5 t/ha.

In the new zone of irrigation of the Hungarian Steppe, perfect irrigation systems with high efficiency were created. On-farm distributing canals were lined with concrete; reinforced concrete laid over polyethylene film with conveyance efficiency was 0.9-0.95.

A tertiary canal system was made from reinforced concrete canalettes on supports or from subsurface asbestos-concrete pipelines with conveyance efficiency of 0.85-0.9. Flexible and rigid pipelines took water from canalettes and supplied it directly into a furrow.

affected the crop productivity. Despite a considerable reduction of intake, a certain rise of groundwater level is occurring. This is the result of drainage systems efficiency deterioration.

Table 1. Indices of vertical and subsurface horizontal drainage efficiency on new and old irrigated land of the Hungarian Steppe.

Indices	Old Irrigation Zone "Pakhtaaral"		New Irrigation Zone Sovkhoz No. 6	
	1	2	1	2
Intake, '000 m ³	-	9.2	-	10.4
Leaching regime coefficient	-	1.15	-	1.2
Irrigation system efficiency	0.65	0.65	-	0.77
Drainage coefficient, %	-	-	-	24
Average groundwater depth during vegetation, m	-	2.65	1.55	2.5
Drainage flow, m ³ /ha	500	1800	-	2700
Ground-water salinity, g/L	4	2	26-30	5
	10	5		
Degree of salinity ¹	67.9	95.9	38.1	75.4
Moderately saline soil	10.6	4.1	39.3	22.0
Severe saline soil	21.5	-	22.6	2.6
Cotton yield, t/ha	2.55	2.96	0.8	2.5
Density of drainage, m/ha	1 well per 125 ha		-	72
Depth of drainage, m	-	70	-	2.8
Water consumption per unit of cotton production, m ³ /100kg	-	230	-	260

Note: 1 column - initial data, 2 column - during drainage operation.

¹area of non-saline and slightly saline soils as % of total area.

Source: Kh. I.Yakubov and G.E. Baturin.

This system provided uniform distribution of water along furrows and soil wetting of the irrigated plot up to 90-92%. Simultaneously, various methods and technology of desalinization of soils were conducted with operational drainage systems, with autumn-winter leaching and pre-irrigation. On the most saline soils, capitals leaching with a norm of 10000 m³/ha were conducted along with construction of temporary drainage system with depth down to 1.5 m and spacing of 25-50 m. Before a temporary drain system construction, the soil was prepared for leaching by ripping down to 0.8-1.0 m to improve soil permeability and leaching conditions. To accelerate the process of desalinization in severely saline soils, effectiveness of various chemical ameliorants were tested (lignin, manure and different chemical - aggregating agents were applied).

After 1994-'95, desalinization was stopped and the process of secondary salinization started almost everywhere. This is confirmed by the data of a detailed salinity survey on experimental production plots. In connection with introduction in 1999 of a limited water use, water availability is decreasing from year to year, especially in the dormant period. The coefficient of leaching conditions at present moment is 0.64-1.0. This

The drainage conditions of territories in the zone of old irrigation decreased down to 1.0-3.0 t/cm/ha, and in the new zone down to 0.5-1.2 t/cm/ha. On the vertical drainage systems, it is connected with ageing of wells due to siltation of filters and zones adjacent to filters. On the systems of subsurface horizontal drainage due to decrease of discharge capacity, siltation is occurring. Some structures are collapsing due to low quality of construction and operation and maintenance. Moreover, on the open horizontal drainage systems and collectors, siltation and weeds overgrowing occurs due to their untimely cleaning. All the mentioned deterioration is a result of poor operation and maintenance caused by the reduction in recent years of repair-reconstruction works due to the lack of material-technical input and financial constrains. The efficiency of the drainage well system does not exceed 0.25-0.45; specific yield of wells decreased by 35-80% (they were constructed 17-25 years ago).

Poor technical conditions of machinery are one of main reasons for the unsatisfactory irrigation and drainage systems. Based on our survey in Syr Darya Oblast in 1996, it is possible to say the following:

- To maintain irrigation and collector-drainage network at sufficiently efficient level, the following equipment is required: 181 excavators, 77 bulldozers, 34 sets of drain-washing aggregates, 2 sets for pneumatic-impulse cleaners of wells, 250 immersed pumps for vertical drainage holes, 80 control stations, and 70 transformers. Actually, water management and construction organizations, Department of Water Resources, and farms have considerably less numbers of such items, and a certain part of them are non-operational;
- Other reasons for decreasing of crop productivity in Syr Darya Oblast are low soil nutrient content. According to the data of Syr Darya agro-chemical laboratory, 54% of the 255,600 ha of irrigated area have very low available phosphorus content; 37% have low content; 6.9% have moderate content; 1.5% have medium-to-high content, and only 0.5% have a very high P content. Of irrigated area, 6% have very low total nitrogen content; 75% have low content; 11% - moderate content, 6% have medium-to-high N content. There is no soil with high content of total nitrogen. However, 6.3% of the area has low exchangeable potassium content; 33% - moderate content; 35 - medium-high content; 23% - high content. Of the area, 2.1% has very low humus content in topsoil; 49% - low content; 45 - moderate content, and 0.3% - high content.

At the same time, actual N application for cotton is 30-40% less than normal. Actual P application for cotton also is 42-73% less than normal. Nitrogen application for wheat in all the farms of the Oblast is 13-41% less than required, and P application is 13-83% less than required. In recent years, in the majority of farms of the Oblast, organic fertilizers practically are hardly applied at all. One of the main reasons for a delay of land preparation, sowing and harvesting is unsatisfactory technical condition of the agricultural machinery. There is a sufficient number of agricultural machines in the Oblast, but the percentage of operational machines is very low and is by rayons from 32 to 68%.

According to information by the Minselvodkhos of the Republic of Uzbekistan during vegetation period of 1997, 28.24% (1,144,160 ha) of total irrigated land in Uzbekistan had groundwater table in the range down to 2 m and 64.1% (2,597,030 ha) down to 3 m; 27.5% (1,117,130 ha) had groundwater salinity more than 3 g/L. 53.3% (2,319,000 ha) of total irrigated land was from slightly saline to severe saline.

Besides, according to experimental-production research, under the present conditions during irrigation and leaching salts are transferred from the topsoil into the subsoil and during dormant period and irrigation intervals soil salinity is restored.

In the long-term, along the Syr Darya and Amu Darya rivers from upper reaches to low reaches, river water salinity is increasing due to discharge of drainage and tail-escape water from the irrigated territories.

Under present conditions, the Syr Darya river water salinity at the Uchkurgan gauging station is 0.22 g/L; Kal - 0.15 g/L; Kzil-Kishlak - 1.0; and Kazalinsk - 1.62 g/L. In the Amu Darya at the gauging station Kerki water salinity is 0.60 g/L, and at Tuyamuyun - 1.06 g/L.

Weighted average salinity of irrigation water in Syr Darya Oblast is 1.59 g/L. The given data on the increase of weighted average salinity of irrigation water along the river's course reflects the consequences of reuse of the river's waters, as well as the use of drainage waters for irrigation. During 1995, 864,21 M m³ of drainage water was used for irrigation, including 111,63 M m³ from vertical drainage wells. Numerous investigations found that an increase of irrigation water salinity requires an increase of leaching norms and, consequently, discharge capacity of drainage system and its construction costs.

Average cotton yield in the Republic in 1995 was 2.68 t/ha. There is a clear relationship between the decrease of average cotton yield and the increase of irrigation water salinity.

According to the SANIIRI's research data in Uzbekistan, the present efficiency of inter-farm canal system is 0.86, and of on-farm one, is 0.75, with overall efficiency canal system 0.64. Taking into account the field application efficiency the overall efficiency is 0.435; an estimated annual total intake in the Republic based on total area of crops in 1995 was 88 km³. Actual annual intake during the period of 1993-'95 was 48-57 km³, i.e., the water availability was 55-65%, and in dormant (leaching) period even less, 49.1-58%. At the same time, at the on-farm level due to lack of incentives, irrigation water is used inefficiently, without observation of irrigation schedule, with lesser number of irrigation application, but at higher rates. Such a practice does not satisfy crop water requirements and optimal soil wetting for different crop development stages. A specific water supply to a field boundary in 1995 was varying by oblasts from 6.38 to 13.13 t/cm/ha. Drainage percentage by oblasts was varying from 29.1 to 80.5% of water supplied. There is no underground lateral inflow of groundwater in Syr Darya Oblast and, in the zone of new irrigated land, 22% of water supplied for irrigation is drained, and, in the zone of old irrigated land, 42% of water supplied for irrigation is drained.

Irrigation and drainage systems have been constructed for water supply and regulation of water-salt conditions of soils on the irrigated lands. However, their technical level does not meet necessary requirements: 62.9% of the length of the inter-farm and 78% of on-farm irrigation network has no lining; of 2,809,000 ha of area with drainage system, 1,709,700 ha have an open horizontal drainage (60.7%); 30.4% of inter-farm and 61.4% of on-farm collector and drains have to be cleaned.

The vertical drainage systems' efficiency was sharply decreased due to the lack of spare parts and

maintenance during recent years; 99% of the total area, is irrigated mainly by furrows and border strips.

Toward the end of the 80s, the scientific and research organizations, developed the whole spectrum of technical solutions, allowing to partially mechanize a labour-consuming process of furrow irrigation and to reduce losses during the distribution of water between furrows.

By the end of 1991, there were production capacities for manufacturing of irrigation equipment to ensuring their use on an area of about 247,000 ha. The biggest industrial enterprises manufacturing irrigation equipment were situated in Uzbekistan. A part of the irrigation equipment was made here by requests of the neighboring republics. The peak of production was recorded in 1989, and it was enough to provide approximately 110,000 ha of irrigated lands with irrigation equipment.

Since 1990 a recession began in production of irrigation equipment for surface methods of irrigation and, since 1994, production has been practically stopped. There are several reasons for that: the supply of materials and spare parts from the republics of the former USSR was considerably reduced or stopped. However, the main reason is the fact that under the conditions of relatively low prices for agricultural production it becomes unprofitable for farmers to buy the irrigation equipment. To a certain extent, the lack of real incentives to rise the efficiency of, irrigation water use is also one the reasons for this situation. For a time being, there is no precise mechanism of efficient water use on the field level in any of the region's countries.

RECOMMENDED ACTIONS

On the basis of above about the water-salt conditions on irrigated lands and taking into account the main reasons causing this situation, to increase a fertility of salt-affected soils, to ensure the sustainable development of irrigated agriculture, to reduce water use per unit of production during a relatively short period, it is necessary to solve the following problems:

- On the basis of market transformations to improve economic and legal mechanisms for attraction of additional financial resources for the support and development of the water economy, to introduce a water charge, which is closely related with increase of state order prices for agricultural production or with possibility for farmer to sell it by the world market prices;
- Improve soil fertility and crop yields by application of required quantities of mineral and organic fertilizers, to carry out timely crop operations, and to follow grass-arable crop rotations;
- Ensure an appropriate efficiency of irrigation and collector-drainage systems as a result of repair works improvement, and provision with material, technical and financial resources;
- Cultivate new drought-resisting and salt-resisting varieties of cotton and other crops, as well as low water-consuming highly productive crops (orchards, vineyards, etc.);
- Improve the reliability of technical means for water resources management, ensuring fulfillment of water-use strategy and rules (reservoirs, head intake and control structures, irrigation canals), to introduce modern water measuring devices, to widely use modern computers and software and modern communication facilities;
- Improve methods and irrigation application techniques, land leveling, uniformity wetting and desalinization of soils to minimize deep percolation of irrigation water;
- Improve soil moisture characteristics by ripping down to 0.8-1.0 m, deep ploughing, and application of various organic and non organic aggregating agents;
- Avoid using of saline drainage water for irrigation;
- Improve drastically the information system in the irrigated agriculture on various hierarchical levels of management on the basis of computerization;
- Eliminate from crop rotation severe saline lands with heavy leaching norms, required for desalinization;
- Establish, in representative rayons, experimental irrigation plots within pilot projects and demonstrate methods of efficient use of irrigation equipment and to train trainers and specialists;
- Work out a system of pilot credit for farmers for a special purpose to purchase good irrigation equipment.
- Ensure a long-term soil fertility, subjected to salinization and a sustainable irrigated agriculture it is necessary to solve the following problems:
- Provide the necessary level of repair and manufacturing of machinery for land improvement and construction works;
- Organize manufacturing and wide-scale introduction of various types of perfect irrigation equipment, ensuring a uniform distribution of water between furrows and moistening of a rooting depth of soil, including a transition to a highly frequent irrigation of alternate furrows;
- Reconstruct irrigation and drainage systems allowing to control water-chemical conditions of soils within optimal limits;
- Improve the efficiency of inter-farm and on-farm canals and irrigation systems as a whole by lining;
- Develop a master plan for irrigation water quality management by changing of amelioration conditions within different parts of a river basin, and also by changing layout of collectors to avoid discharge of drainage water into the river;

- Improve the quality of collector-drainage waters with the help of bioplateau;
- Ensure a sustainable reduction of ground-water level and desalinization of aeration zone and as a result of this to eliminate soil leaching and its costs;
- Ensure the improvement of soil fertility and a high level of crop husbandry for maximization of crop

yields, optimization of cropping pattern in the basins of the Syr Darya and Amu Darya rivers and, as a result, to restore to economically acceptable levels, reuse of water on irrigated lands in the basin of the Aral Sea.

- All such measures require the preparation of highly skilled personnel and constant improvement of their qualification.

Inter-temporal Wastewater Reuse in Irrigation and Revenue Maximization: The Case of Tyre Region, South Lebanon

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ABSTRACT

Land application, or the reuse of secondary-treated wastewater in irrigation, is a potential cost-effective and environmentally sound solution for the wastewater disposal problems; it is a well-established practice in many arid and semi-arid regions in the world. Several studies have addressed the direct and immediate use of the secondary-treated effluent, while fewer have tackled the impact of the storage of excess unused effluent for later use. The focus of this paper is to investigate the economic feasibility of land application in the presence of a storage facility with several capacities. To meet the above objective, a dynamic linear programming model was developed to determine the optimal cropping pattern that will consume all or most of the effluent throughout the optimization horizon, utilize all the effluent's nitrogen, and brings in the highest revenues. A case study in the Tyre region, South Lebanon, was used for model application. Different reservoir-capacity Scenarios were developed and then compared to a no-storage Scenario. The results indicate that the presence of a reservoir can enhance the efficiency of the wastewater usage and the flexibility of the associated cropping pattern. Furthermore, it can reduce the need for supplementary irrigation with fresh water and increase the revenues obtained.

INTRODUCTION

The term wastewater is defined according to the Food and Agriculture Organization (FAO) of the United Nations (1991) as "the spent or used water of a community or industry which contains dissolved and suspended matter". About 99% of wastewater is water and only 1% is solid waste (FAO, 1991). Treated wastewater can be utilized in a multitude of applications like irrigation, recreation, industrial cooling, fire fighting, aquifer recharge, and, essentially, several non-potable uses after the proper treatment is performed.

The need to utilize wastewater increased significantly in the last few decades, as fresh water resources became scarcer. The continuous increase in population volume, and the increase in water demand for different uses with relatively constant water supply, have widened the gap and inflated the problems. Thus, wastewater utilization is becoming the hope of recycling that unique scarce resource.

Land application, or the reuse of treated wastewater in irrigation, is a potential cost-effective solution for the wastewater disposal problem. Land application is defined as "the controlled application of pretreated wastewater onto the land surface to achieve a higher designed degree of treatment through the natural, physical, chemical, and biological processes within the plant-soil-water matrix" (Borrelli and Fedler, 1988).

Land application of treated wastewater is a well-established practice in many arid and semi-arid regions in the world. It is not just an economic and effective way for the disposal of wastewater, but is also a way to alleviate fresh water scarcity. Chansler (1991) stated that "the wastewater business has come full circle", the facilities themselves have gone from wastewater-treatment plants, to pollution control facilities, to water recovery or management facilities. The necessary progression has been from treating and disposing to managing and reusing (Darwish et al., 1999).

Several researchers have studied the land application process as a favorable approach for treatment and reuse of wastewater. Young and Epp (1980) used simulation to show that as the amount of applied wastewater to a certain area, within the existing set of constraints, increases the total annual cost of the treatment decreases. Bouwer and Idelovitch (1987) considered that the use of wastewater in irrigation after being treated up to a certain level is an "excellent" use for the sewage effluent since it is mostly water with nutrients. Itoyama (1990) showed that land treatment of secondary effluent of domestic wastewater was favorable since the quality of the groundwater was scarcely affected and the fertilizing effects on weeds and trees was clearly seen.

Suzuki (1992) indicated that land-application removal-efficiency of BOD (biochemical oxygen demand), COD (chemical oxygen demand), and total phosphorous was more than 90% while that of nitrogen was less than 50%. Ziqing (1992a; 1992b) studied the design of the hydraulic loading rate of paddy rice slow-rate land-treatment systems (SR-LTS). The study showed that SR-LTS is an economically effective solution not just for the disposal of wastewater, but also for the use of nutrients as nitrogen, phosphorous, and potassium.

Many studies utilized linear programming as an optimization technique to determine optimal solutions related to fresh water irrigation issues such as: maximizing net benefits, minimizing costs, determining optimal cropping pattern, daily operation decisions for

irrigation water delivery, and water management strategies for salinity control on farm or regional levels (Bowen and Young, 1985; Tyagi, 1986; Dinar and Yaron, 1986; Afshar and Marino, 1989; Boman and Hill, 1989; Eckert and Wang, 1993; Zhenmin, 1995; Mteirek, 1997). However, limited studies have dealt with linear programming for optimization of wastewater reuse in irrigation. Segarra (1996) used a linear dynamic programming model to determine the cropping pattern that would remove all N from secondary-treated effluent and maximize revenues over variable costs. Darwish et al. (1999) used linear programming to utilize wastewater in the Tyre region and found that such practices bring in revenues that may cover totally or partially the total cost of such operation.

Wastewater treatment is not yet applied in any region in Lebanon, and there is no regulation related to the levels of treatment requirements (Ayoub, 1992). Raw wastewater is disposed directly into the sea in most of the coastal areas, without even preliminary treatment. Such a practice leads to environmental damages for the marine biodiversity and to health hazards to the residents of these coastal areas.

With the potential increase in environmental damages and health hazards due to the dumping of untreated wastewater into the Mediterranean Sea, land application may provide an environmentally safe alternative that is economically sound for wastewater treatment in Lebanon. In addition, it provides a solution for possible future water scarcity, especially with 25% expected deficiency in the Lebanese water budget by year 2020 (Jaber, 1992).

Darwish et al. (1999) determined the optimal cropping pattern that will utilize the total available effluent for Tyre city in south Lebanon using LP modeling. Supplementary irrigation was provided in some scenarios; however, none of the study scenarios did consider storage facility. Several scenarios in this study deemed infeasible due to the inflexibility between the effluent supply and demand on a monthly basis. Thus, the idea of developing a reservoir for effluent seems a legitimate one to study the impact of the presence of the reservoir on net revenues, optimal cropping pattern, land utilization, and reservoir capacity.

The main objective of this paper is to determine the optimal cropping pattern that utilizes all of the secondary-treated wastewater available, consumes all the N available in this treated wastewater (being the most limiting factor), and produces the highest net return for the selected study area. This will be determined under different assumed effluent reservoir capacities and in some cases in the presence of freshwater supplementary irrigation. The optimal conditions will be determined over a 5-year planning horizon.

METHODS AND PROCEDURES

Study Area

The study area is selected in Tyre region, south Lebanon for several reasons. First, it was used in a

previous study (Darwish et al., 1999). Second, the area has a significant portion of green areas for field crops. Third, a wastewater treatment plant will be developed in this area. Fourth, currently wastewater in the study area is disposed into the sea without any treatment, causing significant potential hazards to public health and marine biodiversity in the region. The area is characterized by its Mediterranean climate with dry summers and wet winters. It is a coastal region with high population and a sizable agricultural area along the coast, which makes it suitable for the application of the slow rate technique of land application. The agricultural area in the region is about 1,500 hectares.

CROP SELECTION

Currently, the major crops produced in the area include of citrus, banana, field tomato, field cucumber, melons, peppers, greenhouse tomato (winter and summer), greenhouse cucumber (winter and summer). The distribution of these crops in the area is: citrus (930 ha), banana (330 ha), tomato green houses (36 ha), cucumber green houses (7 ha), and other vegetables (197 ha).

Potential crops for treated wastewater reuse should satisfy all or most of the following criteria: high N uptake, high water requirements, high revenues (Segarra 1996), potential use in processing when needed, potential local or international market, and suitability for Mediterranean climatic conditions (Darwish, 1999). Thus, four new crops that exhibit most of these criteria are proposed for the study area. These crops are: alfalfa, roses (greenhouse), carnations (greenhouse), and Gerbera (greenhouse).

These crops are considered for several scenarios in this study. The objective of introducing new crops to the area is to assess the impact of the presence of such crops on the N uptake, wastewater consumption level, and the change in net revenues. Alfalfa is included for two reasons: first, it has a high N uptake compared to the other field crops; second, it is among the highly recommended crops for irrigation with treated wastewater (USEPA, 1981). Roses, carnation, and Gerbera are chosen for the following reasons: first, they have a high N uptake; second, they are highly profitable; third, they are characterized by their continuous high water consumption for most of the year, and fourth, they enjoy relatively high market demand in Lebanon (Darwish, 1999).

Wastewater production estimates were adopted from the MCC and LIGmbH (1995) survey that was conducted in the study area. The total amounts of wastewater produced in the study area from the different sectors are presented in Table 1. The estimated chemical composition of the secondary treated wastewater in Tyre region was adopted from another study that was conducted in the same area (Jouzy and Partners, 1995; Darwish, 1999). The wastewater of the region is generally domestic. Industrial activities in the area are limited, and the chemical characteristics of the industrial wastewater are assumed to be domestic in nature due to

the absence of heavy industry and the fact that the existing industries use water mainly for cooling (Darwish et al., 1999).

According to Jouzy and Partners (1995), the expected quality of secondary treated wastewater from the area would be generally accepted for irrigation with estimated N content of 50 milligrams per liter. The same study indicates that P and other effluent constituents are expected to be below the limiting rates of the United States Environmental Protection Agency standards (USEPA, 1981).

In this study, it is assumed that the produced crops will not be directly consumed by human, according to USEPA (1981). Data on crop input requirements; expected yields, production expenses, as well as revenues were obtained from Darwish et al., (1999). Figures that reflect optimal production conditions were adopted for these parameters throughout the study. Table 2 presents total variable costs, total revenues, and net revenues for all considered crops.

Table 1. Wastewater production in the study area (Tyre region).

Area	Total Wastewater Produced, m ³		
		Daily	Yearly
	/capita/day	/day	/year
Tyre and large villages	0.1	18,338	6,693,370
Small villages	0.3	6,021	2,197,665
Total		24,359	8,891,035

Source: Mouhit Consulting Company and Lahmeyer International GmbH. 1995.

STUDY SCENARIOS

Three basic scenarios are developed to fulfill the study objectives. In all scenarios, a reservoir with different storage capacities is considered. The storage capacities considered in the study are: one-fourth, one-half, and a one-month storage. The volume of the one-month storage capacity was set equal to the highest monthly effluent received by the municipality, which amounts to 755,098 cubic meters. In some Scenarios, supplementary irrigation with fresh water is allowed to determine its impact on cropping pattern flexibility, land utilization, and net revenues. The maximum allowed amount of supplementary irrigation in these Scenarios is set equal to maximum effluent received in any month. The reservoir is considered to be filled in all the scenarios at the beginning of the planning period, which was considered to be 5 years with May as the starting month.

Basic Scenario 1 (S1) is considered to determine the impact of the reservoir on the current situation (varying reservoir capacity, only current crops, $\pm$ supplementary irrigation). Only the current crops with their associated areas are considered. In the *Second Scenario*, the new crops are incorporated in addition to the current ones (varying reservoir capacity, current and new proposed crops, no restriction on greenhouse area). Different reservoir capacities are assumed, but no supplementary irrigation is allowed. In the *Third Scenario*, supplementary irrigation is allowed but only for the infusible solutions of *Scenarios 1* and *2* (reservoir capacity $\frac{1}{4}$ month with/without greenhouse restriction). The reason of such Scenario is to check if the presence of supplementary irrigation will help in over coming such infeasibilities.

Table 2. Cost of production, total revenues, and net revenues for the crops.

Crop	Total Variable Cost	Total Revenue	Net Revenue
		-----\$/ha-----	
Citrus ¹	2.4	7.4	5.0
Banana ¹	3.2	9.3	6.1
Alfalfa ¹	2.2	3.1	0.8
Tomato field	6.6	9.6	2.9
Cucumber field	2.4	4.6	2.2
Melon	1.8	7.7	5.9
Pepper	2.3	6.2	3.9
Winter Tomato ²	2.9	48.0	18.3
Summer Tomato ²	2.9	48.0	18.2
Winter Cucumber ²	29.0	40.3	11.3
Summer Cucumber ²	29.0	40.3	11.2
Roses ¹²	64.7	250.1	185.3
Carnation ¹²	165.7	349.4	183.6
Gerbera ¹²	87.5	200.0	112.5

¹Perennial crop, ²greenhouse grown.

Model Formulation

Given the model assumptions presented above, a basic form of the model is presented herein. The net return (NR) function can be expressed as follows:

MAX NR_t = \sum TR_{kt} * X_{kt} (TEFF; Avai + STO) - \sum TVC_{kt} * X_{kt} (1)

Where:

NR_t is the annual net return above on-farm variable costs (except for green house crops) per hectare for year t, and k refers to the different cropping activities selected. K_max equals 10 in Scenario 1 and 14 in Scenarios 2 and 3. TR_{kt} is the total revenue for crop k in year t and X_{kt} (the decision variable) stands for the number of hectares allocated for crop k in year t. The number of hectares is a function of the total effluent available (whether storage or used); in some scenarios where supplementary irrigation is provided, it becomes a part of the function of the number of hectares. The TVC_{kt} is the total variable cost per hectare for crop k in year t.

The on-farm fixed costs of the field crops are not included, since they are considered as sunk costs (i.e., they are forgone costs since they do exist regardless of the types of crops that are produced). However, greenhouse amortized fixed costs are included as part of the greenhouse crop cost functions because of the significance in the initial investment. The off-farm amortized fixed costs, including the treatment plant initial and operating costs, are calculated, and subtracted from the objective function of each scenario. The amortized fixed cost amount to US \$8.3 annually (Darwish, 1999). The treatment cost is considered as a fixed cost due to the assumption that, on average, a fixed amount of wastewater should be treated up to secondary level each year whether it is utilized in irrigation or not (Darwish et al., 1999).

Since the objective function of the optimization model in this study is to maximize the net return over variable costs for a 5 year planning horizon, Equation 1 can be detailed as follows:

MAX Z = \sum NR_t (1+r)^t (2)

The objective function is subject to the following constraints:

\sum X_{kt} \leq LAND_r \text{ for all } t, t=1,...,5 (3)

\sum X_{kt} * W_{kt} \leq TEFF_{jt} + SUPP_{jt} \text{ for all } j, j=1,...,12 (4)

STO_{jt} = EFF_{jt} - WX_{jt} + SUPP_{jt} \text{ for all } j, j=1,...,12 (5)

TEFF_{(tm+1)} = EFF_{jt} + stot_j - WX_{jt} \text{ for all } j, j=1,...,12. (6)

STO_{jt} \leq STORCAP_{jt} (7)

NIT_t * X_t \geq NEFF_t (8)

X_{kt}, SUPP_{jt}, STO_{jt}, EFF_{jt} \geq 0 (9)

Where:

Equation 3 stands for the land availability constraint for all scenarios in all years. The total area allocated for all crops in any month j should be less than or equal to the total land area available during that month. X_{kt} is the area (ha) allocated for crop k in year t, while LAND is the total land available in year t (1,500 ha). Eq. 4 represents the total water consumption for k crop month j in year t. Eq. 5 represents the stored volume in month j in year t. In the supplementary irrigation Scenarios, fresh water is not allowed to be stored in the reservoir. This is why it was subtracted from the storage capacity. Eq. 6 is the equation of motion in which the monthly effluent available in the next month is the function of this month effluent, this month storage less this month crop water requirements. Equation 7 is the maximum storage capacity. Equation 8 is the environmental equation in which the N available in the effluent must be used by the optimal determined cropping pattern. Equation represents the non-negativity constraint on all decision variables X_{kt}, SUPP_{jt}, STO_{jt}, EFF_{jt}.

RESULTS AND ANALYSIS

The formulated models were solved using General Algebraic Modeling System (GAMS). The following section presents the results that were obtained from the study scenarios. For Scenario 1, the three scenarios with the above-mentioned reservoir capacities deemed infeasible, under the current cropping area allotment. The only feasible scenario was obtained when citrus and banana areas were reduced to one third and one half, respectively, with one-month reservoir capacity and in the presence of supplementary irrigation. The net revenues above variable cost for the 5-year planning horizon amounts to US \$82.8 million. The amortized fixed cost of establishing the treatment plant facility accounts for US \$8.3 million per year. Thus, the net return above all cost for the planning period amounts to US \$41.3 million. The average total land use per year was 596 ha for the summer season and 1303 ha for the winter one, with land-use efficiency of 40% and 87% for each season, respectively. All supplied N in the effluent was consumed except an annual amount of 0.7 ton.

These figures indicate that the current status of citrus and banana areas should be reduced and supplementary irrigation should be provided if the available wastewater were to be used in land application. The required reduction in the area of citrus and banana can be justified due to the fact that both crops have low N uptake and relatively low water requirements compared to some other crops incorporated in the model.

For Scenario II, which assumed the inclusion of current and new crops, several storage capacities, and no supplementary irrigation, the sub-scenario of a one-fourth monthly storage capacity deemed unfeasible.

However the sub-Scenarios at one-half (S21) and one-month storage capacities (S22) were feasible. The net return of S21 over the 5-year planning period amounts to US \$188 millions. While at one-month storage capacity (S22), the net return increased to \$308 millions over the same period. Table 3 represents the outcome of the one-month storage capacity. A comparison between the outcomes of both scenarios indicates that, as the reservoir capacity increases (with no supplementary irrigation), the land required for application and the crop diversification decrease, but the net return increases.

A sub-scenario was then developed (S23) to restrict the area allocated to greenhouse production, to avoid over-production and bind with the market constraints of the selected crops. The area of greenhouses was set not to exceed a 15% of the total available land. The net return then was decreased to US \$212 million over the same planning horizon with more crop diversification.

A comparison between S22 and S23 results indicate that greenhouses are an excellent option for land application. Moreover, as greenhouse areas are restricted, land requirements for effluent utilization and crops diversification increase while the net returns decrease.

Supplementary irrigation was then provided in scenario S31, with a one-four month of storage capacity and current and new crop inclusion. This scenario was unfeasible with no supplementary irrigation; however, it turns out to be feasible once supplementary irrigation is provided. The net return over the planning horizon amounts to US \$370 million. It worth mentioning that land utilization increased significantly in the presence of supplementary irrigation, even with such a limited reservoir capacity. The results of this sub-scenario indicate that there is a trade off between the storage capacity for the treated effluent and the presence of supplementary irrigation of fresh water. In addition, there is a significant increase in land requirements compared with any other Scenario in this study. Thus, from the above results it can be concluded that the presence of supplementary irrigation requires less storage capacity and more land areas but brings in higher revenues.

Once again, a restriction on greenhouse production was imposed (S32) to insure market feasibility. The restriction on greenhouse areas was again set not to exceed 15% of the total available land. Once again, the restrictions led to lower net revenues and more crop diversification.

CONCLUSIONS

Based on the study assumptions and specifications, several conclusions can be drawn. *Land application may provide an option for wastewater utilization that is environmentally sound and financially feasible.* These financial returns will ease the burden on local and central government of treating wastewater. The presence of a reservoir facility will significantly reduce the need for supplementary irrigation and land requirements, and brings in higher revenues compared to no reservoir

situation. As the storage capacity increases, less land is needed and higher revenues can be obtained.

The presence of supplementary irrigation reduces the need for storage capacity. Moreover, the greenhouse crops provide an excellent option for wastewater utilization. The dominance of the greenhouse crops (especially flowers) in all feasible Scenarios underscores the importance of exploring and opening new markets, domestically and internationally for these products. As such, markets become available, higher revenues may be obtained with more effluent to be utilized and less land requirements.

REFERENCES

- Afshar, A., and M.A. Marino. 1989. Optimization models for wastewater reuse in irrigation, *J. Irrig. and Drainage Eng., ASCE*, 115(2): 185-202.
- Ali, I. 1987. Wastewater criteria for Irrigation in Arid Regions, *J. Irrig. Drainage Eng., ASCE*, 113(2): 173-183.
- Ayoub, G.M. 1992. Wastewater treatment and disposal for communities along the coast of Lebanon, *Report presented to the AUB/MIT collaborative research program*.
- Boman, B.J., and R.W. Hill. 1989. LP Operation Model for On-Demand Canal Systems, *J. Irrig. Drainage Eng., ASCE*, 115(4): 687-700.
- Borrelli, J., and C.B. Fedler. 1988. Recommendations for crops and irrigation of wastewater effluent on the Gray Farm, Dept. Agric. Eng., Texas Tech. University, Lubbock, Texas.
- Bouwer, H. and E. Idelovitch. 1987. Quality requirements for irrigation with sewage water, *J. Irrigation Drainage Eng.*, 113(4): 516-535.
- Bowen, R.L. and R.A. Young. 1985. Financial and economic irrigation net benefit functions for Egypt's northern Delta. *Water Resources Res.*, 21(9): 1329-1335.
- Chansler, J.M. 1991. The future for effluent reuse, *Water/Eng. & Manage.*, 138: 31-34.
- Darwish, M. R, F.A. El-Awar, M.Sharara, and B. Hamdar. 1999. Economic-environmental approach for optimum wastewater utilization in irrigation: A case study in Lebanon, *J. Appl. Eng. Agric.*, 15(1): 41-48
- Dinar, A., and D. Yaron. 1986. Treatment optimization of municipal wastewater and reuse for regional irrigation, *Water Resources Res.*, 22(3): 331-338.
- Eckert, J.B., and E. Wang. 1993. Effects of irrigation water supply variations on limited resources farming in Conejos County, Colorado, *Water Resources Res.*, 29(2): 229-235
- Food and Agriculture Organization Regional Office of Near East (FAO/RNEA). 1991. Wastewater use and human health, *Tech. Bull. No. 3*, Cairo, Egypt.
- Food and Agriculture Organization Regional Office of Near East (FAO/RNEA). 1992. Wastewater as a crop nutrient source, *Tech. Bull. no. 5*, Cairo, Egypt.
- Itoyama, T., H. Yokose, S. Yoshida, and M. Kuwahara.

1990. Evaluation of land application using secondary effluent in a forest slope: Estimation of drained water quality and discussion of the effects upon soil or plants and behavior of bacteria. *Water Res.*, 24(3): 275-288.
- Jaber, B. 1992. Water resources in Lebanon: Domestic and industrial demands. *Proceedings of conference on "Water Supply in Lebanon"*, 27-28 Nov., Beirut, Lebanon.
- Jouzy and Partners. 1995. *Water and wastewater study for Saida drainage zone*, Study presented to the Ministry of Hydraulic and Electric Resources, Beirut, Lebanon.
- Mouhit Consulting Company and Lahmeyer International GmbH. 1995. *Water and wastewater study for sour drainage zone*. Study presented for the Ministry of Hydraulic and Electric Resources, Beirut, Lebanon.
- Mteirek, R. 1997. Irrigation supply system design for optimal cropping pattern. *Unpublished M.Sc. Thesis*, Amer. Univ. Beirut, Lebanon.
- Schrage, L. 1991. *LINDO: An optimization modeling system*. Graduate School of Business, University of Chicago, The Scientific Press.
- Segarra, E., M.R. Darwish, and D.E. Ethridge. 1996. Returns to municipalities from integrating crop production with wastewater disposal. *Resources, Conservation and Recycling*, 17: 97-107.
- Suzuki, T., T. Katsuno, and G. Yamaura. 1992. Land application of wastewater using three types of trenches set in lysimeters and its mass balance of nitrogen. *Water Res.*, 26(11): 1433-1444.
- Tyagi, N.K. 1986. Optimal water management strategies for salinity control, *J. Irrig. Drainage Eng.*, 112(2): 81-97.
- United States Environmental Protection Agency. 1981. *Process design manual: Land treatment of municipal wastewater*, Center for Environmental Research Information, Cincinnati, Ohio.
- Young, E.C., and D.J. Epp. 1980. Land treatment of municipal wastewater in small communities. *Amer. J. Agric. Econ.*, 62: 238-243.
- Zhenmin, Z. 1995. Optimization of water allocation in canal systems of Chengai irrigation area. Technical Sessions about Irrigation Water Delivery Models, FAO.
- Ziqing, O., G. Zhengmin, and S. Tieheng. 1992. Paddy rice slow-rate land treatment systems I. Design of hydraulic loading rates, *Water Res.*, 26(11): 1479-1486.
- Ziqing, O., C. Shijun, G. Zhengmin, S. Tieheng, Q. Enshan, M. Xuejun, L. Peijun, Z. Lishan, Y. Guifen, H. Shuhau, S. Yufang, Z. Hairong, R. Liping, and Q. Xiangrong. 1992b. Paddy rice slow-rate land treatment systems II. Hydraulic balances and results of 4 years' operation. *Water Res.*, 26(11): 1487-1494.

Runoff Modeling of Micro-Catchment Water Harvesting

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ABSTRACT

Water harvesting - the collection and beneficial use of surface runoff - has the potential to greatly increase water availability for agricultural production in dry areas. The amount of runoff water that can be collected depends on the characteristics of the precipitation and the physical properties of the catchment area. Hydrological models that estimate surface runoff can aid the design of efficient water-harvesting systems. To assess the effect of various factors on runoff generation and to collect data to evaluate the use of runoff estimation models, 36 micro-catchments were installed on a montmorillonitic clay soil (*Calcixerollic Xerochrept*) in northern Syria. The plots varied in the following features: soil depth (deep and shallow); slope (5% and 10%); catchment length (4, 8, and 12 m); and surface treatment (natural, compaction, and NaCl). This paper analyzes the rainfall and runoff data from five seasons, starting in the fall of 1994.

The annual rainfall for the five seasons varied between 283, 405 mm, and annual runoff coefficients of the micro-catchments varied between 0.0 and 0.53. As expected, runoff efficiencies were higher at the shallow soil than at the deep soil and decreased with an increase in catchment size. During the 1995-'96 season runoff volumes from the salt-treated plots were almost five times higher than from the natural plots, but the effect of the salt application decreased substantially during subsequent seasons. The data from the micro-catchments were used to test the applicability of linear models and the curve-number method for micro-catchment water-harvesting design. The modeling effort indicated that a robust stochastic modeling approach is needed to capture the effect of the temporal and spatial variability of the rainfall and catchment properties.

INTRODUCTION

The harvesting of runoff water from precipitation has a long tradition in the West Asia and North Africa region (e.g., Bruins et al., 1986; Brunner and Haefner, 1986). Increasing pressure on land and water resources in the dry areas has sprouted renewed interest in these techniques. The occurrence of surface runoff is common in arid regions where high rainfall intensities, shallow soils, dense surface crusts, and poor vegetative cover often cause the rainfall to exceed the infiltration capacity of the soil.

Collection of this runoff water may allow crops, shrubs, and trees to grow in areas where the natural rainfall alone would not be sufficient for their growth. The term "water harvesting" is used to describe a wide range of methods for collecting and concentrating different forms of runoff water such as rooftop runoff, overland flow, and stream flow.

Uses of the collected water include crop production, livestock watering, and domestic needs. Reij et al. (1988) have presented a review of the different terms and classifications used to categorize the various water-harvesting systems and techniques. For agricultural production, two broad categories can be distinguished: macro-catchment and micro-catchment techniques.

Macro-catchment techniques are often referred to as water spreading or floodwater harvesting. These systems reduce, divert, or collect the runoff water from ephemeral streams (*wadis*) to allow infiltration of water in the stream channel bed, irrigation of adjacent cultivated fields, or storage in surface reservoirs. Micro-catchments collect surface runoff over a flow distance of usually less than 100 m and store the water in the adjacent root zone of a crop, or of one or several shrubs or trees. Typical examples of micro-catchment systems are small basins (*"negarims"*), semi-circular bunds, and contour ridges.

Advantages of micro-catchments as compared to macro-catchments are that these smaller systems: (i) have a higher runoff efficiency; (ii) do not require water conveyance or storage facilities; (iii) are less susceptible to destruction by heavy storms; and (iv) can be installed by small farmers using commonly available tools and resources.

The amount of water that can be harvested during a rainfall event depends on the intensity, quantity, and distribution of precipitation events and on the size and characteristics of the catchment area. Factors that affect surface runoff from the catchment area include the soil properties, surface roughness, vegetative cover, stoniness, and slope. To increase the quantity of surface runoff the catchment area can be modified. Techniques may vary from simple surface clearance or compaction to application of sodium salts, paraffin wax, latex, silicone, bitumen, asphalt and oil emulsions, or plastic sheets. Although promising results of experiments with various surface treatments have been reported (e.g., Rauzi, 1973; Mehdizadeh et al., 1978; Frasier et al., 1979), cases of successful use by small farmers seem to be less well documented.

To design efficient micro-catchment, water-harvesting systems the optimum ratio between catchment and cultivated area need to be estimated. Data on micro-catchment runoff efficiencies are few and variable (e.g., Sharma, 1986; Boers, 1994; Oweis and Taimneh, 1996). Critchley and Siegert (1991) advice to install experimental plots for measuring rainfall and runoff at newly to develop water-harvesting sites. To capture the natural variability of the rainfall, plots need to be monitored for various years. This requires considerable investments, time and human resources. Although various mathematical models for the design and of water-harvesting systems have been presented (e.g., Ben Asher and Warrick, 1987; Oron and Enthoven, 1987; Boers, 1994; Sanchez-Cohen et al., 1997), the lack of data required by these models often hampers their application.

To aid the design of micro-catchment water-harvesting systems for agricultural production in dry areas, runoff-monitoring plots were installed on clay soil at Tel Hadya, in northern Syria. Two low-cost surface treatment techniques, compaction and salt application, were included in the experiment. The objectives of this study were: (i) to test the runoff efficiency of micro-catchments for different soils, slopes, catchment lengths, and surface treatments; and (ii) to evaluate the potential use of runoff estimation models for micro-catchment water-harvesting design, considering readily available data.

MATERIALS AND METHODS

Thirty-six runoff plots were installed at Tel Hadya, ICARDA's main research station in northern Syria, 30 km southwest of Aleppo. The experimental site is located 310 m above sea level. The mean annual precipitation (20 seasons) observed at Tel Hadya's meteorological station is 346 mm. The rainfall distribution is typical Mediterranean; approximately 95% of the total annual precipitation occurs from October to April with a maximum in January. The rainfall occurs during the cold season with low evaporation rate. Annual mean evaporation (Class-A pan) is 7 mm/d. Evaporation is lowest in December and January (1-2 mm/d) and peaks in July (15 mm/d).

The soils at Tel Hadya's experimental station are Inceptisols. The soil at the water-harvesting plots is classified as *Calcixerollic Xerochrept* (Ryan et al., 1997). The soil is well drained and consists of moderately weathered minerals with a high clay fraction (montmorillonitic). There is low biological activity in the subsoil and bulk density is higher than in the surface layer; thus less pores and a reduced hydraulic conductivity in comparison to the surface layer can be expected. The underlying limestone is slightly weathered. The soil depth is approximately 80 cm.

The 36 plots were laid out across the contour. The width of the plots is 4 m; and lengths are 4, 8, and 12 m. Small earthen embankments were installed along the boundaries of the plots, preventing upslope runoff to

enter the plot. Small metal flumes guide the runoff water from the lowest corner of the plot into a 0.22-m³ barrel. A tipping bucket rain gauge is installed in the center of the experimental area. The amount of runoff in the barrels was measured daily, in the morning and afternoon.

To test the effect of surface treatment on the runoff potential of clay soils, 12 plots were compacted (5 kg/cm²) and 12 were treated with sodium chloride (1.25 kg/m²), during the installation of the plots. Although the plots are weeded regularly, annual species cover the plots during part of the rainy season. Summing up, the plots varied in the following factors: (i) soil depth: deep, shallow; (ii) slope: 5%, 10%; (iii) catchment length: 4, 8, 12 m; (iv) surface treatment: natural, compacted, salt. The shallow soil is of the same type as the deep soil, but its surface layer has been removed to simulate the properties of a shallow or partly eroded soil.

Precipitation

The average precipitation of the five observed seasons at the water-harvesting site is 352 mm, which is close to the 346 mm long-term mean (1980-'99) for Tel Hadya. The driest and wettest season of the five observed years (Table 1) fell within the 25% left and right tail, respectively, of the annual rainfall distribution. Daily rainfall from the rain gauge at the site was highly correlated with the precipitation observed at Tel Hadya's meteorological station, located approximately 1 km southwest of the site ($r^2 = 0.993$ for the 1998-'99 season). However, the annual precipitation at the site was consistently 5 to 8% lower than the precipitation observed at the meteorological station. This might have been due to the topography of the area. The micro-catchments are located at the lower part of a gentle, westward facing slope, whereas the meteorological station is located in a flat plain.

The distribution of the daily rainfall events in classes is presented in Table 1. The relatively dry 1994-'95 season had a high number of small events, which are not expected to generate runoff. During the wet 1996-'97 season, four events exceeded 20 mm. The distributions of the daily rainfall events of the five seasons were, however, not significantly different at the 5% probability level, according to the Kolmogorov-Smirnov test (SAS Institute Inc., 1988).

Table 1. Precipitation characteristics observed at the water-harvesting site.

Season	Precipitation	Number of events in each class, mm					
		0-5	5-10	10-20	20-30	30-40	40-50
	---mm---						
1994-'95	313	80	12	5	1	2	0
1995-'96	374	71	20	10	0	0	0
1996-'97	405	70	14	8	3	0	1
1997-'98	387	63	18	12	1	0	0
1998-'99	283	56	10	7	2	0	0

RESULTS AND DISCUSSION

Runoff Efficiencies

The design of water-harvesting systems for agricultural production is often based on annual runoff coefficients. This runoff coefficient, also called runoff efficiency, is simply the ratio of catchment runoff to the precipitation falling on the catchment area. Thus, the annual runoff coefficient is computed as:

$RC = R/P \dots\dots\dots (1)$

Where: R is the total annual runoff (mm), and P is the total annual precipitation (mm). The runoff depth is obtained by dividing the runoff volume by the catchment area.

The annual runoff coefficients of the micro-catchments at Tel Hadya varied between 0.0 and 0.53. However, these runoff coefficients slightly underestimate the runoff, because overflow of the observation barrels occurred during some of the larger events. The highest runoff efficiencies were obtained at the salt-treated plots on the shallow soil during the wet 1995-'96 and 1996-'97 seasons. During the dry 1998-'99 season no runoff was observed from all three 12-m plots on the deep soil with a 10% slope.

To assess the long-term efficiency of the micro-catchments under variable rainfall conditions, the annual runoff coefficients were averaged for the five seasons (Table 2). As expected, runoff efficiencies were higher on the shallow soil than on the deep soil. The effect of the surface slope was less clear. An increase in slope decreases the surface storages and increases the flow speed, thus, reducing the potential for the runoff water to infiltrate. The data showed differently: on the shallow soil, runoff efficiencies were higher on the 5% slope than on the 10% slope. The difference was most pronounced at the 4-m plots. For the deep soil, the differences between the runoff efficiencies of the 5 and 10% slopes were small. Sharma (1986), conducting experiments on sandy loam micro-catchments in an arid region in India, found a substantial increase in runoff when the slope increased from 0.5 to 5%, but

The runoff coefficients consistently decreased with an increase in catchment length. This is a commonly observed feature, which is caused by the spatial variability in the infiltration capacity of the soil, microtopography, and vegetation. Surface runoff generated on an area with low infiltration capacity may infiltrate on an adjacent area with higher infiltration capacity. Thus, the longer the plot, the more chance the surface runoff has to infiltrate on its way down. Although the smaller catchments are more efficient, they may not yield sufficient runoff water needed for agricultural production. The longer plots are likely to generate higher runoff volumes, because of the larger contributing area.

For the natural and compacted plots on deep soils, the average annual runoff volumes at the 5% slope were higher for the 4-m plots than for the 8- and 12-m plots; at the 10% slope runoff volumes were highest for the 8-m plots. On the shallow soil, average annual runoff volumes for the natural plot with 5% slope and the salt-treated plot with 10% slope were higher for the 12-m plots than for the 8 and 4-m plots. At the other slope-treatment combinations, the 8-m plots produced more runoff. Theoretically, if one expands a plot in the upstream direction, runoff volumes can only become more, not less. Obviously, the measured runoff volumes were strongly affected by the inherent natural variability of the soils.

Effect of Surface Treatment

The average annual runoff coefficients (Table 2) indicate that the compaction of the catchments had almost no effect on the runoff efficiencies of the deep soils. On the shallow soil, compaction was more effective; it doubled the runoff of the 8-m plots, as compared to the natural plots. However, the effect of compaction decreased with time. After three seasons, the runoff coefficients of the compacted plots were almost the same as those of the natural plots (Fig. 1).

The salt treatment had a substantial effect on the runoff from all plots. The applied NaCl caused soil dispersion, resulting in plugging and sealing of the surface pores by the finer soil particles, similar to the effect caused by irrigating with high sodium content water

Table 2. Average annual runoff coefficients of the water-harvesting plots.

Soil Depth	Slope %	Natural			Compacted			Salt		
		4 ¹	8	12	4	8	12	4	8	12
Shallow	5	0.11	0.04	0.04	0.17	0.09	0.05	0.34	0.24	0.13
Shallow	10	0.08	0.05	0.02	0.11	0.10	0.03	0.24	0.21	0.15
Deep	5	0.09	0.04	0.02	0.07	0.03	0.02	0.11	0.08	0.06
Deep	10	0.06	0.05	0.02	0.06	0.04	0.02	0.12	0.09	0.06

1 Plot length (m).

almost similar runoff efficiencies for 5 and 10% slope plots. Casenave and Valentin (1988) concluded from work in West Africa that the effect of slope on runoff was reduced above a slope of 5%.

(Ayers and Westcot, 1985). During the wet second season, the runoff of the salt treated plots was almost five times as high as from the natural plots. The effect of the salt started to decrease during the third season, especially on the deep soil (Fig. 1). In the fifth season

(1998-'99), the average runoff volume harvested from the salt-treated catchments was 0.50 m³, as compared to 0.29 m³ for the compacted catchments, and 0.26 m³ for the natural catchments.

Linear Model

The most commonly used model for representing the rainfall-runoff relationship is the empirical linear regression model (c.g., Diskin, 1970; Sharma, 1986;

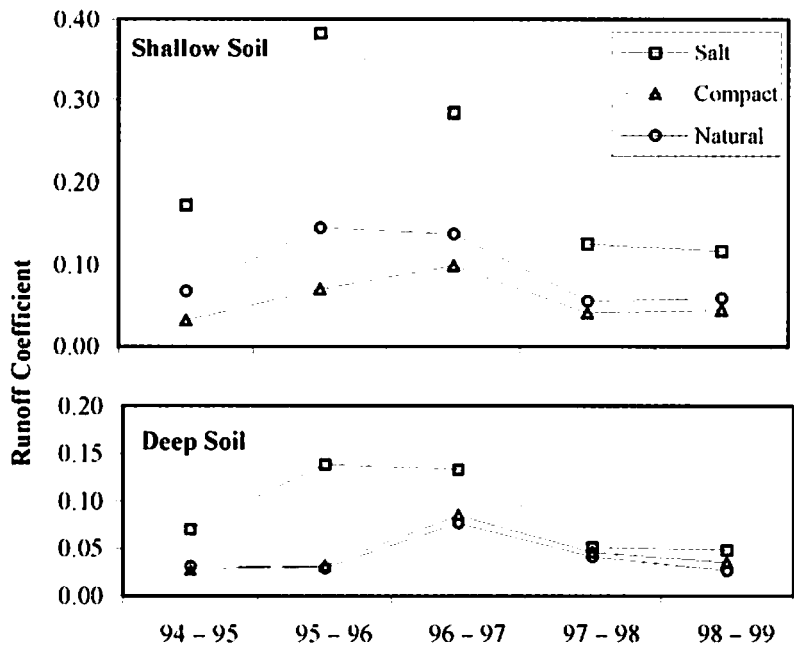


Fig. 1. Runoff efficiencies of surface treatments during five seasons after application.

Sodium chloride has an averse effect on the quality of water for plant, animal, and human consumption. Although most of the applied salt will stay in the surface layer of the catchment, still, part of the salt will wash off and pollute the harvested water, and part may even leach to the groundwater. Therefore, the application of salt, although a relatively simple and low-cost method, should be used with caution. Rauzi et al. (1973), who tested the runoff efficiency of different surface treatments on loam and sandy loam soils, did not recommend the use of salt, because its dramatic effect on erosion from the catchment area and its low efficiency, relative to gravel-covered plastic and asphalt roll roofing.

RUNOFF MODELING

Models can be used to improve our understanding of field observations and to allow the transfer of experimental results to areas without monitoring systems. Infiltration and runoff are rate-based processes, driven by the intensity of a rainstorm (rainfall rate). Because rainfall intensity data are seldom available for potential water-harvesting sites, the models presented here empirically relate runoff to daily rainfall. The application of empirical models requires that the catchment properties and daily rainfall events used to develop the model are representative of the catchment properties and the rainfall intensity pattern in the area of model application. Graphical analysis of the rainfall-runoff data of each runoff plot showed very irregular patterns. The linear model and the curve-number method were selected for testing because of their widespread use.

Boers et al., 1986). This model can be expressed as follows:
 $R = 0 \quad \text{for } P \leq P_o \dots\dots\dots (2a)$
 $R = c (P - P_o) \quad \text{for } P > P_o \dots\dots\dots (2b)$

Where: R is runoff (L), P is precipitation (L), and c (-) and P_o (L) are constants. The constant P_o is the threshold rainfall above which runoff occurs, and c is the runoff coefficient after the threshold rainfall has been exceeded (-). Due to the variation in rainfall-runoff events, the threshold value is not known *a priori*. To determine P_o , Diskin (1970) ranked experimental rainfall-runoff pairs in order of increasing precipitation and computed different linear relationships by varying the value of the constant (P_o). The optimum value of P_o was found by minimizing the residual sum of squares, computed for all rainfall events, for all models.

Because the compacted and salt-treated plots were affected with time, the model assessment focused on the natural plots. The first 3 years of data were used to develop the models; the fourth and fifth season were used to evaluate the models. Linear models for the eight natural plots were obtained according to the above procedure using the data for the first three seasons. Because of the scatter of the data, the sum of square errors was very large. Therefore, the total annual runoff was used as an evaluation criterion for selecting the models, by minimizing the maximum error in the annual runoff.

Application of the models thus selected reduced the errors in the estimation of the annual runoff of the fourth and fifth season. The threshold rainfall (P_0) varied between 0.074 and 0.821 at the shallow soil and between 0.029 and 4.449 at the deep soil. The runoff coefficients (c) varied between 0.021 and 0.106 at the shallow soil and between 0.019 and 0.119 at the deep soil. The highest coefficient of determination (r^2) was 0.30. The average error in the estimation of the annual runoff was 154% for the first three seasons and 146% for the last two seasons. For the shallow soil, these errors were 299% and 164%, respectively. These results indicate that the linear models have little potential for application.

Curve Number Method

A different approach for estimating runoff from daily precipitation is provided by the curve-number method, developed by the U.S. Soil Conservation Service (SCS, 1985). The runoff properties of the catchments are represented by the curve number, which is selected from a table, based on *land use, soil type, soil moisture, and hydrologic conditions* of the catchment area. Due to its ease of use, the concept is widely used over the world, and additional insights and criteria have been added by various researchers (e.g., Boughton and Stone, 1985; Dilshad and Peel, 1994; Steenhuis et al., 1995; Hawkins, 1996). Although this model was developed for small agricultural watersheds in the United States, the form of the rainfall-runoff relation indicate that this approach may also apply to micro-catchments.

Similar to the linear model, runoff starts after some rainfall has accumulated (threshold). The plotted curves of runoff versus rainfall depths asymptotically approach a line with a 45° slope, the difference between rainfall and runoff is defined as the potential maximum retention. The runoff threshold, referred to as the initial abstraction, was empirically estimated as 0.2 times the potential maximum retention. For convenience, the retention parameter is converted into a dimensionless parameter, the curve number, which varies between 0 and 100. The curve number method is expressed as follows:

$Q = 0 \quad \text{for } P \leq 0.2S \dots\dots\dots (3a)$

$Q = \frac{(P - 0.2S)^2}{(P + 0.2S)} \quad \text{for } P > 0.2S \dots\dots\dots (3b)$

$CN = \frac{1000}{S/25.4 + 10} \dots\dots\dots (3c)$

where: Q is the daily runoff (mm), P is the daily precipitation (mm), S is the potential maximum retention (mm), and CN is the curve number.

To account for the effect of soil moisture on the runoff process, the method uses three sets of curve numbers, i.e., for dry, *average*, and *wet* conditions. Ponce and Hawkins (1996) explain that the definition of these conditions, based on the rainfall amount for the previous five days (SCS, 1985), was rather arbitrarily. They report that the current version of the curve number model leaves the selection of the moisture condition to the user. Obviously, more sources of variability affect the runoff process. Ponce and Hawkins (1996) suggest that the curve numbers for dry and wet conditions should be considered as a stochastic component, or error margin.

Curve numbers were determined for the first three seasons of the natural plots, using the above equations. The computed curve numbers for each plot could generally be described by a beta distribution. The 10, 50, and 90% cumulative probabilities were used to determine the *lower limit, average, and upper limit* of the curve numbers for each plot. For the 8-m plots with 5% slope on shallow soil, the low, average, and high runoff conditions are represented by the curve number values 84, 93, and 98, respectively. For the same plot on the deep soil, the curve numbers are 81, 91, and 98. These results confirm the lower runoff potential of the deep soil, as compared to the shallow soil. A more interesting observation is that under extreme conditions, such as high intensity rainfall and high soil moisture conditions, the deep soil could generate as much runoff as the shallow soil.

Evaluation of the models for the 1997-'98 and 1998-'99 seasons showed that a very small percentage of the daily events fell outside the so-called error margins. For the 8-m plot with 5% slope on deep soil, runoff for 2% of the rainfall events fell above and 7% of the events fell below the error margin (Fig. 2). For all natural plots, the total annual runoff fell within the boundaries predicted by the 10 and 90% boundaries. However, the predicted boundaries are so wide that they are of limited practical use. For the aforementioned plot, the error margins of the annual runoff for the 1998-'99 season are 0.12 and 3.87 m³. Thus, this approach will only be useful if the curve numbers can be correctly assigned for each rainfall event, based on the effect and occurrence probabilities of the rainfall intensities, soil moisture conditions, and any other factors.

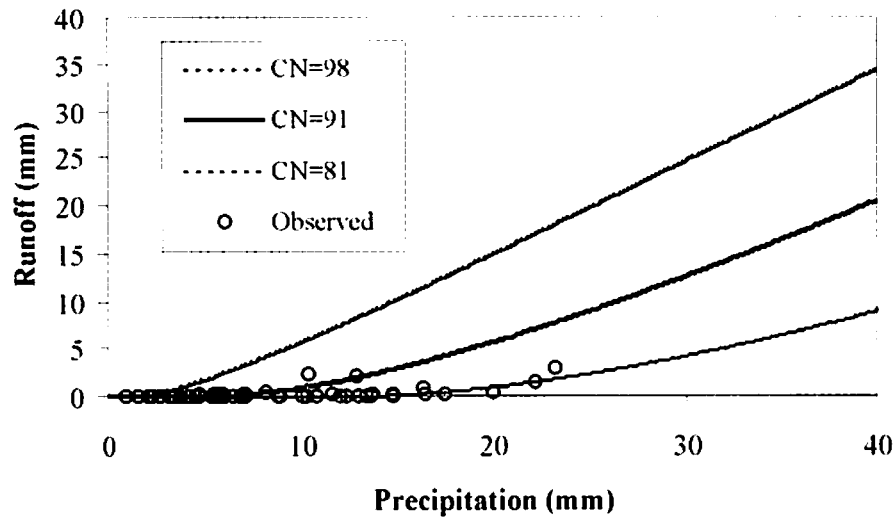


Fig. 2. Curve number model for a natural plot on deep soil with 5% slope and catchment length 8 m.

SUMMARY AND CONCLUSIONS

Five years of runoff, observations from micro-catchments on a montmorillonitic clay soil in northern Syria indicated that *these soils have a very low potential for water harvesting*. The average ratio of runoff versus rainfall for the study period was 0.05 at deep soils and 0.06 at shallow soils. Surface compaction (5 kg/cm²) doubled runoff on the shallow soils, but had little effect on the deep clay soils. Surface treatment with NaCl (1.25 kg/m²) has the potential to increase the runoff efficiencies with a factor five. The results indicated that *to be effective compaction and salt treatment need to be applied once every three years*. Because of its potential harmful effect on the environment, the use of salt need to be treated with caution.

The observed daily rainfall-runoff data were used to test runoff simulation models that could then be used for predicting micro-catchment runoff in similar environments. The linear model and the curve number method were tested. The observed runoff volumes showed an enormous variability between plots, and between events at the same plot. Runoff is affected by the variability and spatial distribution of the soil properties, microtopography, growth of natural vegetation. The effect of these factors could not be combined into a single runoff coefficient for a plot. The model analysis showed that the linear model was not suitable for estimating runoff from the plots.

Instead of falling into the trap of model over-parameterization, it seems more logical to consider a stochastic approach. Because the statistical properties of daily rainfall can be easily determined from existing long-term records, stochastic rainfall-runoff models often consider rainfall as a random parameter, while ignoring the variability of the catchment properties (e.g., Oron and Enthoven, 1987; Sanchez-Cohen et al., 1997). The work of Ben Asher and Warrick (1987) is a

notable exception. Another interesting approach was presented by Hawkins and Cundy (1987). These authors addressed the effect of the spatial arrangements of variable infiltration capacities along a slope.

It should be emphasized, however, that for stochastic models to be meaningful, in-depth knowledge of the statistical properties of the model parameters at the field site is required. The use of the curve number method, combined with a stochastic approach, showed a potential for predicting micro-catchments runoff. However, a stochastic assessment of the effect of rainfall intensities, soil moisture conditions, and seasonal growth of natural vegetation in the catchment area on the curve number remains a subject of further study.

Finally, some observations should be made with respect to the experimental methods. The variability observed at the runoff plots suggests the necessity of an adequate number of replicates. Rainfall and runoff should be checked daily, but it is advisable not to take measurements during a rainfall event. Although models that are based on daily data use the rainfall observation time (e.g., 8:00 a.m.) to distinguish between events, this time does not always coincide with the actual storm events. Therefore, the exact time of measurement should always be reported and the rain gauge should be read at the same time. When an automatic rain gauge is used, the daily rainfall amounts should be extracted based on the actual observation time.

The measurement of runoff with collection tanks or barrels, as recommended by Critchley and Siegert (1991), can be found at experimental plots around the world. When labor costs are low, the use of runoff tanks provides indeed an easily applicable and low-cost technique. However, the runoff observation records indicated that the accuracy of this technique is low and prone to human error. If the data will be used for the evaluation of models and transfer of results, it should be considered to install an automatic rain gauge at the

site and to equip each plots with a simple hydraulic flumes (e.g., H-flume) and stage recorder. The thus obtained runoff hydrographs also provide more insight in the hydrologic processes.

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REFERENCES

- Ayers, R.S., and D.W. Westcot. 1985. Water quality for agriculture. *FAO Irrigation and Drainage Paper* 29 Rev. 1, Rome, Italy.
- Ben-Asher, J., and A.W. Warrick. 1987. Effect of variations in soil properties and precipitation on micro-catchment water balance. *Agric. Water Manage.*, 12:177-194.
- Boers, Th. M., M. de Graaf, R.A. Feddes, and J. Ben-Asher. 1986. A linear regression model combined with a soil water balance model to design micro-catchments for water harvesting in arid zones. *Agric. Water Manage.*, 11:187-206.
- Boers, Th. M. 1994. Rainwater harvesting in arid and semi-arid zones. *Doctoral Thesis*, Wageningen Agricultural University, The Netherlands.
- Bruins, H.J., M. Evenari, and U. Nessler. 1986. Rainwater-harvesting agriculture for food production in arid zones: the challenge of the African famine. *Appl. Geogr.*, 6: 13-32.
- Brunner, U., and H. Haefner. 1986. The successful floodwater farming system of the Sabians, Yemen Arab Republic. *Appl. Geogr.*, 6(1):77-86.
- Casenave, A. and C. Valentin. 1992. A runoff classification system based on surface features criteria in semi-arid areas of West Africa. *J. Hydrol.*, 130:231-249.
- Critchley, W., and W.K. Siegert. 1991. Water harvesting. A manual for the design and construction of water harvesting schemes for plant production. AGL/MICS/17/91. FAO, Rome.
- Dilshad, M., and L.J. Peel. 1994. Evaluation of the USDA curve number method for agricultural soils in the Australian semi-arid tropics. *Austr. J. Soil Res.*, 32:673-685.
- Diskin, M.H. 1970. Definition and uses of the linear regression model. *Water Resour. Res.*, 6(6):1668-1673.
- Frasier, G.W., K.R. Cooley, and J.R. Griggs. 1979. Performance evaluation of water harvesting catchments. *J. Range Manage.*, 32: 453-455.
- Hawkins, R.H., and T.W. Cundy. 1987. Steady state analysis of infiltration and overland flow for spatially-varied hillslopes. *Water Resour. Bull.*, 23(2):251-256.
- Mehdizadeh, P., A. Kowsar, E. Vaziri, and L. Boersma. 1978. Water harvesting for afforestation. I. Efficiency and life span of asphalt cover. *Soil Sci. Soc. Am. J.*, 42: 644-649.
- Oron, G., and G. Enthoven. 1987. Stochastic considerations in optimal design of a micro-catchment layout of runoff water harvesting. *Water Resour. Res.*, 23: 1131-1138.
- Oweis, T. and A. Taimieh. 1994. Evaluation of a small basin water-harvesting system in the arid region of Jordan. *Water Resour. Manage.*, 10:21-34.
- Ponce V.M., and R.H. Hawkins. 1996. Runoff curve number: has it reached maturity? *J. Hydrol. Eng.*, 1:11-19.
- Rauzi, F., M.L. Fairbourn, and L. Landers. 1973. Water harvesting efficiencies of four soil surface treatments. *J. Range Manage.*, 26: 399-403.
- Ryan J, S. Masri, S. Garabet, J. Diekmann, and H. Habib. 1997. Soils of ICARDA's agricultural experimental stations and sites: climate, classification, physical and chemical properties, and land use. ICARDA, Aleppo, Syria.
- Sanchez-Cohen, I., V.L. Lopes, D.C. Slack, and M.M. Fogel. 1997. Water balance model for small-scale water harvesting systems. *J. Irr. Drain. Eng.*, 123:123-128.
- SAS Institute Inc. 1988. *SAS/STAT user's guide*, release 6.03 edition. Cary, NC, USA.
- Sharma, K.D. 1986. Runoff behaviour of water harvesting microcatchments. *Agric. Water Manage.*, 11:137-144.
- Soil Conservation Service. 1985. *National engineering handbook*. Section 4. Hydrology. US Department of Agriculture, Washington, DC.
- Steenhuis, T.S., M. Winchell, J. Rossing, J.A. Zollweg, and M.F. Walter. 1995. SCS runoff equation revisited for variable-source runoff areas. *J. Irrig. Drain. Eng.*, 121: 234-238.

Agroforestry Systems as a Sequential Drainwater Reuse Strategy for Sustainable Irrigated Agriculture

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ABSTRACT

The need for increasing demand on fresh water resources, one of the scarcest resources in dry areas, and deterioration of water quality receiving agricultural drainage water from irrigated land and perhaps posing an environmental risk, are likely to increase the use of drainage water (non-conventional water resources) in agriculture. In California, for example, continued agricultural production on 930,000 hectares of irrigated farmland on the westside of California's San Joaquin Valley is at risk from shallow, saline groundwater tables, the lack of a regionwide out-of-valley drainage system, and the potential concentrated toxic impacts of trace elements in the drainage. Reuse of saline drainage and subsequent reduction of drainage volume in an agroforestry system is being investigated as a drainage management strategy. Subsurface drainage from croplands having an average concentration of 8,000 mg/l total dissolved solids, 10 mg/l B and 350 mg/l Se is reused to irrigate a eucalyptus plantation. Evapo-concentrated subsurface drainage from the eucalyptus plantation is reused again to irrigate euhalophytic herbaceous species such as *Salicornia*. The resultant progressively concentrated unusable drainage, 15 to 20% of the original drainage volume, is disposed in a regulated solar evaporator. Although in the westside of California's San Joaquin Valley, this approach is showing short-term promise, the long-term technical, environmental, and economic feasibility is still being addressed.

INTRODUCTION

There is increasing demand on fresh water resources, being especially scarce resources in dry areas. Deterioration of water quality from irrigation drainage or other poor quality waters further worsen the problem by reducing the limited available fresh water and damaging other natural resources. Marginal water, thus far, has been the least exposed available water resource and is being considered as a waste, causing negative environmental impact. Therefore, perhaps the most logical thing to do is to investigate ways to use such water in agriculture with due consideration to the environment and treat the marginal water with acceptable chemistry level for agriculture as "resource" and not as a "waste". Drainage has been the traditional and it will continued

to be an important and necessary agricultural element in irrigated land.

The reuse of drainage in agriculture and its impacts is becoming the focus of many scientists in many parts of the world, particularly in dry areas (i.e., California, India, Pakistan, Egypt, Jordan, etc). In the westside of San Joaquin Valley (SJV) of California, almost 160,000 hectares (ha) of irrigated farmland are affected by salinity and shallow water-table levels of less than 1.5 m from the soil. According to the 1990 SJV Drainage Program report, as much as 186,300 ha of irrigated land is projected to become unproductive and abandoned by the year 2040, unless a comprehensive approach to managing the drainage problem can be implemented. Irrigation adds an estimate 3.3 million tons of salts annually to the SJV.

Leaching has been the most common method used to remove salts from the root zone of irrigated soil profiles. A portion of drainage water produced from leaching may percolate into deep groundwater, but, in areas of shallow groundwater, subsurface drainage systems are required for the removal of saline drainage water to avoid salinity buildup and water-logging, and hence keep agricultural land economically productive.

The drainage water from tile-drained fields contains potentially toxic elements such as selenium, arsenic, boron, molybdenum, and uranium, in addition to salts. Selenium (Se), for example, bio-accumulates readily in the aquatic food chain. Although Se at low concentrations is an essential micronutrient for animals, it is extremely toxic at concentration levels only slightly above essential. In the recent past, poor quality subsurface drainage water from 1700 ha of tile-drained in Westside SJV cropland was temporarily disposed into the Kesterson Reservoir with disastrous consequences. In 1983, the discovery of reduced reproduction and deformities of waterfowl at Kesterson due to Se poisoning resulted in the plugging of drains and increased the complexity of planning for future drainage management and disposal. After the closure of Kesterson Reservoir, only about 20% of the Westside SJV irrigated land with installed drainage was unaffected by the closure and was able to continue to discharge to the San Joaquin River, disposing of an estimated 565,000 tons of salt load annually.

The lack of environmentally acceptable drainage disposal options has led researchers from various state and federal agencies, and the University of California,

to vigorously search for short and long-term management options for the drainage problem. After 6 years of investigation, they concluded that irrigation source control and drainage water reuse would be the most advisable first step. Maximizing irrigation efficiency (the percentage of total applied irrigation water used beneficially by plants) and distribution uniformity (a measure of the evenness of application of irrigation water over a field) would reduce the volume of subsurface drainage containing elevated amounts of dissolved minerals and trace elements. However, a minimum amount of irrigation water beyond that required for plant growth is needed to leach excess salt out of the root zone. Even after achieving the optimal irrigation efficiency and distribution uniformity attainable, shallow groundwater accumulates and subsurface drainage is required. The 1990 SJVDP report estimated that irrigation-source control practices could reduce the depth of drainage to an average of 6 cm, given an irrigation efficiency of 73-80%.

The next step in reducing the volume of drainage water requiring disposal is on-farm drainage reuse which can be classified into three strategies: (1) a *cyclic strategy* (Hoffman et al., 1990) in which good quality irrigation water is used to irrigate salt-sensitive crops and to germinate and establish seedlings of salt-tolerant crops, and water with marginal quality, i.e. electrical conductivity (EC) exceeding 4 dS/m, is then used to irrigate the tolerant crops; (2) a *blending strategy* (Hoffman et al., 1990) in which water with marginal quality is mixed with good quality water to produce intermediate quality water that can be used to irrigate moderately salt tolerant crops or trees; and (3) a *sequential strategy* in which poor quality drainage water (6 dS/m EC or 4,800 mg/l total dissolved solids, TDS) is sequentially used to irrigate crops and trees of increasing salt tolerance.

Starting with good quality irrigation water on salt-sensitive plants such as lettuce or corn, drainage water collected from the root zone of salt-sensitive crops is used, in turn, to irrigate salt-tolerant crops such as cotton and sugarbeet. Halophytic trees, such as eucalyptus, are then irrigated with sub-surface drainage from the root zone of salt-tolerant crops. Sub-surface drainage from the irrigation of eucalyptus is used, in turn, to irrigate euhalophytic herbaceous species, such as saltgrass or *salicornia*. The resulting unusable concentrated drainage water may then be disposed in a solar evaporator, with precipitated salt and trace elements being the only product.

For the Mendota area of the SJV, the 10-year average annual potential or reference evapotranspiration (ET_0) was 145 cm compared to an average annual precipitation of 23 cm, resulting in a Moisture Deficit Index of 91% (calculated by Thornthwaite formula as reported by Nathan and Sinha, 1996). Due to a high ET demand in the SJV, drainage water reuse for salt-tolerant trees and shrubs with high transpiration rates (Bainbridge and Jarrell, 1987), either alone or in com-

bination with other drainage management options, such as desalination or evaporation ponds, may help relieve the drainage problem in the SJV and elsewhere in the world with similar biophysical and agroecological conditions.

An agroforestry system is defined as the integration of agricultural production with forest elements. The goal of the agroforestry is to separate salt and trace elements from irrigated and drainage-impacted cropland, and to help solve drainage problems in an environmentally safe, economically sound, and socially acceptable way.

EXPERIMENTAL SITE AND OBSERVATIONS

The first experimentally monitored agroforestry site of 11.45 ha was established in the SJV near Mendota in 1985 for the purpose of demonstrating reduction in shallow groundwater by root water extraction and disposal of drainage water through evapotranspiration by eucalyptus and other salt-tolerant species. The site soil is a deep, saline clay loam with a water-impermeable clay layer at the 3.0 to 3.6 m depth. A subsurface relief drainage system was installed at a depth of 2.1 m. Perimeter drainage was installed at a depth of 2.4 m to isolate the experimental plantation from external lateral groundwater flow and salt influx. In 1985 and 1986, 9.43 ha of *Eucalyptus camaldulensis* (Red Gum) were planted in 89 rows on 1.83 m spacing. Several rows of *Casuarina cunninghamiana* were also planted along with 2 ha of the halophyte *Atriplex canescens* (salt-bush). The trees were irrigated with fresh water during the first year to facilitate establishment in the saline soil. Subsequently, the trees were furrow irrigated from April to October each year with saline water (6,400-8,000 mg/l TDS) using subsurface drainage from irrigated croplands near the agroforestry plantation.

In December 1990, the air temperature dropped to -12°C and remained below -7°C for 42 hours causing severe injury to the trees. In 1995, the injured and dead trees were removed and the site was redesigned to include 6.56 ha of eucalyptus, 2.43 ha halophytes and a 1.32 ha of solar evaporator. The majority of the new eucalyptus seedlings were cloned from trees that survived the frost; thus, the new generation is expected to be more salt- and frost-tolerant than the previous generation. The 2.43 ha halophyte area was divided into five sections: 0.33 ha athel and cord grass, 0.41 ha native grasses, 0.47 ha salt grass, 0.6 ha iodine bush, and 0.6 ha *salicornia* (WSRCD, 1996).

A number of research papers have been published on projects at the Mendota site, some emphasizing field studies (Tanji and Karajeh, 1991; Cervinka et al., 1994), laboratory and greenhouse studies (Shannon et al., 1997), and modeling studies (Karajeh et al., 1992; Karajeh and Tanji, 1992a, 1992b; Letey and Knapp, 1995). Other investigations are currently under way to further advance the knowledge of agroforestry system performance and practicality.

The subsurface drainage water used to irrigate the eucalyptus had an average EC of 10 dS/m (1 dS/m = 800 mg/l TDS for EC > 5 dS/m) in 1990 and 8 dS/m in 1996 (Table 1). Total dissolved solids in both years were dominated by Na, SO_4 , and Cl ions, with an average sodium adsorption ratio (SAR) of 11 in both 1990 and 1996. Boron (B) and Se were also present in high concentrations. The subsurface drainage from the eucalyptus had an average EC 3.3 times greater than the irrigation water in both 1990 and 1996, a B concentration 2.3 times greater than the irrigation water in 1990 and 8 times greater in 1996, a Se concentration about 2 times greater than the irrigation water in both 1990 and 1996, and an SAR 6.3 and 4.5 times greater than the irrigation water in both 1990 and 1996, respectively.

The tile drainage from the halophytes was similar in quality to that from the eucalyptus, possibly as a result of lateral flow of groundwater from the tree to the halophyte area. The salinity of the regional shallow groundwater for 1988-'92 was about one-half the salinity in the shallow groundwater of the eucalyptus area, indicating that the interceptor drain around the site perimeter isolated the field from significant lateral inflows. The residual drainage water from the halophyte field (EC about 30 dS/m) is collected in a sump and discharged to a solar evaporator at a rate equal to 0.65 of the normalized reference evapotranspiration (ET_o) to prevent high Se concentrated water from ponding. Real-time ET_o data is collected from a nearby-automated weather station maintained by locals and managed as part of the California Irrigation Management Information System (CIMIS) of the California Department of Water Resources.

In 1990, the 9.43 ha eucalyptus received 0.96 m marginal water with an average salinity level of 10 dS/m; lesser amounts of water were applied in 1987, 1988, 1989 (Tanji and Karajeh, 1993). In 1996, the 6.56 ha eucalyptus received 1.20 m marginal water with an average salinity of about 8 dS/m, the 2.43 ha halophytes received 1.32 m of eucalyptus area tile drainage, and 1.23 m of halophyte area tile drainage was applied to 1.32 ha solar evaporator as the final drainage disposal step. Overall, there was an 80% reduction in water volume from the amount of irrigation applied to the eucalyptus to the amount of drainage discharged into the solar evaporator. The marginal water applied to the eucalyptus contained 513 tons of salt and 291 tons of evaporite minerals such as thenardite (Na_2SO_4) precipitated in the solar evaporator, a 57% salt recovery.

At station AB in the northwest quadrant of the tree plantation, the EC, B, and Se distributions in the soil profile were monitored for 1987, 1990, 1991, and 1996 hydrological years. Significant increases in soil salinity and Se concentrations occurred in 1990, and in B concentration in 1991. Increasing salinity in soil water can change soil thermodynamic properties, lowering potential energy and adversely affecting plant growth. In this case, increasing salinity resulted in a reduction in the

eucalyptus crop coefficient from a standard crop average of 1.35 (for a full-cover of well watered trees in a non-saline environment, Dong et al: 1992) to 0.83 in 1991, a 38.5% decline.

Leaching is essential for soil management, not only to maintain and evapotranspiration rate that will achieve the drainage water reduction objective, but also to ensure eucalyptus survival in an increasingly saline environment. For example, in 1996 when 1.2 m of drainage with 8 dS/m EC was applied to the 6.56 ha eucalyptus, the measured drainage from the eucalyptus area was 0.47 m with 27 dS/m EC. A leaching fraction (LF) of either 30% or 40% was calculated, based on the method of salt concentrations (salt concentration of irrigation water/ salt concentration of drainage water) or measured depth of drainage and irrigation waters (depth of drainage water/depth of applied water), respectively. Therefore, in 1996, the eucalyptuses were able to use only 70 or 60% of the applied irrigation water (1.2 m), a result that compares well with the 1991 field estimation of eucalyptus ET (Dong et al., 1992).

The long-term effectiveness of agroforestry will be determined primarily on the basis of the annual volume of drainage water reduction by evapotranspiration. Preliminary analysis of the data presented shows that the annual eucalyptus evapotranspiration is about 1.2 m (48 inches). Assuming an irrigation application (distribution) uniformity of 80%, 0.44 m is needed in addition to the 1.2 m eucalyptus ET demand, in order to optimize the uniformity of salt leaching across the field, for a total eucalyptus water requirement of about 1.64 m. Additionally, in order to maintain an average soil salinity of about 20 dS/m within the eucalyptus root zone, an estimated 25 -30% leaching fraction is needed for tree survival and evapotranspiration under high saline and B conditions, thus an additional 0.5 m of irrigation water is needed. Some of the losses due to non-uniformity will help leach salt out of the soil profile. Therefore, assuming that 20% of the leaching fraction is resulting from the non-uniform application of the water, only an additional 10% of ET is required, for a total water requirement for eucalyptus of about 1.76 m.

The calculated total eucalyptus water requirement for annual applied irrigation water, under an active drainage system and good water and soil management practices, would allow a sufficient amount of water to seep uniformly through the root zone. This should result in optimal eucalyptus growth under saline and shallow groundwater conditions. Although under high soil salinity ($\text{EC}_e = 20$ dS/m) and high B concentration (10 mg/l), eucalyptus ET may not substantially exceed 1.2 m of applied water. Only about 61% of non-stressed eucalyptus ET. Shannon et al. (1997) reported that evapotranspiration of *Eucalyptus camaldulensis* planted in sand tanks and irrigated with saline solution of 28 dS/m in December 1995, was nearly one-half that from trees irrigated with non-salinized nutrient solution.

However, under field conditions, the combined effect of soil and irrigation management, irrigation method selection, and inter-planting may result in higher total water consumption from the tree area. Data shows that improved water management, by increasing the leaching fraction from 16% to a minimum of 25% since 1995 which some of the irrigation leaching water was applied in the low evapotranspiration demand months in a form of winter irrigation practice, resulted in a reduction of soil salinity, B, and Se to at or below 1987 levels.

RESEARCH RELEVANCE TO OTHER REGIONS

Continued irrigated agriculture in arid and semi arid land around the world, including West and Central Asia and North Africa, is faced with constraints. These constraints are: First, the increasing demand on the available fresh water, which makes the utilization of marginal water for agriculture a necessity rather a luxury. Second, the use of marginal water for agricultural production properly allows the use of what is considered "waste" as a "resource" in an environmentally friendly way. For example, Egypt is currently using about 4 billion m³ annually of agricultural drainage in agricultural production and an estimated of about 1.2 billion m³ of treated wastewater (recycled water), in which the majority of it will be used as irrigation water. In Jordan, approximately equivalent to 10% of the available fresh water resources is produced as treated wastewater. This amount is expected to be available as irrigation water that is in addition to the amount of drainage water being discharged to a saline sink; most likely the majority of it to be designated for agricultural production of non-conventional crop systems, such as agroforestry. Therefore, the above progressing strategy, or elements of it, could be used to achieve agronomic output and insure the sustainability of irrigated land and its resource base.

CONCLUSIONS

Without sufficient leaching and an active drainage outlet, a substantial buildup of salts, B, and Se could occur throughout the soil profile in an agroforestry system.

A leaching requirement of 25 to 30% of applied irrigation water is necessary to maintain acceptable salt and B levels. In general, eucalyptus productivity declines under saline and B-enriched soil conditions, and its annual water consumption may not substantially exceed 1.2 m (4 feet) compared to an estimated average of 2 m for a full-cover of well-watered trees irrigated with non-saline waters and grown under the same climatic conditions. Overall, eucalyptus trees and halophytes may reduce agricultural drainage water volumes by more than 80% of the water applied to eucalyptus, and progressively concentrate drainage water salt by about 300%. Leaching during low evapotranspiration months (winter irrigation) could conquer salinity buildup in the root zone.

Agroforestry systems which include trees, halophytes, and a solar evaporator may require a land area 2 to 4% of an area irrigated with good quality water (EC about 1 dS/m) to be allocated to the system. In the Westside SJV, the system seems promising. However, further pilot studies need to be done on individual farm operations to address the following areas: effects on wildlife; planting design and spacing; feasibility of inter-plantings; drainage pattern design; disease resistance in eucalyptus; effects on soil physicochemical properties including B; effects of chemical amendments on soil permeability; Se volatilization rates to maximize Se loss to atmosphere; reduction of neighboring shallow groundwater influx; final salt disposal options, and economic feasibility.

Sequential drainage water and/or recycled water reuse could provide countries faced with severe water shortage with additional water supply to support their agricultural industry and to protect the environment from potential risk of contamination.

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Table 1. Chemical characteristic of irrigation and drainage waters (mean of four samples obtained at various dates in 1990 and 1996).

Description	Year Sampled	EC	Sodium	Sulfate	Chloride	Nitrate	Boron	Selenium	Sodium Absorption Ratio
		-dS/m-			--mg/l--			--µg/l--	
Irrigation Water,	90	10	1,638	3,236	1,196	91	12	396	11
Eucalyptus	96	8	1,256	2,815	1,311	82	8	299	11
Subsurface Drainage,	90	32	7,899	13,193	5,054	113	27	700	69
Eucalyptus	96	27	7,403	13,082	4,632	82	64	616	49
Subsurface Drainage,	90	30	8,325	12,372	4,729	101	56	665	56
Halophytes	96	30	8,353	13,043	4,935	70	65	686	57

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REFERENCES

- Bainbridge, D.A. and W.M. Jarell. 1987. Using trees to manage groundwater. Paper presented at the ASAE Pacific Region meeting, Tucson, AZ.
- Cervinka, V., C. Finch, G. Jorgensen, F. Karajeh, M. Martin, F. Menezes, and K. Tanji. 1994. Agroforestry as a method of salt and selenium management of irrigated land. A summary report submitted to California Department of Water resources, Water Conservation Office, Sacramento, California. 22 pp.
- Dong, A., K. Tanji, F. Karajeh, and M. Parlange. 1992. Water quality effects on eucalyptus ET. *Amer. Soc. Civil Eng. Proc. National Conf.* Baltimore, Maryland. Ed. E.T. Engman 165-170.
- Karajeh, F. and K. Tanji. 1992a. A numerical model for water and salt simulation in an agroforestry system. II: Field water flow. *J. Irrig. Drainage Eng., ASCE* 120(2): 397-413.
- Karajeh, F., and K. Tanji. 1992b. A numerical model for water and salt simulation in an agroforestry system. III: Field salt flow. *J. Irrig. Drainage Eng., ASCE* 120(2): 588-604.
- Karajeh, F., K. Tanji, and I. King. 1992. A numerical model for water and salt simulation in an agroforestry system. I: Theory and validation. *J. Irrig. Drainage Eng., ASCE* 120(2): 382-396.
- Letey, J. and K. Knapp. 1995. Simulating saline water management strategies with application to arid-region agroforestry. *J. Environ. Qual.* 24: 934-940.
- Nathan, K.K. and S.K. Sinha. 1996. Moisture deficit index evaluation for dry regions of India. *Drought Network News* 8 (3): 14-16.
- San Joaquin Valley Drainage Program. 1990. A management plan for agricultural subsurface drainage and related problems on the Westside San Joaquin Valley. Final report by US DOI (BOR, FWS, GS) and California Resources Agency (DWR, F&G). Sacramento, CA.
- Shannon, M., C. Grive, J. Rhoades, and D. Suarez. 1997. Growth and water relations of plant species suitable for saline drain water reuse systems. Progress report submitted to California Department of Water resources, Water Conservation Office, Sacramento, CA.
- Tanji, K., and F. Karajeh. 1991. Saline drainwater reuse in agroforestry systems. *J. Irrig. Drainage Eng., ASCE* 119 (1): 170-181.
- Westside Resources Conservation District (WSRCD). 1996. California State Department of Food and Agriculture, USDA Natural Resources Conservation Service, University of California at Davis, California Department of Water Resources. 1996. Mendota agroforestry site annual report. A progress report submitted to USDOI - Bureau of Reclamation. Mid-Pacific Region, Sacramento, CA.

Cotton and Wheat Response to Irrigation with Low Quality Water

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ABSTRACT

This paper presents crops response and yield to different salinity levels of irrigation water obtained through blending of irrigation water with drainage water or through the use of saline ground water under field conditions. Crops yields in ACSAD's experimental farm in Deir Ezor in northeast Syria, and in experimental farms in Tunisia and Libya were presented. Yield functions related to salinity of irrigation water (EC_{iw}) were obtained using non-linear programming software. Threshold data obtained were of the magnitude of EC_e values tabulated by FAO (1992), and higher than EC_{iw} tabulated by FAO (1986).

Soil moisture extraction data by cotton and wheat for three years were obtained by gravimetric measurements with soil depth throughout the growth periods using tensiometers to schedule irrigation time. Validity of the model obtained was assessed by repeated integral of w_x function over depth and time to give the water consumption throughout the irrigation period for each salinity level and compared to actual water consumption data. Soil solutions obtained by vacuum lysimeters inserted at different soil depths in the root zones of cotton and wheat were obtained at field capacity and analyzed for cations and anions. Data obtained were correlated with salinity of irrigation water at three levels of leaching fractions for cotton.

INTRODUCTION

There is a growing demand for fresh water for domestic, agriculture and industrial purposes. Scarcity of good quality water in several regions in the world emphasizes the need to use saline water for agriculture with good farm management. Many situations exist where saline ground water or agricultural drainage water could be used for irrigation, if the water is readily accessible and available. However, such reuse should be taken only if long-term deleterious effects on soil properties can be avoided.

Various scientists such as Rhoades (1987) have concluded that the use of saline water for irrigation is feasible, especially when saline waters are blended with good quality water or alternated, especially where annual rainfall is greater than 200 mm. (Abdelgawad, 1995) and drainage conditions of soil are adequate. In the Pecos Valley, Texas, water averaging 2500 mg/L total dissolved salts has been used for irrigation for decades. Moore and Hefner (1976). In Iraq, pear trees have been grown with water ranging up to 4000 mg/L. In Algeria, palm trees (*Phoenix dactylifer*) have been grown with water ranging up to 5000 mg/L for

centuries. In Tunisia and Jordan, olive trees (*Olea europaea*) have been irrigated with water having 4200 mg/L. In Palestine, cotton is grown commercially with 3000 mg/L. (Keren and Shainberg, 1978). This practice is sustained for 15 years in presence of 400 mm of annual rainfall.

In Sherefsh station in Tunisia, Migrada River water with an EC of 2.5-3.5 dS/m have been used for irrigating semi-tolerant and tolerant crops for more than 50 years with no negative effects on soils in the presence of annual rainfall of 350-450 mm (Abuaziz, 1997). In India, irrigation water with an EC of 4 to 5 dS/m has been used successfully for long periods (Paliwal, 1972). In Uzbekistan, cotton irrigated with drainage water having 5000 to 6000 mg/L has been used successfully for many years.

Bressler (1979) and Shalhevet and Kumburov (1976) made a survey of irrigation water salinity, and concluded that water with salinity as high as 6000 mg/L is acceptable for irrigation. Pillashuvy and Blaney (1966) suggested that the upper limit of the salinity of irrigation water should be up to EC of 7.5 dS/m (about 4800 mg/L). In Libya, water with 5000 mg/L has been used for centuries for irrigation of barley (*Hordeum vulgare*), tomato (*Lycopersicon Lycopersicum esculentum*), alfalfa (*Medicago sativa*), squash (*Spinacia oleracea*) and palm trees in the coastal zone of Tripoli, (Abdelgawad, 1981).

Threshold levels of salinity are often used as standards for evaluating irrigation water quality and reflect the response of crops to the average root-zone salinity after the establishment of seedlings. Studies conducted in many arid regions of the world have shown that the water conventionally classified as too saline for agricultural use in one area can be used to irrigate certain crops in other area without a significant loss in yield or quality. Abdelgawad et al. (1981, 1995) provided data on such subject on the use of water with 1200-8000 mg/L for irrigating barley, wheat (*Triticum aestivum*), cotton (*Gossypium hirsutum*), maize (*Zea mays*), sugar beet (*Beta vulgaris*), sorghum (*Sorghum bicolor*), alfalfa, onion (*Allium cepa*), and sorghum. Wheat has been grown in Colorado, Arkansas Valley, with water containing 1500 mg/L to 5000 mg/L (Miles, 1977).

This paper presents results of more than three years of field data on crop response to irrigation with saline water in Syria, Tunisia, and Libya. It also focuses on the water extraction pattern related to salinity of irrigation water. The ionic composition of soil solution as function of ionic component of irrigation water is also presented.

MATERIALS AND METHODS

This research was carried out at ACSAD experimental station in Deir Ezor, Syria, since 1991 to date, and in Tunisia since 1993, and in Libya since 1993. In Syria, the soils are Torrifluvents (thermic mixed, loamy in texture, with soil pH of 7.5). The soil water saturation extract (EC_e) and calcium carbonate. The water used for irrigation of barley, cotton, maize, vetch (*Vicia angustifolia*), wheat, and alfalfa was drawn from agricultural drainage water with an average electrical conductivity of 11.4 dS/m blended with Euphrates River water from irrigation canals with average EC values of 1.5 dS/m. Appropriate ratios of blending was carried out between drainage water and Euphrates River water in concrete reservoirs to produce EC_{iw} values of 1.5, 4.4, 6.4, 8.4, 9.4 dS/m.

The amount of water used in irrigation was based on gravitational measurement of soil moisture at 0.15-m intervals down to 1.0 m depth to this an additional water was added for each mixture with the purpose of leaching the salts, equivalent to 0, 0.15, 0.3 leaching fraction (*LF*). The design of the experiments was a randomized block design; with leaching fraction, being the blocks and salinity levels the treatments with six replicates 50 m² each. The experimental areas were irrigated by furrows.

In Tunisia, the soils had a pH 7.8, dS/m and 35% $CaCO_3$ (Torrifluvents, mixed xeric, silty clay). The design of the experiments was randomized block design with six replicates, and a plot size of 1000 m². The treatments of water salinity were fresh water of 0.3 dS/m from a water well, Migrada river water with EC 2.3 dS/m and agricultural drainage water with EC of 9 dS/m and the mixture between the two to produce EC of 3.9 and 5.4 dS/m. The amount of applied irrigation water was based on previous studies about crop water requirement and crops irrigated were tomato, melon (*Citrullus vulgaris*), maize, pepper (*Capsicum annum*), water melon (*Citr-ullus lanatus*), clover Berseem (*T. alexandrianum*), potato (*Solanum tuberosum*) and broccoli (*Brassica oleracea botrytis*).

In Libya, saline ground waters were used for irrigating barley with EC_{iw} values of 3.9, 8.0, 11.6, 16.7 dS/m with *LF* of 0, 0.1, and 0.2. The soils were siliceous sandy Xeric Psamments, with 95% sand, deep soil profile, with a pH of 8.0 and 5% $Ca CO_3$. Soil samples were collected before irrigation at 0.15 m intervals down to 1.5 m and analyzed for moisture content, and a 1:5 extract was made to determine the ionic composition. Analyses of soil solution ions were carried out according to standards methods of soil chemical analysis (Page et al., 1982).

Soil moisture tension was measured by gauge tensiometers placed at depths of 0.25-0.5 m, and 0.75 m. The irrigation water was applied when the soil moisture tension reached 50 centibar at 0.25 m depth in early stages of plant growth and 50 centibar after the mid season. Soil solutions were collected by vacuum

lysimeters placed at 0.25 and 0.50 m after 48 hours of irrigation time. The soil solution and irrigation water were analyzed for pH, and soluble ions, including NO_3 , P and boron.

RESULTS AND DISCUSSION

Crop Yield vs. Salinity Irrigation Water

Data obtained on yields versus salinity of irrigation water of Syria, Tunisia and Libya were evaluated on the basis of Maas and Hoffman (1977) model in the form:

$Y = A - B (EC - T)$ (1)

Other shift functions as suggested by Abdelgawad and Ghaibeh (1997) were also evaluated for wheat and maize, and related to the model in quadrates and exponential form.

$Y = A + B (EC - T) + C (EC - T)^2$ (2)

$Y = A \exp (EC - T)$ (3)

Where: A = is the absolute yield in ton/ha, B is the slope, EC is the mean electrical conductivity of the irrigation water throughout the season, and T is the estimated salinity threshold expressed in dS/m.

Field data collected in Syria for cotton, maize, wheat and for alfalfa showed that the response of yield to water salinity had a mode of two macro stages; the first stage with low inclination, and the second stage with sharp inclination. The two stages were well defined in the case of alfalfa and wheat, but not well defined for cotton and maize. However, the field data obtained depict a chaotic response to irrigation water salinity which reflects the interference of soil, climatic factors and management practices on quality of irrigation water. Fitting of the data involved a non-linear programming analysis using sequential quadratic programming available in statistical software. The procedure used is a doubly iterative algorithm to search for a solution of the parameters of the linear function. A common constraint was used in the analysis, that was the upper bound for A parameter to equal or less than the maximum yield values obtained. In fact this procedure can also be used to fit data to continuous functions of the kind suggested by Van Genuchten (1983).

Table 1 shows the obtained absolute functions, threshold values (T), relative percentage of yield reduction per unit EC of irrigation waters with different leaching fractions *LF* and the EC of zero-yields. In Syria, cotton T values of 4.75, 4.81 and 4.72 dS/m were obtained for the three *LF* fractions. The corresponding slope values (S) expressed in percentages were 11, 9.8 and 9.1, respectively. It can be deduced that increasing *LF* from 0.0 to 0.15 extended slightly the tolerant stage, but a further increase of *LF* depressed it. The S value was also depressed with the rise of *LF*.

For maize at the same location at different leaching fractions, the threshold values obtained were 3.99, 4.02 and 3.83 dS/m, with an overall value of slope and T of 15.5% and 3.80 dS/m, respectively. The high rate of decline for maize can be reasoned that maize is grown in Syria as an intensive crop after wheat, i.e., in hot and low humidity period (July to Sept.). Shift quadratic and exponential functions gave T values of 3.96 and 3.60 dS/m, respectively, with improvement in R^2 . This manifests the sigmoidal response noted by Tanji (1996) for the whole range.

For vetch, T values obtained were 2.9, 2.99 and 2.98 dS/m, and a slope value of 6.1%. Data reflect the sensitivity of vetch to salinity but with a low rate of decline. For wheat, T values obtained were 3.61, 5.43 and 4.36 dS/m, and the corresponding slopes were 10.2, 8.3 and 9.6%, respectively, at different leaching fractions. The overall T value was 4.36 dS/m and S value 9.5%. LF value of 0.15 increased the T value and depressed S value, indicating better conditions in the root zone, whereas LF of 0% shortened the tolerant stage and resulted in a higher rate of decline. Shift quadrates and exponents gave T values of 3.1 and 5.4 dS/m, respectively, with improvement in R^2 .

Wheat-hay yield gave T values of 4.6, 7.9, and 7.0 dS/m, with corresponding S values of 8.63, 9.91, and 11.6 at different leaching fractions respectively. The T values of hay were higher than the grain T values, whereas the use of 0.3 LF value depressed T and sharpened slope indicating unfavorable conditions induced by extra water added in the root zone.

Barley grain yield gave high T values of 7.1, 8.0, and 5.7, and S values of 7.5, 6.6, and 6.6 at different leaching fractions, respectively, with an overall T value of 7.0 dS/m and S value of 7%. LF value of 0.3 depressed considerably the T value from 8.0 to 5.7. Barley hay yield gave comparable T values to grain yield but with higher rate of decline.

Alfalfa dry yield acquired T values of 6.1, 6.1, and 4.4, with S values of 11.7, 11.7 and 10.2 for the three indicated LF values. The overall T and S values were 6.4 and 12.4, respectively. The sharp decrease of T values from 6.1 at LF of 0.15 to 4.4 at LF of 0.3 indicated less favorable root zone conditions with extra amount of water added for leaching.

This phenomenon stands for the above discussed crops and can be attributed to the presence of water-table close to the surface (1.4 m) and the aridity of the climate, which favors the upward movement of water in case of extra moisture in the unsaturated zone with high LF value and low hydraulic conductivity of these soils near saturation (Ghaibeh, 1989).

For Tunisia, the range of salinity of irrigation water (0.3, 2.3, 3.9, and 5.5 dS/m) in general was lower than the irrigation water used in Syria.

In Libya, irrigation water with salinities of 3.9, 8.0, 11.6, and 16.7 dS/m was used to irrigate barley, with LF value of 0.10. The T value for grain yield was 7.0 dS/m and T value for hay yield was 6.9, which are

comparable to values obtained in Syria with the same variety of barley. Other studies conducted in Libya by Srour et al. (1977) using a wide range of salinity of irrigation water (1.5, 4.7, 9.4, 14.1 dS/m) on three wheat varieties (Bedri, Sedimasri, Florance) got T values of 4.7, 4.9 and 4.8 dS/m, respectively. Hay yields gave T values of 4.9, 4.8 and 4.5 dS/m, respectively, i.e., less than values obtained from field experiments.

In general, it can be noted that long-term field experiments gave strong evidence of higher threshold values of the salinity of irrigation water. Their magnitudes are comparable to those values reported by Hoffman et al. (1983) for the saturated soil paste extract. Linear declination of yield occurs as EC of irrigation water surpasses the threshold value with mild curvature. It can also be noted that A and T parameters are inherently dependent with unit negative correlation coefficient due to the nature of shift models and actual crop response; such negative correlation should be evaluated on different varieties and may have important economical consequences, indicating that higher yielding varieties have low threshold values.

Crop Moisture Extraction Pattern vs. Irrigation Water Salinity

We present cotton and wheat data of measured soil moisture content versus depth, time and salinity of irrigation water in the presence of water table for the years 1994, 1995, 1996, and 1997, which were used to build a model for moisture extraction pattern of cotton in Syria in the form of:

$$wx = (A + B \cdot t + C \cdot t^2) \exp(D \cdot z + E \cdot EC_{iw}) \dots \dots \dots (4)$$

Where: wx is the rate of moisture extraction by cotton and wheat roots in mm/day/depth (cm); t is the time in days; z is soil depth in cm; and EC_{iw} is conductivity of irrigation water in dS/m. Values obtained by non-linear regression analysis were: $A=0.21$, $B=0.0001$, $C=0.0000095$, $D=-0.027$, $E=-0.052$, with $R^2=0.64$ for 686 cases. Equation (4) was integrated twice over root zone depth z (0-1.4 m), and irrigation period of cotton (m) of 135 days to give Et in mm for each salinity level of irrigation water:

$$Et = \int_0^m \int_0^z wx \, dz \, dt = m/D \exp(E \cdot EC_{iw}) (A + Bm/2 + C \cdot m^2/3) (1 - \exp(Dz)) \dots (5)$$

The solution of Equation (5) for the indicated EC_{iw} range was used to give Et of 1214, 1045, 943, 851, 808 mm, respectively. These figures matched closely ($\pm 3\%$) with the actual average irrigation water values applied. Et values obtained showed that the rise of EC_{iw} from 1.5 to 9.4 dS/m had reduced water requirements by 33%. However, the reduction in yield amounted to 59%. This can be attributed to the poor stand of plants irrigated with saline water, which gave rise to increased direct evaporation from the soil surface and the early senescence of crops irrigated with saline water. This is in agreement with the conclusion made by Hamdy (1997).

In Syria, differences between the two soil moisture extraction patterns for cotton and wheat depict differences between root systems and different growth period (winter crop and summer crops). However, the evaluation of such functions is of great importance to apply models such as the simulation model suggested by Dutt et al. (1972).

Soil Solution Ionic Composition vs. Irrigation Water Salinity

Soil solution obtained by vacuum lysimeters inserted at 0.25 and 0.50 m within cotton root zone collected 48 hours after irrigation were analyzed for cations and anions. Regression equations between EC of soil

Table 1. The absolute yield functions, the threshold values T, the slope % and leaching fractions obtained on the use of saline irrigation water in Syria, Libya, and Tunisia.

Crops	Threshold	Slope %	Leaching Fraction	EC _{iw} Zero Yield
Syria: EC _{iw} range = 1.5, 4.4, 6.4, 8.4, 9.4, 11.4 dS/m				
Cotton	4.7	11.0	0.00	13.8
	4.8	9.8	0.15	15.0
	4.7	9.1	0.30	15.7
	4.7	10.2	All	14.7
Maize	3.9	17.5	0.00	9.7
	4.0	16.1	0.15	10.3
	3.8	15.5	0.30	10.3
	3.8	15.9	All	10.2
Vetch	2.9	5.5	0.00	21.5
	2.9	6.1	15.0	19.4
	2.9	6.6	30.0	18.0
	2.9	6.1	All	19.8
Wheat Grain	3.6	10.2	0.00	13.4
	5.4	8.3	0.15	17.5
	4.3	9.6	0.30	14.8
Wheat Hay	4.3	9.5	All	14.9
	4.6	8.6	0.00	16.1
	7.8	9.9	0.15	18.0
Barley Grain	6.9	11.6	0.30	15.6
	7.2	10.4	All	16.7
	7.1	7.5	0.00	20.5
Barley Hay	8.0	6.6	0.15	23.1
	5.7	6.7	0.30	20.5
	6.9	7.0	All	21.4
Alfalfa Dry Production	6.4	9.9	0.00	16.5
	7.3	9.5	0.15	17.9
	6.4	9.4	0.30	17.0
Alfalfa	7.0	9.3	All	17.8
	6.1	11.7	0.00	14.6
	6.1	11.7	0.15	14.6
Tunisia: EC _{iw} range = 0.3, 2.3, 3.9, 5.5 dS/m	4.4	10.2	0.30	14.0
	6.4	12.4	All	14.5
Tomato	3.2	14.7	0.15	10.1
Melon	1.8	9.1	0.15	12.8
Maize	1.2	8.6	0.15	12.9
Pepper	2.1	8.9	0.15	13.3
Water Melon	1.4	8.3	0.15	13.5
Clover	0.3	7.5	0.15	13.5
Potato	1.2	6.9	0.15	15.6
Broccoli	0.5	5.5	0.15	18.8
Libya: Eciw range = 3.9, 8.0, 11.6, 16.7 dS/m				
Barley	2.8	4.5	0.15	25.2
Barley hay	6.97	1.7	0.20	
	6.89	2.4	0.20	

solution obtained from 0.25 m and 0.50 m vacuum lysimeters. Indicate convex slope of the curves, i.e., the tendency of the salinity of soil solution to decline with EC_{iw} of 4-5 dS/m; this was attributed to the decrease of moisture extraction with the increase of salinity mainly due to early senescence of crops.

Increasing LF from 0 to 0.15 depressed the apex of the curves from 18 to 13 dS/m. However, further increase of LF had increased the apex EC_{ss} from 13 to 15 dS/m. This indicates the delicacy of management practices using saline water in arid regions, a phenomenon manifested in yield functions discussed earlier.

For corresponding ionic composition of EC_{ss} versus ionic composition in EC_{iw} , at 0 LF, sulfate and chloride anions, with sodium and calcium cations, dominated the soil solution composition. However, chloride apex at 20 meq/l then tended to decline. Increasing LF to 0.15 had considerable effects on reducing chloride and sulfate concentrations in soil solution. With 0.15 and 0.30 LF rates, sulfate ion tended to stabilize near 40 meq/l. There was an apex for calcium with 30% LF rate at 10 meq/l. The ratio of Ca/Mg in soil solutions approximated unity which might cause serious nutrient problem considering the negative charge of plant membrane and electrostatic theory of cation exchange as indicated by (Cramer et al., 1986).

In general, a linear relationship between EC_{ss} and E_{iw} was not found as suggested by Rhoades (1984), a phenomenon to be considered in management practices considering early maturation of crops irrigated with such water.

CONCLUSIONS

Crop yield functions obtained parameters which were found to be dependent on leaching fractions. A two-piece model recommended for the relationship between yield and EC_e can be used to fit the model for yield and EC_{iw} .

A model for moisture extraction pattern of cotton and wheat was suggested and was found to be dependent on the salinity of the irrigation water. However, the reduction in yield exceeded the reduction in moisture extraction. The model depicts a case where the water table is close to the surface, which, under arid conditions favor surface accumulation of salts.

A non-linear relationship was also found between EC_{ss} and EC_{iw} , as well as for cations and anions for different LF values. This was attributed to early senescence of crops irrigated with saline water. It was found that LF value of 0.15 was more effective than 0.30 either in depressing the ionic content of soil solution or reflected on an increasing crops yield. This applies to the specific condition of the location, i.e., water quality used, and soil physical properties and drainage efficiency.

REFERENCES

- Pillsbury, A., and H. Blaney. 1966. Salinity problems and management in river systems. Proc: ASCE (IRI).
- Dutt G.R., M.J. Shaffer, and W.J. Moore. 1972. Computer Simulation model of dynamic bio-physicochemical processes in soil. Department of Soils, Water and Engineering, Agric. Exp. Station. Univ. of Arizona, Tucson. *Tech. Bull.* 196.
- Paliwal, K. 1972. Irrigation with saline water. *IARI Monograph No. 2*. WTC/IARI, New Delhi, India.
- Moore, J., and J. Hefner. 1976. Irrigation with saline water in Pecos Valley of west Texas. Proc: Int. Salinity Conference, Managing Saline Water for Irrigation. Texas Tech. University, Lubbock, USA.
- Shalhevet, J., and Kamburov, 1976. Irrigation and salinity - A worldwide survey. K.K. Frajmi (Ed.). *Int. Comm. Irrig. Drain*, New Delhi, India.
- Sror, F., M. Shban, and M. Shalan. 1977. The tolerance of different wheat varieties to saline water. *Libyan Agric. J.* No. 6: 20-26.
- Maas, E., and G. Hofman. 1977. Crop salt tolerance - current assessment. ASCE, *J. Irrig. Drainage Div.* 103 (IR2).
- Miles, D. 1977. Salinity in Arkansas Valley of Colorado. Environmental Protection Agency. Interagency Agreement Report EPA-AIG-D4 - OSS4, C.O.
- Keren, R., and I. Shainberg. 1978. Irrigation with sodic brackish water and its effects on the soil and on cotton fields. *N. Harrade*, 58.
- Bressler, M. 1979. The use of saline water for irrigation in the USSR. Joint Commission on Scientific and Technical Cooperation, Water Resources.
- Abdelgawad, G., G. Mohmoud, M. Bakhbakhi, and E. Salawi. 1981. Water resources quality for irrigation in Libya. International committee of inorganic fertilizer publications on the use of water and fertilizer in arid and semi-arid condition-fertilizer center. Vienna, Austria. p. 205-210
- Hoffman, G., Maas, I. Prichard, and J. Tand Meyer. 1983. Salt tolerance of corn in Sacramento-San Joaquin Delta of California. *Irrig Sci.*
- Van Genuchten, T. 1983. Analyzing crop salt tolerance data. USDA-ARS-USSL *Research Report No. 120*.
- Rhoades, J. 1984. Using saline water of irrigation, Scientific Reviews on Arid Zones Research. Sci. Publ., Jodhpur, India.
- Cramer, G., R. Lauchli, and E. Epstein. 1986. Effects of Na Cl and Ca Cl₂ on ion activities in complex nutrient solutions and root of cotton, *Plant Physiol.* 81.
- Rhoades, J., 1987. Use of saline water for irrigation. Water quality bulletin 12.
- Ghaibeh, A. 1989. *In situ* measurement of under-saturated hydraulic conductivity in Euphrates soils, proc. - AOAD. Khartoum. Sudan.
- Suarez, D., and I. Lebron. 1993. Water quality criteria for irrigation with highly saline water. In H. Lieth

- and A. Al Masoom (Ed.) Toward the rational use of high salinity tolerant plants. Vol. 2. Kluwer Academic Publishers, The Netherlands.
- Abdelgawad, G. 1993, Rationalization of the use of water of different sources and salinity in Arab agriculture and its environmental effects, ACSAD. 1993. Publ. No. 120.
- Abdelgawad, G. 1995. The use of highly saline water for irrigation. *Desertification Bull.* No. 26.
- Abdelgawad, G., and A. Ghaibeh. 1996. The effect of four soil amendments on soil surface sealing and crust formation. ISCO, Bonn, 1996.
- Buaziz, E. 1997. Tunis. Country paper on the use of saline water in agriculture, ACSAD Workshop Proceedings, Cairo, Egypt 21-27 July.
- Hamdy, A. 1998. Saline irrigation management for sustainable use. CIHEAM/ MAI-Bari/ Italy.

Monitoring Irrigation Canal and Drainwater Quality in the Egyptian Delta

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ABSTRACT

Samples of water were collected monthly from irrigation canals of Mahmudia, Ismailia; and Bahr Moiece, and the Drains of Edko, Mahsama, and Hanut, besides collecting samples from Damietta and Rossetta branches of the River Nile. Locations of water samples were (a) at start of canal and (b) a point midway before the mixing site of drain water with Nile water, as well as (c) a point after the mixing site. Mixing of drain water with irrigation canal waters is practised in many places in Egypt in order to utilize much of the water resources in Egypt.

Ranges of EC of waters were mainly 0.35 to 0.40 dS/m increased by mixing to between 0.50 to 0.70 dS/m. For drainage waters, ranges were between 1.0 and 3.0 dS/m in most cases. The Mg-ratio of Nile water in the two Nile branches ranged from 16 to 40. It increased from 50 to 65 in irrigation canals, and from 60 to 70 in waters of the drains. Determination of the sodium adsorption ratio (SAR) and Adjusted SAR, as well as soluble sodium percentage (SSP), were also made.

Sodium adsorption ratio was very low and ranged between less than one to 3 in the fresh waters of the Nile whereas it ranged between 4 to 7 in the waters of the drains. Adjusted SAR, was less than 1 in water of the two branches; between 2 to 6 in the canals waters; and between 6 to 17 in the drainage waters. Soluble sodium percent in the two Nile branches ranged between 24 to 40, increasing to 30 to 50 in the irrigation canals, and increasing further in the drain waters to a range of 50 to 60.

Waters of the drains may be used for irrigating crops with little risk of adverse effects from the salinity and sodicity viewpoints provided that some precautions are taken.

INTRODUCTION

Egypt, in its efforts to increase the agricultural production is intensifying its agricultural input in the old arable land and is also expanding the cultivated area outside the Nile Delta and the Nile Valley. Drainage waters flowing in the drains (the drain canals) are generally more saline than waters flowing in the River Nile itself, or those flowing in its branches or in other canals (whether irrigation or navigation ones) branching off the Nile. Salt composition and concentration in water may vary from one location to another and with the time of year. The objective of the present study was

monitor to the chemical composition regarding salinity, sodicity, sodium, magnesium and carbonates status in the River Nile water in some of its irrigation canals, as well as in some drains in the Delta region.

Systems for water quality assessment for salinity included those of USDA (1954) of mainly four salinity classes C1 to C4 (modified later to six classes as reported by the FAO/UNESCO (1973)). Also, four sodium hazard classes, S1 to S4, were mentioned. Nomenclature of hazards, were being "low", "medium", "high" and "very high" corresponding to the class numbers of 1, 2, 3, and 4, respectively. The other system is the FAO system (FAO, 1976), which is a "tri-class" system proposed by the University of California Committee of Consultants. Such a system was reported as a monograph of in the FAO Series "Soils Bulletin", No. 29 (edited and prepared by Ayers and Westcot). The same system was also reported briefly as a paper by Ayers (1976) in a consequent FAO "Soils Bulletin" No. 31. This "tri-class" system consists of three classes with the following nomenclature: Class 1, "no problem"; Class 2, "increasing problems"; Class 3, "severe problems". It covers salinity, sodicity, and some other parameters.

For assessment of magnesium hazards, the parameter of Mg-ratio (i.e., percentage of Mg in relation to Ca + Mg) was used; according to FAO/UNESCO (1973), Mg-ratio of > 50 indicates Mg hazards on soil conditions. Regarding hazards of excess sodium bicarbonates, the parameter of residual sodium bicarbonate (RSC) was used. It consists of three classes as follows: Class 1, "safe" (RSC < 1.25), Class 2, "marginal" (RSC = 1.25 to 2.50), and Class 3, "unsuitable" (RSC > 2.50), according to FAO/UNESCO (1973). For assessment of sodicity in terms of soluble sodium percent (i.e., percentage of soluble Na relative to total cations), ratings mentioned in FAO/UNESCO (1973) will be used (hazards are expected if SSP exceeds 80 for waters of less than 1 dS/m, or exceeds 60 for waters of more than 1 dS/m).

MATERIALS AND METHODS

This study was carried out to monitor water quality for irrigation purposes on waters of a number of waterways (water canals) in the Nile Delta region. Water canals under investigation included the followings:

1. The two Nile Delta branches of Rossetta and Domietta, both carrying Nile fresh water.

2. Three freshwater canals. These were: Mahmodeya canal, west of Delta; Ismailia canal, east of Delta; and Bahr Moieece canal, east of Delta.
3. Three agricultural drainage-water canals or "drains". These were: Edko drain, west of Delta near Mahmudeya canal; El-Mahsama drain, East of Delta near Ismailia canal; and Hanut drain, east of Delta near Bahr Moieece canal.

Water Sampling Sites

For each of the Nile branches, water samples were taken at their starting places about 200 m after The Nile Barrage (Al-Kanater El-Khairiya). For each of the fresh water canals of Ismailia, Bahar Moieece, and Mahmudiya, samples were taken from three sites. The first site (location) was at the starting place of the canal, i.e., at the beginning of the canal where it branched off the major waterway, i.e., its head. The second and the third sampling sites were some distance downstream along the waterway canal.

Such two locations were situated relative to the place where drainage water of the relevant nearby drain is mixed with the canal's water. Mixing practice is carried out by the Government in order to make use of some of the drainage water for irrigation purposes. One of these sites was about 200 m before the point of mixing drainage water with the canal water. The other site was taken about 200 m after the point of mixing (i.e., downstream).

The former location may be termed as the "pre-mixing location", and the later as the "post-mixing location". The reason was to assess the effect of mixing drainage water with fresh water before and after the mixing vicinity. With regard to the drains, samples were taken from them at the locations where their waters were mixed with waters of the irrigation canals.

Time of Water Sampling and Analysis

Samples of water were taken monthly around the year and in some cases every two months. Locations of mixing of drain waters with the fresh waters of the irrigation canals were: for Ismailia canal, 117 km downstream; Bahr Moieece canal, 71 km downstream, Mahmodiya canal, 8 km downstream. Such distances are from the start of each canal, respectively. Electric conductivity, soluble ions, and pH were done on water samples (USDA 1954). Parameters of sodium adsorption ratio (SAR) adjusted sodium adsorption ratio (Adj. SAR), soluble sodium percent (SSP), magnesium ratio (Mg-ratio), and RSC were calculated from the analytical results in order to assess water quality for irrigation with regard to such parameters.

RESULTS AND DISCUSSION

The results and discussion will be oriented to stating the status of water quality regarding hazards of salinity (expressed as EC), sodicity (expressed SAR, Adj.-SAR, and SSP), and magnesium expressed as Mg ratio, and

bicarbonates (expressed as RSC). With regard to water pH, values were around neutrality, indicating no pH hazards.

Salinity Assessment

Rossetta and Damietta Nile Branches

Salinity was rather low, and EC ranged between 0.32 and 0.39 dS/m, thus being C2 (according to USDA, 1954); or Class 1 "no problem" (according to FAO, 1976). The soluble salts in river Nile near Cairo were reported to have been averaging between the equivalents of 0.21 and 0.36 dS/m during the period between 1919 and 1927 (Abo El-Attaa, 1978; Ministry of Irrigation, 1981). Salinity before and after mixing canal and drainage water can be summarized from Fig. 1.

Mahmudeya and Edko Drain

Salinity started low at the head of Mahmudeya canal, then it increased downstream. The EC at head of the canal was 0.33 to 0.39 dS/m increasing to 0.49-0.67 dS/m downstream before mixing, then to 0.51-0.90 farther at the post-mixing location. The rating is thus C2 to C3 (USDA); or between Class 1 to Class 2, "i.e., between no problem to increasing problems" (FAO). In the drain water, EC was greater than in the canal, being 0.93 to 2.60 dS/m. The rating would be between C3 and C4 (USDA 1954), or Class 2 (FAO).

Ismailia Canal and Mahsama Drain

Results resembled those of Mahmudeya canal, with Edko drain being lowest at head of canal, increasing downstream to reach highest at the post-mixing location, and that the drain's water was more saline than the canal's water. Mixing refers to blending drain waters with irrigation canal water before mixing and after mixing refer to sample site; head refers to the site of the head of the canal. At the head of the canal, EC was 0.35 to 0.38 dS/m increasing to 0.38 to 0.57 dS/m at the pre-mixing location, then to 0.48 to 0.96 dS/m at the post-mixing one. The rating would thus be C2 to C3 (USDA) or Class 2 "increasing problems" (FAO). The EC of the drain water was 1.11 to 1.69, i.e., C3 (USDA) or Class 2.

Bahr Moieece Canal and Hanut Drain

The pattern was similar to the other two canals and two drains, though with slightly different values. At start of Bahr Moieece canal, EC was lowest (0.33 to 0.39 dS/m), increasing to 0.39-0.50 dS/m downstream at the pre-mixing location, then increasing further to 0.46-1.12 dS/m at the post-mixing one. The drain water had a higher EC value of 0.96 to 1.66 dS/m.

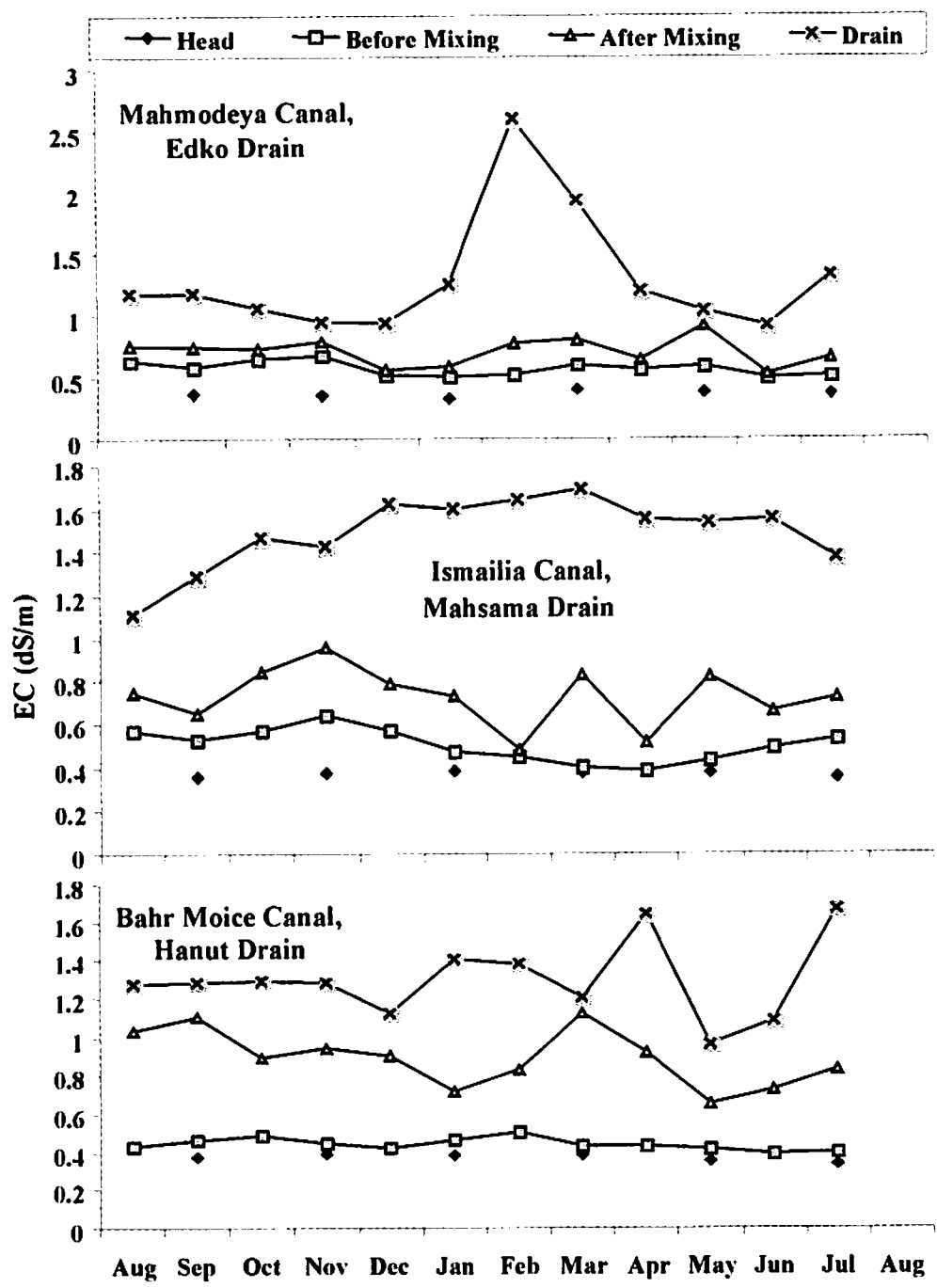


Fig. 1. Salinity before and after mixing in canal and drain.

Sodicity Assessment

Sodicity in terms of "SAR" will be assessed according to USDA (1954); and in terms of "Adj. SAR ", it will be assessed according to FAO (1976). Data can be summarized as follows:

Rossetta and Domietta Nile Branches

The water's SAR was low in the two branches, and did not exceed 1.0 in most cases. Therefore, no sodium hazards would be expected.

Mahmodeya Canal and Edko Drain

In Mahmodeya canal, SAR was lowest at its start (mostly below 1.0), increasing downstream, reaching its highest at the mixing location (1.4 to 2.6 before mixing; and 1.8 to 3.0 after mixing). The rating would be S1. In Edko drain, SAR surpassed 4.2 and went up to 7.3 in most cases giving the rating as between S1 and S2 (in the light of its salinity).

Ismailia Canal and Mahsama Drain

The SAR pattern was similar to that of Mahmudia canal and Edko drain; SAR in Ismailia canal was

lowest at its start (from 0.7 to 1.5), increasing downstream to between 1.4 and 2.8 at the pre-mixing location, to between 2.0 and 3.3 at the post-mixing one. The rating is thus "Class 1". In Mahsama drain, SAR was between 4.3 and 7.3; thus being between Class 1 and Class 2.

Bahr Moiece Canal and Hanut Drain

In Bahr Moiece canal (as in the other two fresh water canals), SAR was lowest at its start (mostly below 1.0) increasing downstream; reaching its highest at the water-mixing location (1.1 to 2.1 at the pre-mixing site; and 2.0 to 4.5 at the post-mixing one); with S1 rating. In Hanut, drain SAR was mostly above 4.2 going up to, 4.7 making its rating between S1 and S2.

Rossetta and Damietta Branches

Adjusted SAR was very low, mostly not exceeding 1, indicating Class 1, "no problem". Mahmudia canal it was lowest at its start (not exceeding 1.0), increasing downstream to between 2.0 and 3.8 at the pre-mixing location then increased further to between 2.8 and 4.5 at the post-mixing one; the rating is Class 1. At Edko drain, Adjusted SAR was 5.7, to as high as 16.8, i.e., between Class 1 and Class 3.

Ismailia Canal and Mahsama Drain

The pattern resembled that of Mahmudia canal and Edko drain. Adj. SAR was lowest at Ismailia canal's start (0.8-1.4), increasing downstream. Values were 1.6 to 2.5 at the premixing location, and 3.0 to 6.6 at the post-mixing one. It may be stated that the rating is mostly class 1 except in late winter when the value exceeded 6.0 i.e., class 2. In Mahsama drain, Adj. SAR. was between 7.6 and 12.6, i.e., Class 3 (i.e., having increasing to severe problems).

Bahr Moiece Canal and Hanut Drain

The pattern resembled those of the other canals and drains. Adj. SAR was lowest at Bahr Moiece start (1.6 or less), increasing downstream to between 1.4 and 3.2 at before mixing, to between 2.9 and 7.5 at after mixing with drain water. The rating is thus between Class 1 and Class 2. In Hanut drain, Adj SAR values were between 6.0 and 9.6, i.e., Class 2 to 3.

Soluble Sodium Percentage

Rosseta and Damietta Nile Branches

The SSP of waters in these two branches was low, ranging from 25 to 32. In the light of the low EC of such waters, there would be no hazard due to soluble sodium in water.

Mahmudia Canal and Edko Drain

In Mahmudia canal SSP was lowest at its head, 25 to 30, increasing downstream to between 35 and 45 at the

pre-mixing location; to greater values of between 40 and 54 at the post-mixing one. Therefore, according to the SSP and in the light of water's EC there would be no harmful effects since the SSP never exceeded 60. In Edko drain SSP exceeded 60 in most cases rendering it harmful.

Ismailia Canal and Mahsama Drain

In Ismailia canal SSP was lowest (23 to 39) at its start, increasing downstream to between 39 and 58 at the "post-mixing" location. Thus, it is of no harmful effect. The Mahsama drain water had SSP of mostly above 60 indicating harmful effects.

Bahr Moiece Canal and Hanut Drain

In Bahr Moiece canal SSP was lowest at its start (25 to 44), increasing downstream to between 32 and 48 at the pre-mixing location, and decreased farther to between 40 and 67 at the post-mixing one. In the light of EC values, there would be no harmful effects due to soluble sodium. In Hanut drain SSP did not exceed 60, which renders it not harmful.

Magnesium Ratio

Rosseta and Domietta Branches

The Mg-ratio was very low in the two branches ranging from 16 to 42 i.e., no hazard.

Mahmudia Canal and Edko Drain

In Mahmudia canal, Mg-ratio ranged between 28 to 66 in the pre-mixing location and 44 to 67 in the post-mixing one thus "having a harmful" effect in cases of Mg ratio exceeding 50. In Edko drain the Mg-ratio exceeded 60 indicating a harmful effect.

Ismailia Canal and Mahsama Drain

In Ismailia canal Mg-ratio ranged from 28 to 66 at the pre-mixing location; and between 44 and 67 at the post-mixing one; thus being between "non-harmful" and "harmful". In Mahsama drain, Mg-ratio exceeded 60 mostly, indicating a harmful effect.

Bahr Moiece Canal and Hanut Drain

In Bahr Moiece canal, Mg-ratio exceeded 50 in all its locations; and the same occurred with Hanut drain. Thus, there would be hazards concerning soluble Mg. Values of residual sodium carbonates indicate whether or not there would be soluble sodium carbonates, and in which magnitude. Water containing RSC greater than 2.5 meq/L was considered unsuitable for irrigation since it may develop sodicity and alkalinity in soil due to the presence of sodium carbonate. Water having RSC of between 1.25 to 2.50 is considered marginal. The value of RSC found in waters of the current study were negative or positive, but lower than 1. This indicates that the canals waters as well as the land drainage waters had no RSC hazards.

CONCLUSIONS AND PRACTICAL IMPLICATIONS

Waters of the freshwater canals used for irrigation fluctuated in their salinity, sodicity parameters, as well as their Mg ratio. The marked observation was that waters contained the lowest soluble salts as well as the lowest values of SAR, Adjusted SAR, SSP, and Mg ratio at the head of each of the three fresh water canals than at any point downstream; and that the canals had lower values than the drains. Also, values were lower in the two Nile branches (most probably because sampling was taken at these branches at their start) than in the canals or drains. Waters of the drains had greater values.

Increased salinity could not be solely due to evaporation. The increase in some ions, such Mg and Na, was in contrast to the very little change in Ca concentration (a near stability of concentration of Ca) as we moved downstream or in drains waters relative to other waters, indicates an enrichment of ions such as Mg and Na. Waters of drains were characterized by their considerably higher concentrations of Na, Mg, and Cl ions in particular. These ions are easily leached through the soil.

Mixing waters of drains with those of the irrigation canals, though increased values of such parameters, would still be possible to utilize such waters for irrigation. However, there may be some hazards concerning items other than those of salinity (e.g., heavy metals). Although greater in these parameters than waters of the canals, drain waters may be utilized, as they are or after mixing the less saline waters of irrigation canals. Shaban (1998) and Mostafa et al. (1998) reported the practicality of using such waters in Sharquiya region, east of the Delta.

The increase in salinity, sodicity, and Mg ratio of Nile waters as they traveled downstream may have

been partly due to a possible input (or influx) of ground water, seepage water, and drainage waters through the body of lands around the irrigation water canals. This may have been the case thus contributing to such increases. Shaban (1998) and Mostafa et al. (1998) reported EC values of around 3 to 4 dS/m in some drains in Sharqiya region with rather high (though not toxic) contents of some heavy metals such as Pb and Cd, and high contents of some trace elements such as Cu and Zn.

REFERENCES

- Ayers, R.S., and D.W. Westcot. 1976. Water quality for agriculture. *Irrigation Drainage Paper No. 29*, FAO, Rome.
- DRI., 1991. Reuse monitoring programme. 1991. Yearbook published by The Drainage Research Institute (DRI), Ministry of Water Resources. Egypt.
- El Atta, A. 1987. Egypt and the Nile after the High Dam, *A report in Arabic*, Published by the Ministry of Irrigation, Egypt.
- FAO, 1973. Irrigation, drainage, and salinity, FAO/UNESCO, FAO, Rome. Ministry Water Resources, Egypt 1981. Water master plan: *A report about water quality*, Report No. 7.
- Mostafa, M., M. Abd El-Naim, and K.A. Hassan. 1998. Trace element content in soil and plant as influenced by irrigation sources. *Annals Agric. Sci. Moshtohor* 36: 1991-2004.
- Shaban, K.A. 1998. Studies on pollution of some cultivated soils. *M.Sc. Thesis*, Fac. Agric, Zagazig Univ.
- USDA, 1954. Diagnosis and improvement of saline and alkaline soils. U.S Dept. Agric. *Handbook No. 60*. Washington, DC.

Crop Row-Spacing Influence on Transpiration and Soil Evaporation in Winter-Grown Wheat in Northern Syria

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ABSTRACT

A study was conducted on the long-term, two-course, wheat-lentil rotation trial established at International Center for Agricultural Research in the Dry Areas (ICARDA) in northern Syria, on a swelling clay soil (*Calcixerollic Xerochrept*) during the crop growth season of 1996-97. At this site, an allied study showed that saturated (+5 mm tension) and unsaturated (-40 mm tension) hydraulic conductivities were inordinately high (typically between 300-500 mm and 30-60 mm hr⁻¹, respectively) relative to conductivities reported in the literature for similar-type soils elsewhere. The purpose of the present study was to investigate for winter wheat sown with different row spacings how evapotranspiration partitions into evaporation and transpiration on highly conductive soils. The wheat crop was sown at 17 and 30-cm row spacing at a sowing rate of 200 kg ha⁻¹. In this study, evapotranspiration from the crop was inferred from changes in soil moisture content over time, while evaporation and rainfall interception were measured daily using micro-lysimetry.

Between sowing and Day 80 (tillering stage), evapotranspiration was mainly soil evaporation. However, after Day 80, transpiration became progressively more important. For both row spacings, cumulative evapotranspiration over the season was approximately 390 mm of soil water. In the narrow row spaced crop, transpiration and soil evaporation were approximately 192 mm and 195 mm of water, respectively. Conversely, for the wide row-spaced crop, 168 mm of water was transpired while 220 mm of water evaporated from the soil surface. As the amount of the incident radiation intercepted at the soil surface did not differ significantly between the two crops over the growing season, it seems likely then that the increase in evaporation was due to increased convection of water vapour to the atmosphere due to the enhanced movement of air between the rows in the wide-spaced crop.

In addition, other studies conducted on similar-type soil have measured loss of water vapour via soil evaporation and interception in similar seasons to be approximately 150 mm, with transpiration being approximately 170 mm commonly achieving grain yields in excess of 5 t ha⁻¹ compared with 1.5 t ha⁻¹ (ranging from 0.5 to 2.6 t ha⁻¹ in the last 10 years)

in the study zone. This suggests that soils with high hydraulic conductivity may have heightened levels of soil evaporation and concomitantly lower levels of transpiration when compared with soils of low hydraulic conductivity. Hence, in order to improve transpiration efficiency in these soils, physical methods to impede soil evaporation such as reducing row spacing, or direct sowing into stubble may be necessary for yields on these soils to be increased.

INTRODUCTION

A major constraint to rainfed agricultural production in the Mediterranean environments of West Asia and North Africa (WANA) is the frequently low and commonly highly erratic patterns of rainfall. Results of studies undertaken in this and in other regions to investigate improvements in the efficiency of use of stored soil moisture by crops and their nutrition have suggested that by improving crop nutrition and patterns of water use, there exists a large potential to improve the water-use efficiency of agricultural systems operating in rainfall zones of less than 500 mm (Cooper et al., 1987; Hamblin et al., 1987).

Most water vapor movement from the crop to the atmosphere occurs by evapotranspiration (E_t) from the plant community. This process comprises transpiration (T), the evaporation of moisture from the surfaces of green tissue for the crop; and evaporation of water from soil directly beneath the crop canopy. While plants benefit directly from transpiration (T), the benefits to plant communities from soil evaporation from beneath the crop canopy (E_{sc}) are indirect and are associated with an amelioration of the crop microenvironment (Leuning et al., 1994). Early work investigating the elements of E_t assumed that soil evaporation (E_s) and T were independent such that T was derived from E_t by subtracting E_s as measured from bare soil plots. Work of Denmead (1973) suggested that T and E_{sc} were essentially independent of each other in water non-limited conditions.

However, other work has been performed which suggest that some interdependency between T and E_{sc} may exist, and, to this effect, Cooper et al. (1987) suggested that manipulating the ratio of E_{sc} to T either via plant breeding or using agronomic techniques showed some potential as a method to improve yield in climatic

zones where rainfall was erratic. If T and E_{sc} are to some extent interdependent, techniques need to be employed to separately quantify E_s and T over the growing period of a crop in order to understand the ramifications of manipulating one upon the other. Various approaches have been used to estimate the E_s from beneath the canopy of a growing crop. Micro-lysimetry provides a method to directly estimate E from the soil surface either on bare ground or beneath the canopy of a growing crop. This technique has been used to a limited extent to directly estimate soil evaporation from under the crop canopy (Boast and Robertso, 1982; Shawcroft and Gardiner, 1983; Allen, 1990; Leuning et al., 1994). However, micro-lysimetry is very labour intensive and has problems during periods of rainfall. As a result, alternative methods for estimating E_s using either empirical (Cooper et al., 1983), semi-analytical (Ritchie, 1972) or modeling (Lascano, 1987) approaches have been readily adopted. However, while these approaches are convenient, very few studies exist (i.e., Allen, 1990; Yunusa et al., 1993) which have contrasted these techniques with micro-lysimetric estimates of E_s .

In the study reported here, micro-lysimetry was used to measure rainfall interception, and evaporation rates from soil beneath the canopy of wheat sown at two different row spacing at Tel Hadya in northern Syria. The objectives of the work reported were to: (1) investigate the influence of crop row spacing on canopy architecture and the sequestering of light between the canopy and the soil surface; (2) ascertain the influence of row spacing on rates of soil evaporation from beneath the crop canopy; and (3), investigate the relative importance of canopy structure on rainfall interception as a function of row space.

MATERIALS AND METHODS

Experimental Site

Measurements were made on the long-term two course wheat-lentil rotation trial located at International Center for Agricultural Research in the Dry Areas (ICARDA) field station at Tel Hadya (35° 55' N 37° 10' E) in northern Syria. This site is representative of the cereal-growing region of northern Syria, being of a typical Mediterranean-type climate and with a long-term mean annual rainfall of 330 mm.yr⁻¹. The soil at the site is classified as a swelling clay soil (Calcixerollic Xerochrept) with a pH in a saturated paste extract of 7.6.

The trial plots were prepared in either of two methods. The narrow-spaced crops were cultivated prior to sowing using disc-harrow cultivation equipment and then sown using a Nordstein planter with the sowing width set at 17cm. The wide row space was directly sown using a locally manufactured no-till seed drill fitted with Australian-made Kaldow sowing points set at a drill row width of 30 cm. In both treatments, wheat

was sown at a rate of 200 kg ha⁻¹, and at the time of sowing 60 kg ha⁻¹ of triple superphosphate and 60 kg ha⁻¹ of urea were applied. Due to the prior use of the plot, the present study was laid out as a randomized block with each treatment replicated within each block either three times in the wide-row space treatment or five times in the narrow row-space treatment.

Micro-lysimeters

Soil evaporation beneath the crop canopy was estimated directly using micro-lysimeters, which were weighed at 9 am each morning from Day 80 after sowing until Day 190. Micro-lysimeters were constructed from standard PVC pressure pipe. Each micro-lysimeter consisted of open PVC cylinders 200 mm in length, 120 mm outer diameter and with a wall thickness of 3 mm. Eighty-eight cylinders were manually pressed into soil in each experimental plot in early January 1997. The cylinders were regularly spaced at ~ 1m intervals along two transects (2 m apart) running parallel to the drill row direction in each plot and centered upon a drill row. Plants were allowed to grow in the lysimeter until sampling therefore ensuring that moisture contents of the soils were about the same as the surrounding soil at the time of sampling. About 10 mm of each cylinder was left exposed above the soil surface to aid in extraction of the cylinders at sampling.

At sampling, opposite edges of the cylinder was clamped using vice grip-style pliers and the soil containing cylinders gently removed from soil and the plant tops were cut at the soil surface. The hole remaining in the soil was carefully widened using a 150 mm wide auger, and a specially fabricated sheet metal cylinder of 205 mm in length and 145 mm outer diameter was inserted into the hole to line the cavity. The extracted cores were transported from the field to a field station, cleaned, and the base sealed with a thick plastic film bound to the PVC cylinder using thick adhesive tape. The cylinders were then weighed to a precision of 0.01g and returned to their respective locations in the field. Care was taken at all times to ensure that no disturbance occurred to the surface of the soil contained within the lysimeter.

Four micro-lysimeter replicates were sampled in each experimental plot at each sampling. Weighing was carried out daily at 9 am for 5 days in succession. After 5 days, it was felt that the moisture content of the soil in the lysimeter may not well represent the moisture content in the surrounding soil so a new set of lysimeters were prepared. When collecting and returning lysimeters to the field, extreme care was taken to ensure that the sites about the lysimeter were disturbed as little as possible in an attempt to ensure integrity of the canopy of the crop about the lysimeter. At the end of each sampling, soil-containing cylinders were removed from the field, weighed and then oven-dried for 3 days at 105°C from which soil bulk density and volumetric moisture content was estimated.

Weather Data

Weather data were collected using the ICARDA automatic weather station located close to the experimental site. Data collected included daily rainfall, rainfall intensity, maximum/minimum temperature, net radiation, and wind run. Rainfall data were manually checked on site manually using a 200-mm rain gauge at the time of sampling. Saturated deficit was calculated from wet and dry bulb temperature. The evaporating potential of the air E_o was estimated daily using a Class A evaporation pan, also located at the automated weather station.

Soil Moisture Content

Neutron moisture meter accessions tubes were installed at each location to a depth of 180 cm prior to sowing. Soil moisture content was regularly monitored throughout the crop-growing season at 15 cm depth intervals from 30 cm using a Mk II Wallingford Neutron Moisture Probe. Moisture content in the top 15 cm was sampled gravimetrically using a volumetric sampler. Evapotranspiration was estimated over the sampling period was estimated using the equation below:

$$Et = P - \Delta SS - R_{off} - DP$$

Where: ΔSS is the change in soil volumetric moisture content over the 0-180 cm soil profile between samplings, R_{off} is surface runoff, and DP is deep percolation beneath 180 cm.

At this site, negligible surface runoff occurred over the growing season and that as prior experience at the site suggested was that deep percolation was a rare event, we assumed that deep percolation was negligible.

Canopy Light Interception

From February until May, the amount of solar radiation reaching the ground surface in each of the replicated plots was measured in triplicate using 1-m solarimeters (Delta-T Devices Model TSL). At the same time, incoming solar radiation above the crop canopy was simultaneously monitored using an additional three 1-m solarimeters. All readings were run for a 15-minute period replicated in time, and were conducted over consecutive days at approximately the same time per day. Solarimeter outputs were recorded using hand held, micro-integrator units (Delta-T Devices model MV1). Comparison between the above canopy and surface mounted solarimeters allowed for the sequestering of solar radiation by the canopy to be determined.

RESULTS AND DISCUSSION

Seasonal Climatic Conditions

Cumulative rainfall and rainfall distribution recorded over the 1996-1997 growing season at Tel Hadya are presented and maximum/minimum temperatures (Fig. 1). Cumulative rainfall data shows that rainfall

experienced over the growing season was 433 mm and was approximately 60 mm in excess of the long-term average recorded for the region.

Examination of Fig. 1 shows that rainfall was well distributed over the crop growing season with a series of heavy falls occurring toward the end of season, post anthesis. As evidence from other studies show that appreciable yields can be achieved with wheat crops that evapotranspire between 350 and 400 mm (French and Schultz, 1984; Hamblin et al., 1987; Leuning et al., 1994), the rainfall over the crop growth season should have been adequate for the crop to have achieved appreciable yields. However, during February 1997 when the crop was in the physiological stage just prior to anthesis, night temperatures were commonly dropping beneath -5°C , and occasionally dropping beneath -10°C , sufficient to significantly damage the newly emerging reproductive parts of the plant and suppressing effective yield potential. As a result, grain yields were very low, typically less than 1 t ha^{-1} .

Canopy Light Interception

The proportion of incident solar radiation reaching the soil surface as a function of crop row spacing is shown in Fig. 4. Irrespective of row spacing, the general effect as the season progressed and as the canopy developed, was for the amount of light that reached the soil surface to decrease.

While in general the amount of light reaching the soil surface was greater in the wide row-space crop than in the narrow row-spaced crop, this effect was only minor. Hence, the effect of row spacing on the architecture of the canopy did not appear to be a particularly significant factor affecting light penetration through the canopy.

Rainfall Interception by the Crop Canopy

The rainfall storage capacity of the canopy was determined on several occasions between 80 days after sowing (DAS) and harvest. During these determinations, the influence of night rainfall on the accession of soil moisture by the micro-lysimeters was studied. Soil evaporation during these events was estimated in relation to soil volumetric moisture content and pan evaporation. Our determinations estimated that between 80 DAS and harvest for each rainfall event, between 0.2 and 1 mm of rainfall per rainfall event was irreversibly intercepted by the canopy, and are similar to estimates made by Leuning et al. (1994).

Using these indices, calculated cumulative interception losses between 80 DAS and harvest were 27 mm and 30 mm for the wide and narrow row spaced crops, respectively (Table 1) and did not differ significantly. Cumulative plots of rainfall and effective rainfall ($P_e = P - I$) are shown in Fig. 3. These data show that over this period 206 mm of rain fell and that effective rainfalls for the two treatments were 179 and 176 mm for the wide row spacing and narrow row spacing, respectively.

Table 1. Seasonal water balance.

	Wide Row (30 cm)	Narrow Row (17 cm)
	-----mm-----	
Rainfall	433	433
Interception (80DAS-190DAS) ¹	27	30
Evapotranspiration	388	387
Soil Evaporation	220	195
Transpiration	168	192

¹Days after sowing.

Leuning et al. (1994) showed that in their study for the crop at a similar stage of physiological development the ratio of interception-to-precipitation (I/P) was about 0.32, and about 0.2 during heavy rainfall events, whereas in the present study the aggregate I/P for the period 80 DAS to harvest was about 0.14. This may have been due to more heavy rainfall events occurring in the present study or to a less well-developed canopy. However, as the canopy storage potential between the two studies were similar, it seems likely that the difference is not a function of canopy structure but intensity of rainfall.

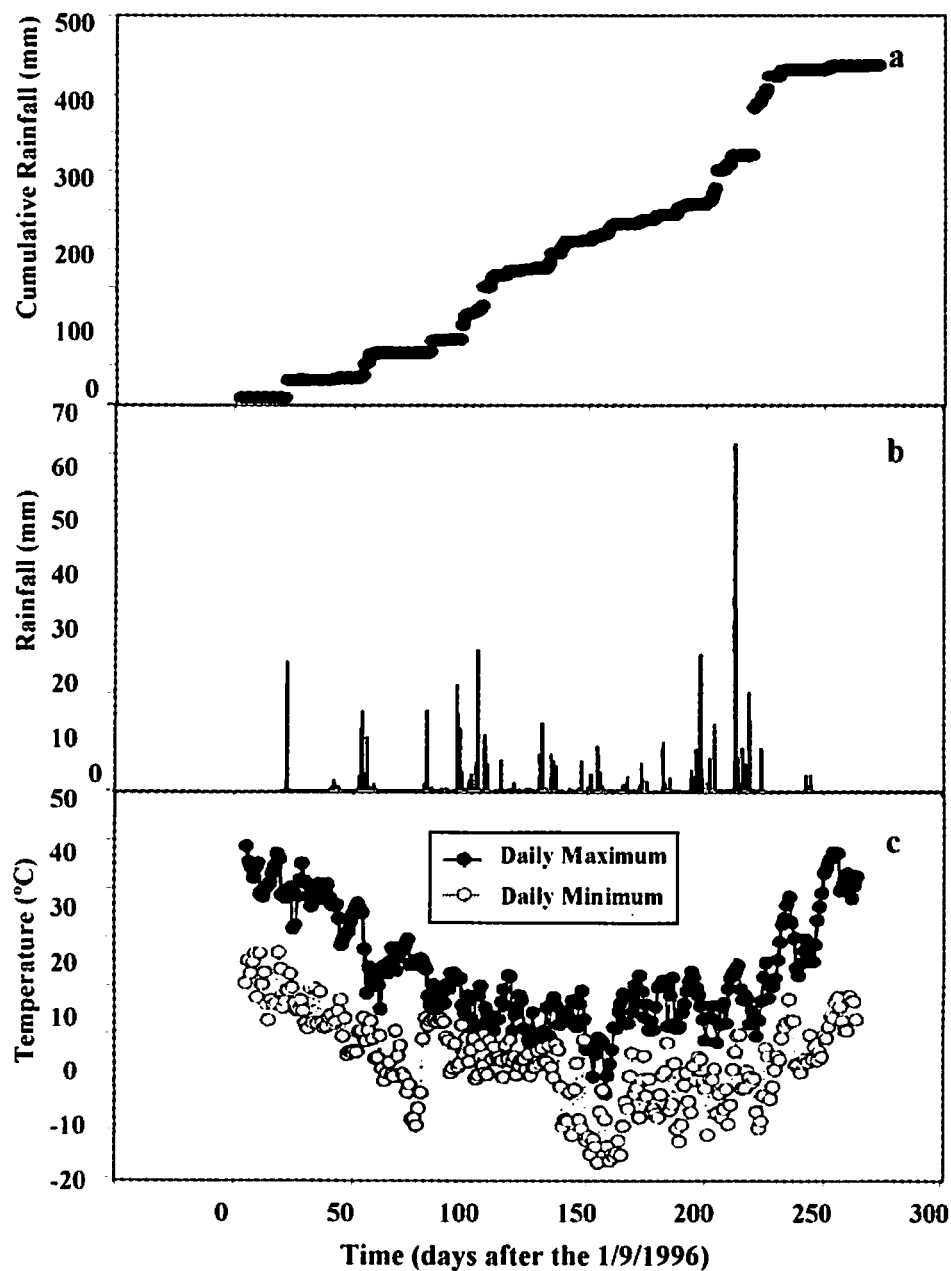


Fig. 1. Cumulative rainfall, rainfall distribution, and maximum/minimum temperatures over the 1996-1997 crop growth season at Tel Hadya.

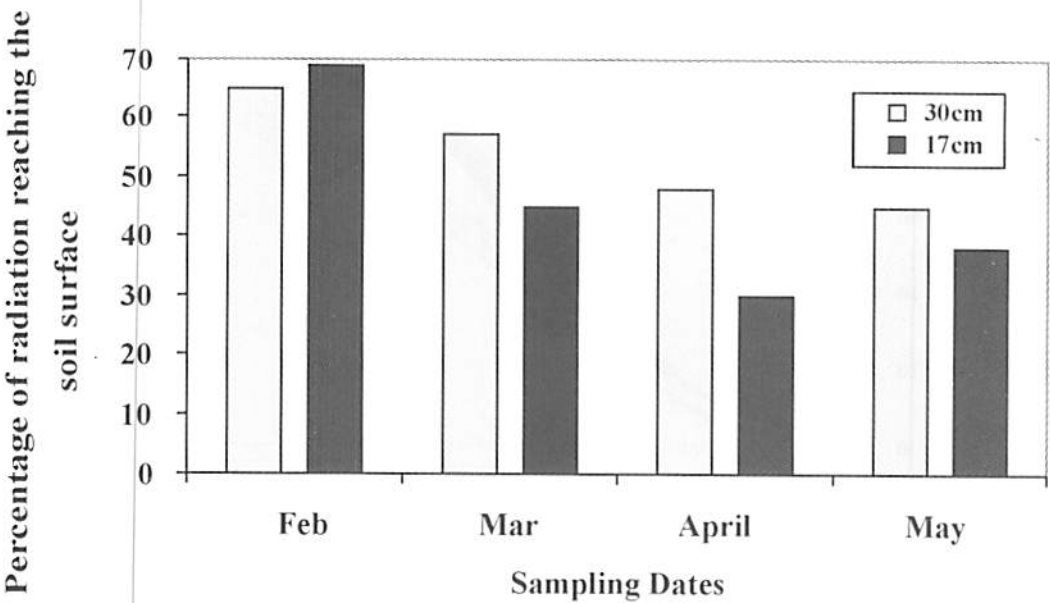


Fig. 2. Comparison of penetration of photosynthetic radiation to the soil surface beneath the crop canopy as a function of crop row spacing.

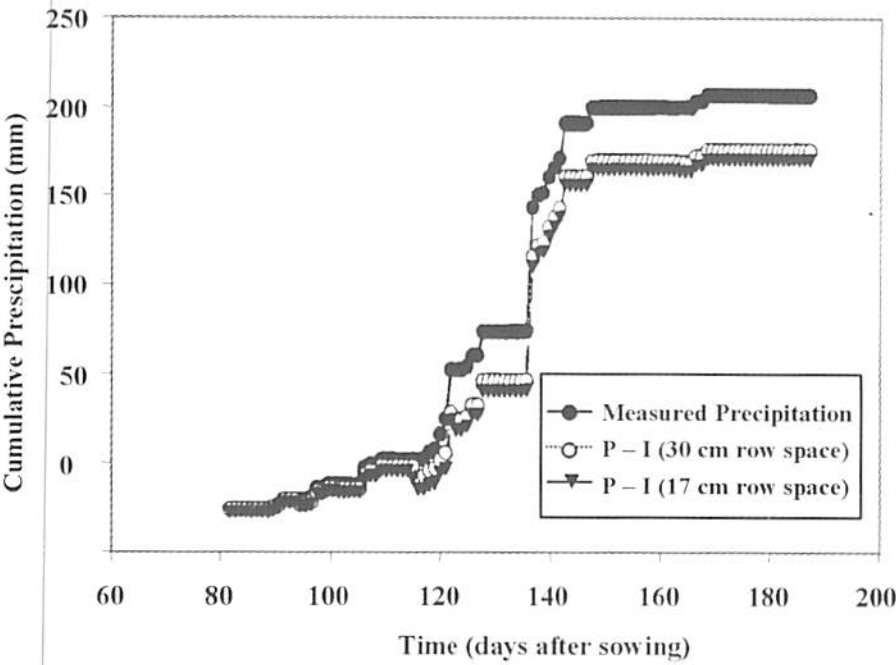


Fig. 3. Precipitation and effective precipitation as a function of crop row spacing between 80 days after sowing and harvest.

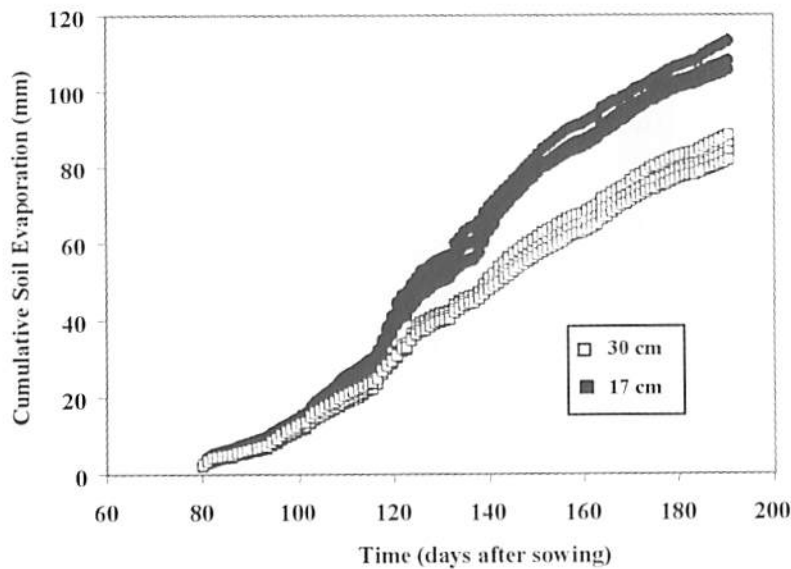


Fig. 4. Cumulative soil evaporation as affected by crop row spacing.

Evapotranspiration and Soil Evaporation vs. Row Spacing

The mean cumulative soil evaporation from beneath the crop canopy for the two row spacings from 80 until 190 DAS were 109.5 mm and 85 mm for the wide and the narrow row spaced treatments, respectively (Fig. 6). Contrasting E_{sc} to the amount of effective rainfall that fell over this period, the amount of rainfall entering the soil and available for the crop was 69.5 mm and 91 mm for the wide and narrow row space crops, respectively. This implies that the wide-spaced crop system had foregone 21.5 mm of transpirable plant available moisture. Assuming a transpiration efficiency of 20 kg of grain mm⁻¹ ha⁻¹ for wheat (as in Passioura, 1976), this implied a potential yield loss to the wide row-spaced crop of at least 430 kg of grain ha⁻¹.

As between 0 and 80 DAS, canopy development was slight, Et was likely to consist mainly of E_{sc} but beyond 80 DAS, as the canopy developed, T would be expected to consume a greater proportion of Et. Neutron moisture meter readings indicated that by DAS 80 in both treatments approximately 110 mm of soil moisture had been evapotranspired. Assuming this to be mainly soil evaporation, combining this figure with direct estimates made of E_{sc} over the period 80 DAS to harvest, then total seasonal estimates of E_{sc} for the wide and narrow row-spaced crops were 220 mm and 195 mm, respectively. Neutron moisture meter estimates of cumulative Et over the entire growth season for the two row spacings were almost identical, i.e., 388 and 387 mm for the wide and the narrow row-spaced crops, respectively (Fig. 5).

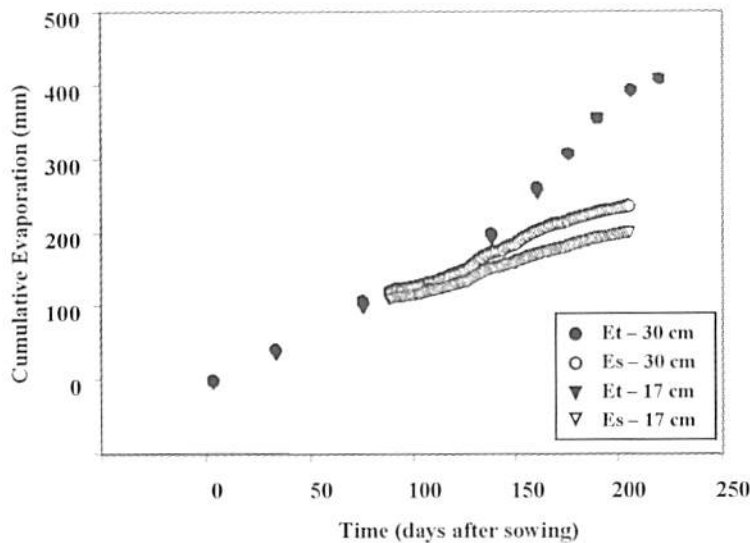


Fig. 5. Cumulative evapotranspiration and soil evaporation in relation to crop row spacing.

An analysis of the proportion of E_{sc}/E_t for the wide and narrow row-spaced crops showed indices of 0.57 and 0.5, respectively. Work of others have shown these values to range from 0.37 (Leuning et al., 1994) and 0.32-0.38 in fertilized and unfertilized wheat (Cooper et al., 1983) to 0.67 to 0.77 in barley grown in Breda, northern Syria (Allen, 1990). While the effective rainfall in the year of the present study ($P_e \sim 400$ mm) exceeded rainfall in the study of Leuning et al. (1994) ($P_e \sim 329$ mm), and that E_t values reported here were greater than of Leuning et al. (1994) (E_t 323mm), it could be expected that with adequate crop nutrition, the adequacy of effective rainfall should promote canopy development and allow for a reduction in E_{sc}/E_t to values similar to those observed (Cooper et al., 1983, and Leuning et al., 1994). However, the considerably higher values observed here might well be due to other contributing factors. Exceedingly cold night temperatures as occurred during February may have damaged vegetative development of the crops. Observations made subsequently suggested that the canopy of either crop did not fully develop, therefore promoting E_{sc} relative to T .

A second contributing factor may relate to the high hydraulic conductivity of the soil used in this study. In this soil in an allied study, these soils had a seasonal unsaturated hydraulic conductivity (-40 mm tension) ranging between 30-60 mm hr⁻¹. Conversely, work of Suwardji and Eberbach (1998) conducted on an adjacent paddock to that of the Leuning et al. (1994), where soils were similar, showed unsaturated hydraulic conductivity at the same tension to be less than 3 mm hr⁻¹.

This suggests soils of the present study had a considerably higher potential to redistribute soil water in the unsaturated phase and therefore may have had greater potential to supply water to the soil surface to meet evaporative demand.

The major effect of row spacing on rate of soil evaporation was most apparent soon after rain and can be seen in Fig. 6. In an attempt to try to eliminate daily variability in the drying potential of the air, the ratio of E_{sc} to E_o for both data sets were calculated. This showed quite clearly that immediately after heavy rain in April, when the upper soil profile was almost full of water, that greater E_{sc} occurred in the wide row than in the narrow row-spaced crop. As light interception by the canopy was similar between the two row spaced treatments and soil hydraulic conductivity was not likely to be particularly different between the treatments, then elevated rates of E_{sc} were likely to be due to some other property, possibly crop structure.

We postulate that this effect may be due to a difference in wind speed at the soil surface in the between the two row spaced crops. Our observations were that in the narrow-spaced crop, the crop was of sufficient density to impede turbulence between the ground surface and the canopy. However, in the wide row-spaced crop, the inter-row space was sufficiently wide to allow rapid movement of air and hence enhanced convection of water vapor to the atmosphere. We therefore postulate here that the difference observed between the two row-space treatments is contributed to by the architecture of the crop and the enhancement of turbulence within the rows of the wide row spaced crops.

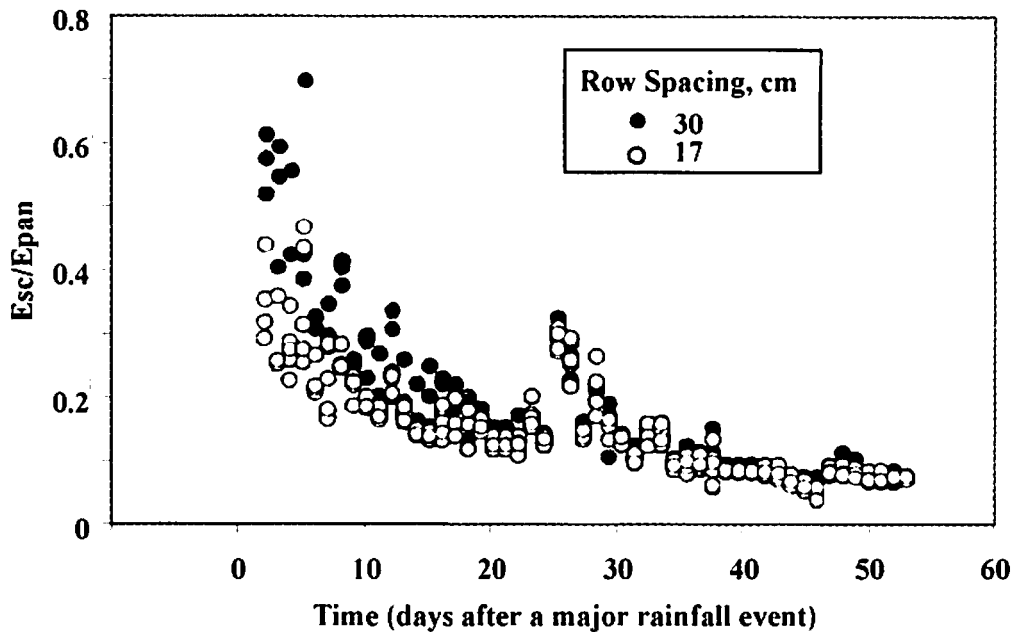


Fig. 6. Changes in soil evaporation as a proportion of pan evaporation after rain as affected by crop spacing.

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REFERENCES

- Allen, S.J. 1990. Measurement and estimation of evaporation from soil under sparse barley crops in Northern Syria. *Agric. For. Meteorol.* 49: 291-309.
- Cooper, P.J.M., P.J. Gregory, D. Tully, and H.C. Harris. 1987. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. *Exp. Agric.* 23: 113-158.
- Cooper, P.J.M., J.D.H. Keatinge, and G. Hughes. 1983. Crop evapotranspiration - a technique for calculation of its components by field measurements. *Field Crops Res.* 7: 299-313.
- Denmead, O.T. 1973. Relative significance of soil and plant evaporation in estimating evapotranspiration. In: Plant response to climatic factors. Proceedings: Uppsala Symp. UNESCO, Paris, p. 505-511.
- French, R.J., and J.E. Schultz. 1984. Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. *Aust J. Agric. Res.* 35: 743-764.
- Hamblin, A., D. Tennant, and M.W. Perry. 1987. Management of soil water for wheat production in Western Australia. *Soil Use Manage.* 3: 63-69.
- Lascano, R.J., C.H.M. van Bavel, J.L. Hatfield, and D.R. Upchurch. 1987. Energy and water balance of a sparse crop: simulated and measured soil and crop evaporation. *Soil Sci. Soc. Am. J.* 51: 1113-1121.
- Lenuing, R., A.G. Condon, F.X. Dunin, S. Zegelin, and O.T. Denmead. 1994. Rainfall interception and evaporation from soil below wheat canopy. *Agric. For. Meteorol.* 67: 221-238.
- Passioura, J. 1976. Physiology of grain yield of wheat growing on stored water. *Aust. J. Plant Physiol.* 3: 559-565.
- Ritchie, J.T. 1972. Model for predicting evaporation from a row crop with incomplete cover. *Water Resour. Res.* 8: 1204-1213.
- Shawcroft, R.W., and H.R. Gardner. 1983. Direct evaporation from soil under a row crop canopy. *Agric. Meteorol.* 28: 229-238.
- Suwardji, P., and P.L. Eberbach. 1998. Seasonal changes of physical properties of an Oxic Paleustalf (Red Kandasol) after 16 years of direct drilling or conventional cultivation. *Soil Tillage Res.* 49: 65-77.

III. Range Management

Conservation and Pastoral Livelihoods in Jordan's *Wadi Araba*

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ABSTRACT

In late 1997, a decision was taken at the Royal Society for the Conservation of Nature in Amman, Jordan, to develop a pilot project to fatten and sell goats from the local livestock population owned by nomadic Bedouin in the Dana Reserve. This Project is probably unique in the Middle East region in attempting to close the gap between the conservation interests of a major nature reserve and the pastoral livelihoods of an indigenous population. The underlying philosophy of the Project was simple, i.e., to develop a common shared interest and grounds for profitable co-operation between both groups and to give the local community an important stake in the success of the conservation project. This paper describes the first stage in the development of this Project and the reasoning behind its design. In doing so, it highlights some of the technical possibilities for community-based development among pastoralists in an arid, resource-scarce region.

INTRODUCTION

The Dana Reserve in Jordan is the largest of five protected areas under the management of the Royal Society for the Conservation of Nature (RSCN). The Dana Reserve lies on the dissected eastern slopes of the Wadi Araba (Fig. 1), with an area of 308 km² which

encompasses a wide range of ecosystems and habitats that shelter a number of plant and animal species of global conservation importance.

In 1993, a UNDP/World Bank GEF-funded project began in Dana aimed at the Conservation of the Dana Wildlands Global Environment Facility (GEF). In 1996, after an external review of progress at the completion of the GEF 1 Project, the World Bank took the unprecedented step of extending support for the project for a further 3 years (GEF 2). The RSCN Dana Reserve Management Plan (RSCN, 1996) follows the guidelines of the Nature Conservancy Council (NCC), UK, and is one of the first comprehensive management plans for the sustainable conservation of a reserve area anywhere in the Middle East Region. The contents of this Management Plan reflect the contemporary philosophy of integrating indigenous populations into conservation strategies through development (IIED, 1994). Some progress had been made towards this goal at the time of the GEF 1 review, including the creation of approximately 30 jobs for villagers in organic agricultural schemes and handicraft workshops at the Project center in Dana village. However, a stipulation of the GEF 2 funding was that the nomadic pastoral population of the lower (western) part of the Reserve should be incorporated to a greater extent into the Reserve and derive greater livelihood benefits from it, for, although they were the area's principal users, they had been largely by-passed by development efforts.

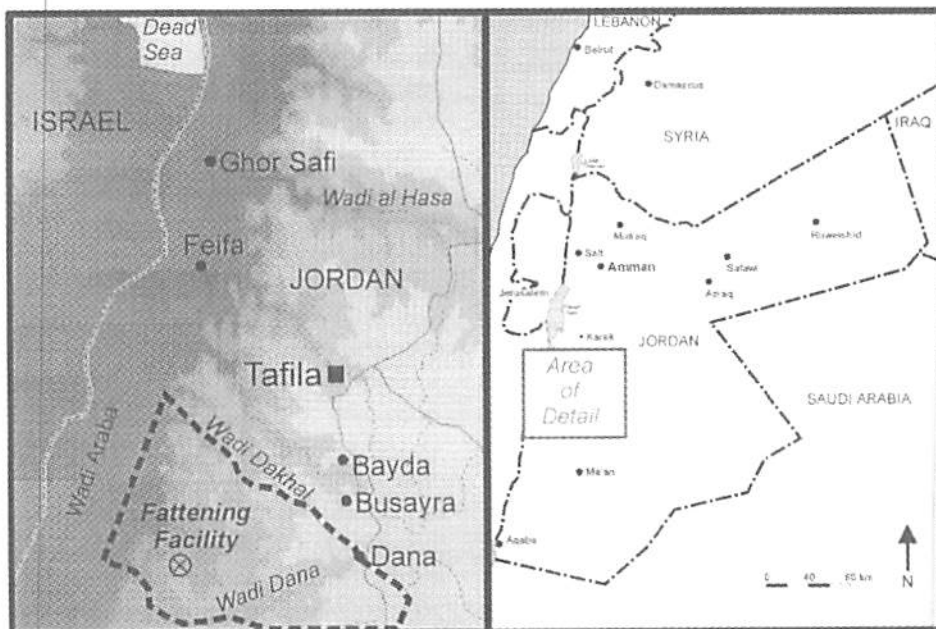


Fig. 1. Location of Dana Nature Reserve and Project in the Wadi Araba.

THE PROBLEM

With case studies from Oman and Syria, Chatty (1997) indicated the poor track record of attempts to integrate pastoralists into Middle Eastern conservation projects, where conservation interests seem to invariably clash with pastoral livelihood strategies. This seemed very much the case with the Bedouin population of the Wadi Araba in the lower Dana Reserve. Ecological studies within the Reserve (RSCN, 1994) had suggested that intensive livestock grazing was a problem in the rehabilitation of the natural flora and could even result in future loss of biodiversity. Consequently, ecologists stressed the need to reduce grazing to optimal levels. Socio-economic studies of the Bedouin population of the lower Reserve had described the principal tribes of the area and their various multiple-resource livelihood strategies (Lancaster and Lancaster, 1993), and established that a population of about 6,000 goats and some camels was being herded by approximately 35 households (Swenne, 1995). Furthermore, it seemed clear that livestock constituted the principal source of livelihood for many of those households and that any reduction in grazing would impact households severely.

Owing to the wide distribution of this pastoral population, their high level of mobility, and the cultural differences between Bedouin and Reserve staff, communications between the two groups had been poor. One of the few points of contact between them concerned the introduction of a zone-based grazing scheme. Consistent violations of this scheme demonstrated that the pastoralists saw few potential benefits from the Reserve and failed to identify with its objectives.

In May 1997, a further study was commissioned to reconsider the possibility of harmonizing interests between conservationists and the indigenous population of the lower Reserve area. After 3 months of meetings and discussions, a report was compiled entitled *Pastoralists of the Lower Dana Reserve Area: Attitudes to and Prospects for Integration within the Reserve Management Strategy* (1997). This study began to clarify the fuller dimensions and complexity of the apparent conflict of interests over land use in Wadi Araba. Major pertinent findings are summarized below:

1. The principal herd-owning tribe of the area, the Azazme, are migrants from Beersheva in Palestine and arrived in the Wadi Araba area in 1948 after the creation of Israel.
2. For this reason the Azazme lacked both legal and traditionally (tribally) recognized rights of usage to land for any purpose other than transitory grazing.
3. Most households had only recently acquired full legal status in Jordan. Thus, since their arrival, they had been excluded from formal State benefits and the possibilities of employment or military service.
4. Landless, uneducated and without networks of kinsmen in official positions, the Azazme had no livelihood alternative but subsistence goat pastoralism on

the marginal slopes of the Dana Reserve.

5. Studies of livestock production and domestic economics suggested that the Azazme were highly dependent on consumption of livestock products. Livestock production was found to be inefficient.
6. Other than carbohydrates, essential nutritional requirements were not being met by the Bedouin diet and all, principally women and children, were at risk from malnutrition.
7. The pastoralists understood and empathized with the concerns of the Reserve. They, perhaps more than the conservationists, had a deep vested interest in the conservation of their environment.
8. The Bedouin themselves considered the Reserve area to be overstocked with goats, but could not afford to reduce their herd sizes.

Several solutions to these problems were suggested by the local community themselves, but pastoralists showed little confidence in the handicraft activities favored by the Reserve as a substitute for herding, believing that handicrafts could not guarantee livelihoods in the same way as livestock. Instead, many had inquired about the possibility of assistance with goat production. At first, these requests were rejected out-of-hand, as the Reserve refused to sanction anything that might further encourage livestock herding.

However, a review of data collected from Azazme herds and households emphasized a salient point. Azazme herd structures constituted an unusually high proportion of juvenile male goats (comparative data from Redding, 1981), which seemed linked to slow growth and the great difficulty the Azazme had in marketing animals. Consequently, a bottleneck was occurring in production, which was keeping animal numbers within the Reserve artificially high.

In June 1997, these Bedouin were managing an approximate total of 6,000 animals within the Reserve boundary. Of these, an estimated 1600 were juvenile male goats being prepared for sale (Rowe et al., 1997). Under traditional systems of management, these juveniles might require 12 months of grazing within the Reserve area (requiring labor and supplementary feed) before being ready for sale. They may therefore account for up to a quarter of all the grazing that occurs within the Reserve. Bedouin owners and the Reserve thus shared an interest in removing these animals into feedlots. There existed clear scope for a livestock project that would fulfill community expectations on terms acceptable to the Reserve, and a suitable framework for this was sought through shuttle negotiations between both groups.

Opposition to the idea of livestock-based livelihoods within the Reserve was finally broken by arguments that such resistance only served to bring the Reserve into direct and irresolvable conflict with the indigenous population. By assisting the local community with livestock, the Reserve would be in a much better position to influence management practices

generally, and perhaps work towards a more sustainable use of range resources in the interests of both groups. On the strength of these arguments (Table 1) it was agreed that a feasibility study should go ahead to investigate the technical possibilities for cooperation between pastoralists and the Reserve in livestock production.

calculated for optimal nutrition and growth, was considerably cheaper than the supplementary feeds available to pastoralists.

During winter 1998-99 the basic infrastructure of the Project was built. This included a supervisor's office, a feed store, and room for 250 kids with sheltered accommodation. The British grant had been made to build a facility for 500 animals, but construction was initially focused on ten pens holding 25 animals each.

Table 1. Potential benefits and dangers in the livestock fattening Dana Reserve Project.

<u>Potential Dangers</u>	expertise of the local community, not introducing new activities.
High livestock incomes might attract reinvestment into more animals	
High incomes might attract more households into Reserve area	- All target group households own livestock so all can benefit from Project equally.
<u>Potential Benefits</u>	- Provides incentive and basis for further cooperation with Reserve.
- Directly reduces animal numbers in Reserve.	- Compatible with resource scarce environment.
- Builds upon the existing skills and	- Compatible with household's nomadic lifestyle.

THE PROJECT

On the strength of highly encouraging results from the feasibility study (Rowe and Allonby, 1998), the British Embassy in Amman awarded the RSCN a small grant of about 10,000 JD to construct a fattening center and establish a community livestock project in the lower Dana area. Serum sampling of the local goat population had demonstrated that most were free from the production diseases (PPR and Blue Tongue) that undermined livestock productivity elsewhere in Jordan (Allonby, 1996). Discussions continued with the Azazme community for feedback from the fattening experiment and for ideas upon which to establish a project in cooperation with the Dana Nature Reserve.

The agreement between the Reserve and community was simple. The Reserve would record receipt of juvenile young kids from participants in the fattening scheme. From the date of induction, responsibility for management of these animals would be transferred fully to the Reserve until their sale. All expenses (feeds, veterinary, labor and marketing) would be met by the Project and, in return, income generated from the sale of every animal would be divided between Project and participant according to a mutually agreed formula. The scheme never took more than running costs, and offered a guaranteed sum returned to owners in the event of animal death before sale.

Throughout the fattening period animals were fed a mixed ration, including *berseem*, barley, wheatbran, soya, and dried by-products from olive and tomato processing. The recycling of factory waste was, in this way, encouraged, following in line with the conservation philosophy of the Reserve. Furthermore, this mix,

The facility stood on the main track through the center of the Reserve. In this central location, all the pastoralists of the area (including the owners) could monitor the progress and condition of the animals over time. Until the advent of the Project the pastoralists had been unaware of the full genetic growth potential of their animals and thus the goats in the Project soon became a major local talking point. A Project supervisor had earlier been recruited from the Azazme tribe, who inspired confidence locally and went on to become the driving force behind the community development of the Project. He was later joined by an assistant (nominated by the local stakeholders).

On the strength of the results of the first trial, there was much local interest in the development of the new Project. A series of community meetings were called by the Reserve manager and the relationship between the Reserve, the fattening project, and pastoralists was discussed further. In discussions, the Project was described as a tool for relieving grazing pressure on the Reserve while boosting local incomes. Several potential problems with the concept were voiced by the Bedouin. One of the main comments was that a formula should be found for extending the scheme to the rest of their herds, not just the juvenile males. The Bedouin argued that they would be happy to have their herds managed entirely in enclosures away from the Reserve. This was obviously not economically viable, and the reasons were given. However, constructive dialogue of this kind demonstrated to observers that the pastoralists were beginning to see their own interests (for the first time) converging with those of the Reserve.

Finally, in the last week of November a total of 81 animals were taken into the still incomplete Project enclosures. These goats came from no less than 11 separate pastoral households (approximately one-third of the 35 target group households within the Reserve). Most of these households had only sent a handful of animals to 'test' the benefits of the new Project for themselves, before committing themselves more fully.

On induction, all animals were ear-tagged, weighed, and vaccinated against PPR, Foot-and-Mouth disease, Clostridial disease, and Goat Pox by Project staff with the assistance of owners. Growth during the four-month fattening period (Fig. 2) was generally good (15 kg in Nov. 28, 1998 to 34 kg on March 18, 1999), the average improving after the first 2 weeks when six poor-performing animals were returned to their owners (as agreed with them earlier). However, in January the Project was struck by an outbreak of mange, introduced

Total income from the sale of goats was 4943 JD (average of approximately 63 JD per goat). The pastoralists were astonished when two animals from this second fattening group fetched just over 90 JD at sale. This was approximately double the highest sale price secured for any kid from the area prior to the inception of the Project the previous year. The total income was divided thus: Owners income 3741 JD, and Project income 1202 JD. Discounting the original value of each kid at induction, the Project generated a clear profit of 23 JD per goat to stakeholders. Furthermore, approximately half the Project share of income also went back to the Azazme community as staff wages. While the Project made an overall loss of 281 JD, this shortfall would normally be made up by economies of scale when the facility fattens over 150 animals simultaneously.

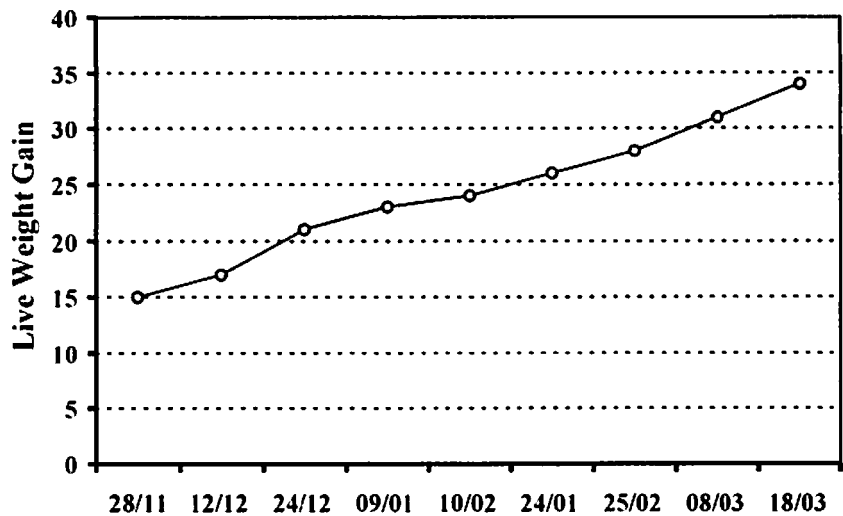


Fig. 2. Average live weight gain from Wadi Araba fattening project (Nov. 98 - Mar. 99).

from a source herd, which undermined growth until eradicated by intensive dipping, spraying, and use of endectocides. A total induction liveweight of 1153 kg (excluding returnees) had risen to 2467 kg at time of sale, giving an average weight gain of over 100%. Feed conversion occurred at 7:1; producing a profit of 1.35 JD for each kilogram of weight gain after feed costs.

On a parallel track to the fattening in Wadi Araba, the possibility of marketing Bedouin goats had earlier been explored elsewhere. It was found that by excluding the normal small traders and middlemen and selling directly to butchery companies, price increases of up to 20% could be obtained. Thus, the marketing support of the Reserve and RSCN alone, even without fattening, could bring major benefits to the pastoralists. In combination with fattening, returns were even greater. A trial to compare growth rates and income from non-fattened kids from a participating herd demonstrated that animals outside of the trial were sold by the owner at 37 JD per head. Those sold by the Reserve (after management costs had been recouped) brought the owner an average income of 48 JD.

Conservation through Partnership

By the conclusion of the first session of fattening at the new facility, the Wadi Feinan Livestock Fattening and Marketing Project had established itself as a highly profitable investment opportunity among the local community. When the next session of fattening began in May 1999, demand for places far outstripped available capacity at the facility. Yet, quite aside from its technical accomplishments, in a remarkably short period of time (approximately 2 years), the Project had fostered excellent working relations between the Reserve and members of the pastoral community of the lower Wadi Dana area. Formerly, these pastoralists had regarded RSCN interest in their livestock with nothing but suspicion, but as a result of the fattening scheme they now sit and openly discuss specifics of their own herds and view the Reserve as an important future partner in the development of their livelihoods. Perhaps this new spirit of trust is one of the most valuable outcomes of the Project. Through a growing dialogue between both groups and tacit acceptance of each other's positions

and objectives, an important step has been taken towards harmonizing the long-term interests of both groups in the Reserve area.

Direct conservation benefits (in terms of reduced grazing pressure) are tied to the confidence with which the Reserve management embrace and expand the new Project. At current capacity (250 animals), the reduction of the overall grazing population of the Reserve is negligible. However, available funds will expand the Project to accommodate 500 animals. Assuming two fattening sessions annually, a total of 1000 animals could be removed from the Reserve. However, it would be optimal from a rangeland conservation standpoint to remove the total male kid population from the Reserve simultaneously as soon as weaned. This would require accommodation for over 1000 goats. At this larger scale, it is calculated that the Project would sustain a staff of three, the running costs of a vehicle and produce an additional 1000 JD to cover contingencies (e.g., falling market prices, increasing feed costs, or widespread disease or death of animals).

It has been perceptively argued that increasing profits from the livestock enterprise may encourage Azazme pastoralists to increase herd sizes still further in the Wadi Araba. This is undeniably true. And it is on this point that the newly found spirit of trust and common interest between conservationist and pastoralists may be tested.

COMMUNITY DEVELOPMENT IN ARID LANDS

The experience from Wadi Araba suggests several guidelines for the development of community-based income generating projects.

1. The Project should recognize the wider context and needs of the community. It is insufficient to address the technical possibilities for development in isolation from these.
2. It is not enough to 'involve' the community. They have to feel involved and recognize from the outset how the Project may affect their lives.
3. If a project builds upon indigenous skills and experience (e.g., goat raising) rather than the transfer of exotic technologies, this empowers the community.
4. The project should be compatible with indigenous (mobile) lifestyles rather than forcing new (residence) systems on would-be beneficiaries.
5. Project benefits should be commonly and universally accessible. Incomes should not be restricted to the most progressive, talented, or influential members of the community.

It is also worth drawing attention to the following technical findings of the Wadi Araba Project, which

have significant implications for economic development in arid environments:

1. Wadi Araba livestock were found ideal for fattening because of their generally good disease status. It is possible that livestock in other remote desert locations may share similar advantages.
2. Low water requirements, at about 3 liters per head per day, were much less than irrigated agriculture and possibly a more sustainable use of arid land resources
3. Fattening costs were significantly reduced by appropriation of agricultural residues and by-products
4. Production of manure (estimated at about 10 tons from 250 goats over three months) has potential for fertilizing agricultural soils

These latter points suggest that fattening might be undertaken as a supplementary activity where irrigated agricultural projects are already in operation, generating both income for the indigenous populations and organic fertilizers for agricultural use, while benefiting from available residues.

CONCLUSIONS

This paper has described the early developmental stages of a community-based income-generating project in the Wadi Araba of Jordan. Clearly, it is too soon to judge the long-term viability of the Project or its applicability as a model for similar development elsewhere, but the technical and financial performance of the Project at this early stage has been very encouraging.

However, the real significance of the Dana Reserve Livestock Fattening and Marketing Project is that it is a livestock development project supported by a conservation non-governmental organization for the purpose of relieving grazing pressures in a nature reserve. As such, it probably represents a unique endeavor in the Middle East. For this reason, the extent to which the Project successfully mediates pastoralist and conservation interests in the longer term will be of interest to a wide range of governmental and non-governmental bodies faced with similar problems.

Furthermore, the Project in the Wadi Araba provides a rare (in the region) example of 'roots-up' development planning, where a Project was identified by a community itself rather than having the scheme imposed on it from above (indeed, the supporting agency initially opposed the idea). In this way, the Project targets a key aspect of local livelihoods, following the indigenous (as opposed to the external) development agenda. It is hoped that this route will bring real meaning to the term 'participation', a term which is commonly heard but less commonly effected among development projects in the arid Middle East.

REFERENCES

- Allonby, E. 1996. The effects of disease on the productivity of sheep and goats in Jordan. *Paper presented at the Workshop on Population and Livestock-Related Studies in the Eastern Badia of Jordan*. Higher Council for Science and Technology, JBRDP.
- Chatty, D. 1997. Pastoral tribes in the Middle East and wildlife conservation schemes: The endangered species? *Paper presented to the 96th Annual Meeting of the American Anthropological Association*. Washington, D.C.
- International Institute for Environment and Development (IIED). 1994. Who's Eden? An overview of community approaches to wildlife management. London. IIED.
- Lancaster, W., and F. Lancaster. 1993. Dana Reserve Project Socio-Economic Survey. British Institute for Archaeology and History, Amman.
- Redding, R. 1981. Decision-making in subsistence herding of sheep and goats in the Middle East. *Unpublished Ph.D. Dissertation*. University of Michigan.
- Rowe, A., R. Salti, S. Sirhan, and A. Audi. 1997. Pastoralists of the Lower Dana Reserve Area: Attitudes to, and prospects for, integration with the reserve management strategy. *Technical Report*, Amman.
- Rowe, A., and E. Allonby. 1998. Dana Reserve goat fattening and marketing trial: Financial report and Project evaluation. *Technical Report*, Amman.
- RSCN. 1996. Dana Nature Reserve Management Plan. Royal Society for the Conservation of Nature, Amman.
- RSCN. 1994. Dana Nature Reserve: Baseline Ecological Survey. Royal Society for the Conservation of Nature, Amman.
- Swenne, A. 1995. Dana Nature Reserve: rangeland and livestock management. Amman.

Natural Restoration Potential of Overgrazed Slopes in Dryland Northwestern Syria

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ABSTRACT

Plant diversity, ground cover and total biomass production are strong indicators of the degree of degradation of natural grazing lands. To gauge the potential for natural restoration of the land, it is necessary to investigate plant diversity and degree of ground cover under protected and unprotected conditions. This will help to assess the potential regenerative capacity of the land. If, on protected sites, plant cover and plant diversity can recover quickly, then the effects of degradation (e.g., low productivity) can be reversed easily.

Results are presented from *in situ* trials in a typical degraded dryland valley in the transitional zone between agriculture and rangeland with an average rainfall of about 200 mm. At six sites, protected (fenced) and grazed (open) plots were monitored. At the end of the dry season, plant cover on the grazed plots decreased to 5%, while on the protected plots it had stabilized at around 20%. For the same period, observations also revealed that the total above-ground biomass production on protected sites was four to ten times higher than on grazed sites. After one season, 71 plant species were identified in the monitoring areas; 81% of all the species were found on the protected plots, while only 39% of the species were found on the grazed plots. After two consecutive seasons, 104 plant species were identified; 84% were found on the protected plots and 36% were found on the grazed plots.

This high degree of diversity on the protected plots indicates that degraded grazing land in the area can be brought back to the potential productivity quickly. After a longer time, the protected plots will show the site-specific plant diversity under undisturbed conditions. This will then be the maximum possible protective plant cover which can re-establish itself in the area without costly rehabilitation measures. Protected plots may also serve as plant diversity pools for *in situ* conservation and seed multiplication.

INTRODUCTION

Grazing lands cover about 3.2 billion ha, i.e., approximately one quarter of the world's land area of 13.1 billion ha (Hadley, 1993). The last 2-3 centuries have seen large-scale transformation of natural grazing lands into arable land, and an even larger conversion of forests into grazing lands and pastures of various kinds. Only

about 500 million (M) ha (i.e., one sixth of the world's grazing lands) are in good or medium condition; five-sixths are rated as degrading (Ghassali, 1997).

In West Asia and North Africa (WANA), grazing lands are important sources of feed for livestock. According to FAO (1995), there are 169 M ha of permanent pasture (i.e., 18% of the land surface) in the combined areas of Afghanistan, Algeria, Cyprus, Iran, Iraq, Lebanon, Libya, Morocco, Pakistan, Syria, Tunisia, and Turkey. In Syria, about 45% of the land surface (i.e., 8.32 M ha) are natural grazing lands. These lands provide the feed basis for 14.2 M sheep and goats (Central Bureau of Statistics, 1997). They support the livelihood of a large part of the population.

Degradation of land and vegetation is widespread in the arid lands and is a main cause for the expansion of deserts. However, there are large geographic differences in the importance, intensity, and extent of desertification. There is a close link to the density of people and livestock populations (Le Houérou, 1993), but also to the standard and conditions of living of the land users and to the management practices that are applied to the land. The world's grazing lands will continue to be a major source of animal feed for the foreseeable future. Encroachment into the grazing lands by cereal cropping will continue, but for much of what is now natural pasture exploitation by grazing animals will remain the major means of obtaining an economic return (Riveros, 1993).

Because of their marginal nature, drylands are particularly sensitive to degradation processes. The general climatic conditions permit only limited plant growth. The natural vegetation has been adapted to these conditions and will usually survive periods of climatic stress, such as heat and drought. It provides protective cover against soil erosion by wind and water, and at the same time, these lands are feeding grounds for game and livestock. However, the main stress on the vegetation is exerted by inappropriate land-use (i.e., grazing) practices. *The resilience of dryland grazing grounds to degradation is low*, and long-term overuse may lead to irreversible losses of the productive potential of the land.

Ecological conditions determine the basic carrying-capacity of grazing lands. If the vegetative cover is reduced, wind and water-erosion processes remove topsoil and organic matter contained within it. Because the soil surface is not protected against raindrop impact, sealing will occur and crusts will form and reduce the

infiltration of water into the soil. This, on one hand, reduces the capacity of the soil to supply sufficient moisture to the plants and, on the other hand, contribute to increased overland flow, the development of rill and gully erosion, and increase of downstream flash-flooding. With high grazing pressure, the trampling of the animals will also contribute to the disturbance of the soil surface and lead to pulverization and compaction of the surface soil.

Periods of excessive stress - by climate and grazing - must be followed by rest periods for the plants to regenerate and reproduce. If the plant communities cannot regenerate, they will slowly decrease both in total biomass production and plant diversity. In the long run, if these processes continue, the productive potential of the land will decrease below recoverable limits and the feed basis will be destroyed (Le Houérou, 1993). To control degradation processes, it is important to assess the regenerative capacity of overgrazed rangelands. An assessment of the regenerative potential of the grazing land will also help to establish location-specific carrying-capacities for different management systems.

This paper describes the recovery process of degraded natural vegetation in the Khanasser Valley in northern Syria. The grazing areas in this Valley are visibly degraded and the natural vegetation has decreased both in plant diversity and degree of plant cover. Many plants only survive in small niches, inaccessible or difficult to reach for the animals. The vegetation cover and plant diversity on the grazed areas are strong indicators of the degree of land degradation of this natural grazing land. The aim of this study was to establish the location-specific potential for natural restoration of the degraded vegetation cover in the Khanasser Valley under undisturbed conditions and without any intervention, and the short-term effects that improved plant growth has on the soil conditions.

MATERIALS AND METHODS

The Study Area

The study was conducted in the Khanasser Valley, a typical dryland valley in the transitional zone between agriculture and rangeland, with seriously overgrazed and degraded slopes.

The Khanasser Valley is located approximately 70 km southeast of the city of Aleppo and south of the Jabul Salt Lake in northwestern Syria. The area can be classified as semi-arid and is located at the northwestern fringe of the Syrian Steppe (Soumi, 1991). The annual rainfall in the area is 200-250 mm, with high annual and inter-annual irregularity. It is a winter-rainfall area (Nov. - April/May) with a peak in January. Over most of the year, the potential evapotranspiration greatly exceeds the precipitation, and water is continuously available to the plants for only 3 months during the winter.

The Valley has an altitude of approximately 350 m above sea level, and is situated between the hill ranges of Jebel Al Hoss in the west and Jebel Shbith in the

east. The Valley is a gently undulating plain. The hill ranges of Jebel Al Hoss and Jebel Shbith form gently rolling plateaus, which end in well-defined steep scarps towards the Valley with v-shaped erosion channels. The slopes of the hill ranges are seriously degraded grazing lands.

The soils in the Valley floor are fine and moderately textured dark-brown to brown *Calcisols*, *Gypsisols*, *Leptisols*, and *Cambisols* (Louis Berger International, 1982; van de Steeg and Zöbisch, 1999). The soils of Jebel Al Hoss and Jebel Shbith plateaus are *Inceptisols*. In general, the soils are well drained and have a high infiltration capacity. The slopes and the plateaus are extremely stony. Soil depths range from less than 1 m at the foot of the slopes to 16 m in the center of the Valley.

There are three main types of agricultural production systems in the Valley, i.e., *rainfed farming*, *irrigated farming*, and *livestock rearing*. Most households practice a combination of crop production and livestock rearing. Rainfed farming, with barley as the dominant crop, occupies the major part of the arable land. The footslopes of the Valley and the eastern hill plateau are intensively grazed.

Vegetation Monitoring Plots

To study the regenerative capacity of the overgrazed areas in the Valley, six typical sites were selected on the western and eastern foot slopes. The characteristics of each site are summarized in Table 1. At each site, four monitoring plots were identified using the procedure proposed by Le Houérou (1993). One of these plots (10 × 10 m) was fenced with barbed wire to protect it from grazing. The other three plots (5 × 3 m) were left open and just marked with short iron pegs fixed in the ground for plot identification. These plots were freely accessible to the animals and were grazed by the flocks in the usual way. On all plots, plant-cover development, the presence of plant species, plant biomass, soil organic matter, and aggregate stability were measured.

Plant-Cover Measurements

On each plot, regular plant-cover measurements were carried out. Plant cover was measured monthly, except for the dry period between July and September. The plant cover was measured on the 5 × 3-m monitoring plots using the photographic technique described by Zöbisch (1986).

Plant Species and Biomass Measurements

On all six sites, vegetation surveys were carried out in April and May, i.e., during the peak development stage of the plants (1998 and 1999). The occurrence of annual and perennial plant species was measured and their grazing value (palatability) was determined according to Sankary (1978). Dry plant biomass was determined once (April 1999) for three selected sites (*Um-Mial north*, *Um-Mial south*, and *Khullat*).

For the same sites, total plant biomass was determined on 15 April 1999. For the below-ground biomass, the soil was sampled to 20-cm depth. For each plot at each site, five circular samples of 20-cm diameter were taken according to the method described by Le Houérou (1993). Total plant numbers were also calculated for the three representative sites.

RESULTS
Vegetation Cover

The trends in the development of the vegetation cover were clearly different between the grazed and the protected plots. Figure 1 depicts the overall cover development over the two growing seasons, 1997/1998 and

Table 1. Characteristics of the plant-cover monitoring sites.

Site	Village	Location		Altitude m.a.s.l	Average Slope	Physical Characteristics			
		Longitude	Latitude			Stone Cover	Aspect	Soil Depth	Water- Intake Index
						-----%-----	Degree	-cm-	-cm ha ⁻¹
1	Al-Qura'a	37° 30.880'	35° 49.135'	360	10	10-12	80 E	30	88
2	Mgherat	37° 30.855'	35° 48.061'	350	9 - 14	10-12	110 E	40	110
3 ¹	Um-Mial(S)	37° 35.348'	35° 45.073'	360	15	40	65 E	55 - 60	127
4 ¹	Um-Mial (N)	37° 35.334'	35° 45.554'	375	8 - 11	35	245 W	60	257
5	Serdah	37° 36.013'	35° 48.028'	390	7	50	240 SW	50	210
6*	Khullat	37° 36.067'	35° 48.797'	380	12	35	320 NW	40	184

¹Sites 3, 4, and 6 have been studied in more detail.

Soil Organic Matter and Aggregate Stability Measurements

After two seasons, soil organic matter and aggregate stability of the topsoil (0-20 cm) were measured to see the effect of plant-cover improvement on the soil structure parameters.

Soil organic matter was determined in the laboratory using the method of Walkley and Black (Ryan et al., 1996). Aggregate stability was measured using the wet-sieving method described by Kemper and Rosenau (1986). With this method, the water-stable aggregate sizes >0.5 mm and 0.5-0.2 mm were determined.

1998/1999. At the beginning of the measurements (March 1998), the overall average degree of cover on all plots was 12%. After fencing, the protected plots reached a maximum 25% of cover in May 1998. At this time, plant cover of the grazed plots had already decreased to about 7%. During the summer 1998, the protected plots remained with a cover of about 20%, while there was still a further reduction of plant cover on the grazed plots to about 5%. After the onset of the rains in October/November 1998, re-growth began immediately. However, the figure shows clearly that the recovering of the grazed plots to its initial degree of cover went much slower than on the protected plots.

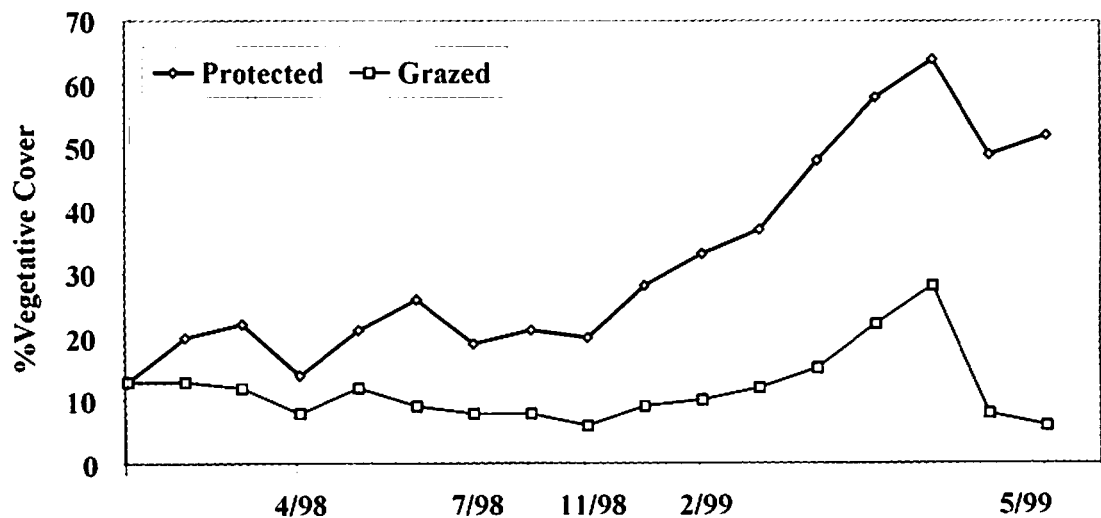


Fig. 1. Vegetative cover development for protected and grazed plots during two consecutive seasons.

Within a period of just two growing seasons, the cover on the protected plots had recovered beyond 50%, without any other conservation measure except fencing. From a soil conservation point of view, the degree of cover on the protected plots is more than adequate to protect the soil from erosion by wind and water.

Plant Diversity

The results clearly show the difference in the number of plant species between the grazed and the protected plots (Table 2). Already after the first rainy season (1997/1998), the protected plots overall had nearly three times the number of species (Species Index = 81%) than the grazed plots (Species Index = 29%). On some sites, the protected plots had five times the number of species than the grazed plots. During the second season (1998/1999), the protected plots showed a slight increase in the Species Index from 81 to 83%.

These figures clearly demonstrate the natural restoration potential of the land. For both years, annual species represent approximately two-thirds of the plant population and also depicts the occurrence of different species according to their grazing value or palatability (Table 3). The figures show clearly that only one-third of the plants have a medium and high grazing value. Most plants have a low palatability or are unpalatable. A few plants are poisonous. After 2 years, the highest increase in species is with the low-palatable plants (15 species). However, with seven new species in the second year, the high palatable plants are also increasing significantly.

Plant Density and Plant Biomass

Plant density on the three selected sites (i.e., *Um-Mial* north, *Um-Mial* south, and *Khullat*) showed very clear differences between the protected and the grazed plots (Table 4). On the protected plots, plant numbers were

Table 2. Number of plant species on protected and grazed plots over two seasons.

Site	Species Number		Species Index per plot			
	1997/98	1998/99	Protected		Grazed	
			1997/98	1998/99	1997/98	1998/99
Al- Qura'a	25	37	80	65	36	45
Mgherat	24	34	71	79	42	48
Um-Mial (South)	26	51	88	92	28	26
Um-Mial (North)	33	57	88	91	18	33
Serdah	43	52	84	83	22	30
Kullat	45	54	73	87	25	33
Overall averages	33	48	81	83	29	36
Total species (No)	73	104				

1Species Index = (number of plant species per plot / total number of plant species identified on the site) × 100.

Table 3. Overall species distribution by number according to grazing value or palatability over two seasons1.

Palatability	Species Number 1997/98				Species Number 1998/99				Species Increase
	Annual	Perennial	Total	%2	Annual	Perennial	Total	%2	
Poisonous	3	4	7	9	4	5	9	9	2
Unpalatable	4	9	13	18	5	13	18	17	5
Low	18	8	26	36	26	15	41	39	15
Medium	6	-	6	8	7	1	8	8	2
High	15	6	21	29	20	8	28	27	7
Total	46	27	73	100	62	42	104	100	31

1according to Sankary (1978). 2percentage of plant community.

However, also on the grazed plots, the Species Index increased significantly from 29 to 36%; no immediate explanation for this could be found. It may be that the vicinity of the protected plots, where more seeds were produced during the first season, had a positive influence on the grazed plots and that seeds were transferred by wind to the grazed plots. After 2 years, the average number of species identified at the sites rose from 33 to 48. The total number of species identified on all six sites rose from 73 to 104.

between 2-6 times higher than on the grazed plots. The overall relationship was the same for the total biomass. However, the ratios between above-ground and below-ground biomass were distinctly different. On the protected plots, the above-ground biomass was 1.5 to 3 times higher than the below-ground biomass. On the grazed plots, the above-ground biomass was roughly the same as the below-ground biomass, except for *Im-Mial* south, where the above-ground biomass was even lower (one third) than the below-ground biomass.

Although it was expected that, because of the grazing, the ratio between above-ground and below-ground biomass on the grazed plots would be smaller than on the protected plots, the extent of this was, however, striking.

vegetative cover, i.e., to protect the soil from erosion, to enhance soil quality through the build-up of soil organic matter, and to provide feed, can be easily re-activated. The overall land productivity of the grazing land will be increased.

Table 4. Plant data at the peak of the growing season (15 April 1999) for three selected sites.

Site	Number of Plants		Plant Biomass (g m ⁻²)					
	Protected	Grazed	Above-ground	Below-ground	Total	Above-ground	Below-ground	Total
<i>Um-Mial</i>								
(North)	5600	2600	277.2	113.0	390.2	77.8	68.6	146.4
(South)	12100	2040	388.5	251.6	640.1	29.2	78.3	107.5
Khullat	6200	2400	203.6	66.0	269.6	45.2	44.0	89.2

Soil Organic Matter and Aggregate Stability

After two seasons, the organic matter of the topsoil on the three selected sites showed a remarkable difference between the protected and the grazed plots. On the grazed plots, organic matter ranged between 2.2 and 2.3%. On the protected plots, the organic matter values were between 2.8 and 3.0%. The differences are probably related to the higher levels of biomass on the protected plots, which produced more litter and dead roots.

One of the most important environmental functions of vegetation is its protection of the soil against erosion by wind and water (Hudson, 1992). Research has shown that an average seasonal vegetation cover of 25% can reduce soil loss to 30% compared to bare soil, and that at 40% cover; soil loss will be reduced to 10% (Stocking, 1994). The degree of vegetation cover is therefore a good indicator for the erosion susceptibility of grazing lands. The study demonstrated that protective ground cover could easily establish within 2 years.

Table 5. Topsoil soil organic matter content and soil aggregates retained after wet sieving.

Site	Soil Organic Matter		Aggregates			
	Protected	Grazed	> 0.5 mm		0.5-0.2 mm	
			Protected	Grazed	Protected	Grazed
			-----%			
<i>Um-Mial</i> (North)	3.0	2.3	22	9	19	13
<i>Um-Mial</i> (South)	3.5	2.2	25	10	14	11
Khullat	2.8	2.4	14	10	12	11

Aggregate stability is closely related to the amount of organic matter in the soil. Increased root growth results in higher levels of root exudates and organic residues, which contribute to the aggregation of the soil. It was therefore expected that aggregate stability would be higher on the protected plots, which showed better overall plant development. Table 5 shows that the percentage of aggregates >0.5 mm was about two times higher on the protected plots than on the grazed plots. Conversely, the percentages of the smaller aggregates (i.e., 0.5-0.2 mm) were less significantly higher on the protected plots. Overall, the soils on the protected plots showed a significantly higher resistance to dispersal, and hence lower erodibility, than the soils on the grazed plots.

DISCUSSION

The study showed that, from a purely technical point of view, the vegetation and soil conditions on the over-grazed slopes in the Khanasser Valley could be restored within a very short time. The qualities of a good

A high degree of plant diversity on natural grazing lands shows that the environment can support vegetation with a wide scope of requirements. As a whole, a diverse plant community presents a high degree of resilience to stress and therefore can bridge periods of climatic extremes (e.g., droughts) and overuse. However, if these stresses, such as persistent overgrazing, continue for long periods, the more sensitive species of the plant community start disappearing and only the more hardy species survive. These are usually less palatable perennial plants.

The degree of plant diversity is therefore a good indicator for the *quality* and *resilience* of the vegetation to stresses. The study confirmed this, with the less palatable species dominating, but plants with a higher grazing value coming up in the second year. The high degree of diversity and high number of new plant species on the protected plots indicates that degraded grazing land in the area can be quickly brought back to the potential productivity. The fact that annual species

increased significantly shows that protected plots serve as field seed banks and are therefore important *in situ* plant-diversity conservation pools.

Soil organic matter content and soil aggregation are important indicators of soil fertility. They are also directly linked to the infiltration characteristics of soils and the resistance of the soil against erosion. A well-structured soil rich in organic matter provides optimum plant-growth and water-uptake conditions. It is expected that, with an improvement of vegetation cover, these soil parameters would also improve. Consequently, the improvement of vegetation also improves soil conditions.

The positive effect of aggregate and soil organic matter can be attributed to better growth of plant roots and thereby a greater contribution of root exudates and of organic residues to the soil, and also to a better organic matter status that is presumed to have arisen from the return to the soil of dead plant. The higher levels of water-stable aggregates on the protected plots indicate that the soil resistance to detachment and erosion is being built up concurrently with the improvement of the vegetative cover.

The link between population growth and grassland degradation is of major importance. Rates of population growth in developing countries with Mediterranean climates (such as in Syria) are among the highest in the world, and contrast sharply with developed countries with similar climates. Land ownership complicates grassland management in most of the West Asia - North Africa (WANA) region. The interaction between the growing population and the 'first-come-first-served' principle of access to grazing lands creates a vicious cycle whereby overgrazing leads to loss of vegetation cover and increased erosion, decreased seed production, and reduced regenerative capacity and pasture productivity.

Most development plans for the rangelands and the attempts to help pastoralists failed to accomplish real human development or sustainable use of pastoral resources. The pastoral production systems in WANA countries are still far behind and unable to cope with the new environmental changes, population growth, and new consumption patterns. According to AOAD (1994), the grazing resources of the region can provide only 60-65% of the feed requirements for the grazing animals. This implies that, overall, the grazing resources are over-stretched by about 35%, and in the long run, and this will lead to irreversible degradation.

The best soil stabilizers are plants. Vegetation cover stabilizes the soil against wind erosion by the holding action of plant roots and by the reduction of the wind velocity at the soil-atmosphere interface. Therefore, ground cover is an important determinant of soil erosion. Ground cover monitoring of the grazing areas over the course of the year will provide indices of erosion susceptibility for periods critical for erosion, such as the onset of the rains and the windy periods during the dry season, when plant growth has come to a stand still.

All the results obtained show essentially the positive environmental effects of improving vegetation cover. Biomass, above-ground and below-ground was greater in the fenced plots. There was also a clear positive restoration effect by the increasing number of species. Despite lower rainfall during the second year of the study (in 1997/1998 there were 212 mm; in 1998/1999 there were 134 mm), 31 more species occurred on the study sites.

The results, though only from two consecutive years, provide an important insight into the restoration potential of overgrazed land and the possibilities this opens for rehabilitation measures and improved land management. *We have here a timely warning that sustainable grazing land utilization depends on the maintenance of vegetative cover and its positive effects on soil quality.*

However, if the grazing pressure on the land remains, these natural restoration processes will not take place. Under the current system of high-density open grazing, the vegetation resources will continue to degrade, with its known consequences on soil quality and soil productivity. It is therefore necessary to develop alternative land-use and land-management practices that will safeguard the precious soil and vegetation resources while maintaining a maximum possible productivity. To achieve this, major changes in land use are needed.

An option would be to reduce the general grazing pressure through reduction of the animal numbers and a better regulated rotational grazing. However, these changes will not be feasible without considering the property and land-use rights and the effects of an increasing population that needs to make an acceptable living of the land. The problems of grazing-land degradation cannot be solved alone by direct measures on the grazing lands. Only combined efforts addressing the pressure on the resources in a larger policy, economical and ecological context, and with the involvement of all concerned partners, will lead to a sustainable management and conservation of the grazing-land resources.

REFERENCES

- AOAD. 1994. Environmental impact on range lands in the Arab World. Arab Organization for Agricultural Development. League of Arab States, Khartoum, Sudan.
- Central Bureau of Statistics, 1997. Statistical Abstract. Central Bureau of Statistics, Office of the Prime Minister, Damascus, Syria.
- FAO, 1995. FAO Production Yearbook. Vol. 49, Rome, Italy.
- Ghassali, F. 1997. Rehabilitation of degraded Mediterranean grasslands under on-farm conditions in northern Syria. M.Sc. Thesis. University of Western Australia, Perth, Australia.
- Hadley, M. 1993. Grasslands for sustainable ecosystems. p. 21-27. In: Proc. XVII International Grassland Congress, 8-21 February 1993,

- Palmerton, New Zealand. New Zealand Grassland Association, Auckland, New Zealand.
- Hudson, N. 1992. Soil Conservation. B.T. Batsford, London, UK.
- Kemper, W.D., and R.C. Rosenau, 1986. Aggregate stability and size distribution. In: A. Klute (Ed.). *Methods for Soil Analysis, Part 1*. Agron. 9: 425-442.
- Le Houérou, H.N. 1993. Grazing lands of the Mediterranean Basin. p. 171-196. In: R.T. Coupland (Ed.). *Natural Grasslands, Eastern Hemisphere. Ecosystems of the World*, Vol. 8B, Elsevier Scientific Publ., Amsterdam, The Netherlands.
- Louis Berger International. 1982. Land classification and soil survey of the Syrian Arab Republic. Vol. 2 (Reconnaissance Soil Survey of Syria, 1:500,000). Louis Berger International Inc., Remote Sensing Institute, South Dakota State University, and United States Agency for International Development, Washington, DC, USA
- Riveros, F. 1993. Grasslands of our world. p. 15-20. *Proceedings: XVII International Grassland Congress*, 8-21 February 1993, Palmerton, New Zealand. New Zealand Grassland Association, Auckland, New Zealand.
- Ryan, J., S. Garabet, K. Harmsen, and A. Rashid, 1996. A soil and plant analysis manual adapted for the West Asia and North Africa region. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.
- Sankary, M.Z. 1978. Ecology, flora, and range management of arid and very arid zones of Syria. Conservation and Development. Aleppo University Press, Aleppo, Syria
- Soumi, G., 1991. Supplemental irrigation systems of the Syrian Arab Republic. p. 497-511. In: Perrier E.R. and A.B. Salkini (Ed.). *Supplemental Irrigation in the Near East and North Africa. Proceedings: Workshop on Regional Consultation on Supplemental Irrigation*, International Center for Agricultural Research in the Dry Areas (ICARDA) and FAO, 7-9 December 1987, Rabat, Morocco. Kluwer Academic Publ., Dordrecht, The Netherlands.
- Stocking, M.A., 1994. Assessing vegetative cover and management effects. p. 211-232. In: R. Lal (Ed.). *Soil Erosion Research Methods*. Soil and Water Conservation Society, Ankeny, Iowa, USA.
- Van de Steeg, J.A., and M. Zöbisch. 1999. Effects of saline irrigation water on the biomass production of irrigated field crops and salt accumulation in the root zone. Progress Report on a Field Study in Khanasser Valley, Northern Syria. International Center for Agricultural Research in the Dry Areas, (ICARDA), Aleppo, Syria. Mimeo
- Zöbisch, M., 1986. Erfassung und Bewertung von Bodenerosionsprozessen auf Weideflächen im Machakos-Distrikt von Kenia. Supplement No. 27, *Der Tropenlandwirt-J. Agric. in the Tropics and Subtropics*.

Improvement of Rangelands in Al-Shegaya Area of Kuwait

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ABSTRACT

Kuwait rangelands, estimated to be 75%, compared to agriculture (2.7%), and oilfields (6.8%), are deteriorating due to overgrazing, uprooting of shrubby plants, off-road use by vehicles, increasing demand for recreation, and natural processes such as drought. Additionally, the Gulf War in 1991, a man-made destruction of the environment, added more constraints on the desert development. This emphasized rangeland improvement and rehabilitation in Kuwait. The objectives were to develop methods which are both effective and can be used on a broad scale.

To develop suitable methods, a rangeland rehabilitation experiment was started on a 6-ha site at Al-Shegaya, representing about 30% of Kuwait. The soil type is a typic Petrogypsid, with high gypsum content (30-50% below 30 cm), coarse fragments (approximately 15% or more), and a hardpan mainly at 30-60 cm. Multi-species seed mix of grasses; forbs and shrubs (23 species) were used for seeding. The seeds were sown in a pelleted condition (with clay, limestone and dust using lignin-based glue) to attract moisture and to avoid threat from insects and birds, and unpelleted, in ripped, pitted, and undisturbed soil treatments. Supplementary fertilizer (N, P) and irrigation was used at minimum rates.

Of the sown species, *Medicago* was readily found across all plots and was abundant in the ripped treatment, while undisturbed soil gave very low densities and chenopod species were present but sparse. Soil disturbance greatly reduced the emergence of native seedlings. There were far less germination of the native species in the ripped and pitted treatments of all the tagged seedlings; 4.3% survived until early May, 1999, which is the end of the rainy season in Kuwait.

INTRODUCTION

The State of Kuwait is situated in the northeastern corner of the Arabian Peninsula; it covers an area of approximately 17,818 km², extending between latitudes 28° 3' and 30° 05' N, and between longitudes 46° 33' and 48° 30' E. Similar to other parts of the Arabian Shield, Kuwait is characterized by a desert-type environment with scant rainfall, and a hot, dry climate. Summer is very hot, especially in July and August, with a mean temperature of 37.4°C and a maximum mean temperature of 45°C. The mean total precipitation is approximately 113 mm yr⁻¹; the rate of evaporation, which greatly exceeds precipitation, is approximately 16.6 mm day⁻¹. The winds usually blow from the

northwest and, to lesser extent, from the southeast.

Dust and dust storms, locally known as *toze* are common throughout the year, but are more frequent during the spring and summer months.

Rangelands, from the land-use point of view, are those areas which by reason of physical limitations are a source of free-ranging native and domestic animals, as well as a source of wood products, water, and wildlife (Stoddard et al., 1975). Rangelands are categories of land not under forest or cultivation, and especially those that sustain grazing or browsing animals on an extended basis. However, the World Bank (1995) defined rangelands in North Africa and Iran as lands which, in general, receive annual rainfall of less than 600 mm, whose fragile soil is unsuitable for agriculture but whose vegetation cover is used for extensive raising of ruminants. *Each of these definitions of rangelands emphasizes unsuitability for agriculture.* The Forage and Grazing Terminology Committee (1991) defined rangelands as lands on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs, and is managed as a natural ecosystem.

As per the above definitions, the majority of Kuwait's land can be categorized as rangeland (Annual Statistics, 1989). Recently (KISR, 1999), Kuwait rangelands are re-estimated to be 75%, compared to agriculture (2.7%), and oilfields (6.7%). The rangelands are deteriorating due to overgrazing, uprooting of shrubby plants, off-road use by vehicles, increasing demand for recreation, and natural processes such as drought. Additionally, the invasion of Kuwait in 1990 and the Gulf War in 1991 added further constraints to the desert flora and soils of Kuwait (Omar, 1999). This was fairly evident and well documented by the mass destruction and ignition of more than 700 oil wells, and the placement of more than one million mines in the rangelands (Al-Awadhi et al., 1996). The results of the above combined factors are the degradation of genetic resources and acceleration of the desertification process.

Range management research in the State of Kuwait was initiated by the Kuwait Institute for Scientific Research (KISR) in the late 1970s (Taha, 1978; Taha et al., 1983). Research was primarily focused on the assessment and evaluation of resources and manipulation of rangelands for forage and livestock production. These activities resulted in the designation of protected areas/reserves (Omar et al., 1986), as well as the establishment of databank information on vegetation and livestock (Omar, 1986; Omar et al., 1980; 1983), and enhancement of national manpower capabilities and

experience in range management research (Taha et al., 1983). International and regional linkages were also developed through the convening of three international conferences on range management and desert development at KISR in 1985, 1990, and 1996 (Halwagy et al., 1990; Omar et al., 1994). Recently, an overview on rangeland activities for desert development in Kuwait has been documented in Omar and Shahid (1999).

The purpose of this paper is to present results from a rangeland rehabilitation project, initiated to explore different methods of rangeland rehabilitation and to develop a method which is both effective (i.e., results in adequate vegetative cover and soil stability) and can be used on a broad scale (i.e., is inexpensive, simple and implementable given likely constraints of equipment and materials). This experiment aimed at examining elements of likely suitable rangeland rehabilitation methods, and was designed to provide insights into reasons for the relative success or failure of the various methods and species used. From this information, and from information gained from similar work done elsewhere, a "best-bet", broad-scale rangeland rehabilitation methodology will be developed.

Objectives

This experiment was designed to achieve the following outputs and outcomes:

- Demonstrate that revegetation is possible in the arid lands of Kuwait.
- Produce a vegetative cover of mixed species endemic to the Kuwait rangelands and foreign species of similar ecological ecosystems to compensate for the poor availability of native plant seeds.
- Understanding of the reasons for the relative successes of the various methods used.
- Synthesis of a "best-bet" methodology to rehabilitate similar areas of Kuwait's rangelands on a broad scale.

STUDY AREA AND CHARACTERISTICS

The study area is situated at Al-Shegaya, as an enclosure in the northwestern corner of Kuwait, 10 km from the Salmi borderpost with Saudi Arabia (29° 05' N, 46° 49' E., 279 m above sea level). The enclosure is proposed by the Public Authority for Agriculture and Fish Resources (PAAFR) as a demonstration farm. The enclosure is representative of the rangeland conditions for about 30% of Kuwait. The site is well protected by a 2.5 m diamond-mesh fence topped with coiled barbed wire. Previously the main gate of the enclosure was opened to enable stock to camp there overnight, and several feeding stations were evident from dung accumulation. The enclosure is also traversed by numerous old vehicle tracks which had compacted the soil beneath them. Nevertheless, there was a light cover of dried annual grass (estimated at 50 kg/ha) over most of the enclosure, a greater quantity than outside. Special precautions were taken to protect the site from grazing.

The gate was securely locked, and regular police patrols arranged from the nearby border post at Salmi.

Geologically, the site is part of an ancient delta. The site is flat, and very uniform at the surface. The soil is petrogypsic, high in gypsum (30 to 50% below 30-cm depth), calcium carbonate (10 to 15%) and coarse fragments, including stones of various species (approximately 15% throughout the profile), lightly cemented, with a hardpan at variable depths, mainly at 30 to 60 cm, with some locations > 90 cm. The soil is coherent, i.e., it will hold its shape when excavated, but upon disturbance, the soil turns quickly to powder. The surface had a light cover of dead annual grass (mainly *Stipa capensis*) with some scalded areas. The soil surface in the grassed areas was loose, but was hard and smooth in the scalds. Damage by grazing animals is not included as a possible cause because the site was fenced to exclude mammals and humans.

DESIGN AND METHODS

To overcome deficiencies in the seed bank, mixed-species seeds were spread (seeding) over the site by hand, or no actual seeding, just natural germination, took place. Some seeds were coated (seed pelleting) with clay using lignin-based glue in a mixer, to increase both the duration and amount of moisture available to the seed, and to minimize seed removal by seed predators. In contrast, some seeds sown were untreated. The soil surface was uniformly ripped with grader tynes to a depth of approximately 30 cm. The effect of this was to break up any surface crusting and thus cultivate the soil. In other instances, the soil surface was uniformly pitted (pitting) with pits 6-10 m long by 70-90 cm wide by 10-15 cm deep in rows approximately 1.5 m apart. The soil mounds were 10-15 cm high; thus, the depth from the top of the mounds to the bottom of the pits was 20 to 30 cm.

The pits in adjacent rows overlapped to minimize the risk of erosion. The pits ran perpendicular to the direction of the prevailing wind (i.e., on a bearing of 60° to maximize trapping of seeds and litter). The pits created micro-catchments to trap water, litter and loose sand, and the pitting treatment created several distinct germination niches: on the bottom of the pit, various locations up to the side of the pit, at the edge of the pit, on the loose mound, behind the mound, and on the relatively undisturbed soil surface between the pits. Furthermore, because of the direction of travel of the grader, the pits on the southeastern half of the plots (mounds of soil to the southeastern edge of the pit) were the mirror image of those on the northwestern half (mounds of soil to the northwestern edge of the pit), which provided further germination niche differentiation due the location of the sun and the direction of the prevailing wind. In still other instances, no soil surface treatment was undertaken, i.e., the soil was left undisturbed. Causes of and possible solutions to limitations are summarized in Table 1.

A light dressing of granular triple superphosphate (46% P₂O₅) at 20 kg/ha and urea (25 kg/ha) was broadcasted at seeding. The aim of the fertilizer treatment was to provide a small improvement in nutrition. The species selected came from low nutritional environments; in any case, it would be uneconomical to apply fertilizer at a high rate for broad-scale rehabilitation.

A wood-glue solution (Borresperse CA calcium lignosulfonate CAS No. 8061-52-7, from Borregarard Lignotech, Norway; 2.7% solution at 1,500 l/ha) was sprayed (soil-surface binder) onto the soil surface. There was local anecdotal evidence that this kind of treatment increases germination, even of the natural seed bank.

Experimental Layout

Two replicated 6-ha blocks were laid out. The treatments requiring pitting and ripping were contiguous for the practicalities of using the grader. Treatments that were not seeded were placed upwind of the seeded treatments to minimize the risk of contamination between plots by wind-blown seed. Thus, the replicated blocks were split into the soil treatments within which

the non-seeded treatments were placed upwind, treatments seeded with unpelleted seeds were placed downwind, and pelleting, soil sticker and fertilizer treatments were randomly allocated to the remaining area. The plot size was 50 by 26 m (1,300 m²), or 50 by 52 m before the split for repeating the treatments in Year 2. The treatment area in each block was thus 29,900 m², i.e., approximately 3 ha.

A multi-species seed mix of grasses, forbs and shrubs was used, both indigenous species and introduced species, with suitable attributes for this harsh environment, to maximize chances of success and to create a species-diverse and structurally diverse plant community. The criteria for selecting the species were as follows: native or similar attributes to Kuwait rangelands, seed availability, (not too expensive), and low palatability to resist overgrazing. The species used, and quantities of seeds sown, are shown in Table 2. A seed rate of 1 to 4 kg/ha/species was suggested by Humphreys (1980) and others for pure plantings (and thus less for mixed sowings) and seeding rate.

Table 1. Limitations to establishing vegetation.

<u>Cause</u>	<u>Possible Solutions</u>
- Insufficient seeds - Insufficient seedbank - Seeds blown away	- Seeding - Sticking seeds to soil surface - Roughening soil surface by pitting, ripping, or mulch- - Edging plots with an earth bund to retain seeds - Kill predators (e.g., scatter poisoned seed) - Pellet seeds to make them too big or unrecognizable- Bury seeds (e.g., by sowing)
- Seeds removed by predators (ants, beetles, birds) - Too dry - Inadequate < soil-seed contact	- Stick seeds to soil surface - Bury seeds - Create niches by soil disturbance - Pellet seeds with moisture-adsorbent compounds - Bury seeds or create niches - Use mulch (including surface sticker) - Irrigate
- Insufficient moisture	- Loosen soil by ripping, etc - Add fertilizer to promote root growth - Inoculate with mycorrhiza if lacking
- Seeds germinate, but cannot establish - Soil too hard for roots to penetrate	- Add fertilizer - Inoculate with mycorrhiza if lacking - Irrigate. - Use mulch - Protect and control as appropriate
- Seedlings establish, but grow poorly - Inadequate nutrition	
- Desiccation	
- Disease, predations	

Table 2. Species of seeds used in the seed mix, separation into various seed lots, and sowing rate.

Species #	Species	Dispersal Unit	Total	A ¹	B ²	C ³
1	<i>Acacia burkitti</i>	Seed	1.25	0.71	0.41	0.125
2	<i>A. hemiteles</i>	Seed	1.25	0.71	0.41	0.125
3	<i>A. victoriae</i>	Seed	1.25	0.71	0.41	0.125
4	<i>A. saligna</i>	Seed	1.25	0.71	0.41	0.125
5	<i>Atriplex amnicola</i>	Fruit	5.0	2.85	1.65	0.5
6	<i>A. nummularia</i>	Fruit	5.0	2.85	1.65	0.5
7	<i>A. semibaccata</i>	Fruit	5.0	2.85	1.65	0.5
8	<i>A. semilunaris</i>	Fruit	5.0	2.85	1.65	0.5
9	<i>A. codonocarpa</i>	Fruit	5.0	2.85	1.65	0.5
10	<i>A. vesicaria</i>	Fruit	5.0	2.85	1.65	0.5
11	<i>Maireana pyramidata</i>	Fruit	5.0	2.85	1.65	0.5
12	<i>M. triptera</i>	Fruit	5.0	2.85	1.65	0.5
13	<i>Eragrostis dielsii</i>	Seed	5.0	2.85	1.65	0.5
14	<i>Sclerolaena densifolia</i>	Fruit	5.0	2.85	1.65	0.5
15	<i>Senna artemisioides ssp. filifolia</i>	Seed	1.5	1.425	0.825	0.25
16	<i>Rhodanthe sterilescens</i>	Fruit	5.0	2.85	1.65	0.5
17	<i>Cenchrus ciliaris</i>	Awed seed	5.0	2.85	1.65	0.5
18	<i>C. setigerus</i>	Awed seed	5.0	2.85	1.65	0.5
19	<i>Medicago littoralis</i> (Harbinger)	Seed	5.0	2.85	1.65	0.5
20	<i>M. truncatula</i> (Parabinga)	Seed	5.0	2.85	1.65	0.5
21	<i>Rhanterium eppasum</i>	Fruit	5.0	2.85	1.65	0.5
22	<i>Haloxylon salicornicum</i>	Fruit	1.2	0.68	0.40	0.12
23	<i>Stipa capensis</i>	Awed seed	0.05	0.0285	0.0165	0.005
	Total			50.58	29.29	

¹Pelleted seeds comprise 57% of the seeds by weight.
²Seeds to remain unpelleted; 33% by weight. Ratio of pelleted: unpelleted seeds are 63: 37, corresponding to the plot areas of those treatments.
³Remainder kept as reference collection (approximately 10% by weight).

The pelleted seeds and unpelleted seeds were apportioned equally into the number of plots receiving those treatments, and placed into bags, with 1 bag of mixed seeds per plot. The seed in these bags was then thoroughly mixed. Records were kept of the weights of seed applied per plot, and, using information from the germination tests, the density of viable and germinable seeds sown per plot will be calculated.

Seed Pelleting

The aim was to produce pellets of seeds coated with clay, with the pellets being 3-4 times the size of the seeds. The size of the pellets varied with the types of seeds, e.g., *Medicago littoralis* (3.8 mm), *Cenchrus ciliaris* (10.4 mm), and *Rhanterium eppasum* (9.3 mm). Seeds were placed in a portable cement mixer in single-species lots, or as mixed lots when quantities allowed. It took at least 30 minutes to pellet one lot of seeds, thus pelleting mixed lots saved time. Lots which were amalgamated for pelleting consisted of similar kinds of seeds. Not all seeds formed pellets. For some (especially the winged, papery *Maireana* seeds), it was only possible to coat the fruits with clay and limestone dust.

Applying Treatments

The treatments were applied on 15 December 1998. There was a light-to-moderate wind all day from an easterly direction. Seed and fertilizer was spread by hand uniformly over the surface of each plot, from the pre-prepared bags of ingredients for each plot. Treatment 20 was sown immediately prior to spraying the soil binder. The soil binder was sprayed, using a pressure hose and spray nozzle. It took about 2.5 h to spray the four plots.

Environmental Conditions

The first winter was drier than usual, judging from the rainfall data from Kuwait International Airport. Light showers were received in January, and heavier rain in the first week in March 1999, sufficient to moisten the soil profile to at least 30 cm. By 7 March there was a light covering of annuals across the site.
 Twenty-four hours after each rain, soil samples were collected from only one treatment from each of the ripped, pitted, and undisturbed plots. The samples were collected from the wetting zone at 0-5, 5-10 and 15-20 cm depths. The soil samples were oven-dried at 105°C to calculate the moisture content. This moisture information were added to the supplementary irrigation data.

Supplementary Irrigation

To help ensure reasonable germination and establishment conditions at the site, supplementary irrigation was undertaken using water tankers, with the water applied uniformly across all plots by hand-held hoses with spray nozzles. The irrigation was done fortnightly, and the final supplementary irrigation was delivered on 15 May 1999, as this date marks the end of the rainy season in Kuwait. By this date, a total of approximately 15 mm of supplementary water would have been delivered to the experimental plots. Furthermore, the irrigation used was tertiary-treated sewage water.

Germination Tests

It is necessary to know the viability and germinability of the seeds, as a baseline for comparing field emergence (i.e., to calculate the number of germinable and viable seeds applied to each plot). It is also necessary to know the number of viable and germinable seeds per unit weight of sown fruits-seeds to calculate what has been applied to the plots.

The germination tests were also carried out by sowing 200 seeds in trays of potting mix and irrigating them in the greenhouse. These seedlings were used for identification in the experimental site, and to form the reference herbarium.

Seeds, Seedling Identification and Treatment

In order to identify the seedlings of species which occur naturally at the site, but which have not been included in the sown seed mix, bulk samples of the surface (2 cm) soil were collected by excavating about 50 sites around the perimeter of the blocks. The soil was spread on to shallow trays and irrigated in the greenhouse. As the seedlings emerged, they were identified, and the data were recorded for comparison. Herbarium sheets, one per species, were mounted in a form suitable for field reference (e.g., in plastic sleeves in a spring-bound folder). The species name, and the key features were annotated for field identification.

It is possible that seeds will germinate at Al-Shegaya, but that the seedlings will not survive the harsh summer to become established plants. An ancillary experiment on each of the sown species (at least the introduced ones) has been established and hardened off in pots, and will be planted into the field as established plants.

The densities of all seedlings, native and sown, were surveyed on 9 March 1999, 15 and 25 March and 7 April 1999. Five quadrates per plot (1.0×0.1 m) were thrown in a restricted random manner to give even cover in each plot; and the number of seedlings of each species were counted. Each species type was allocated a code, and voucher herbarium specimens were taken for subsequent identification. *Stipa capensis* has been the most dominant grass species with an average height of 14 cm on the last day of the survey (7 April 1999).

Seedling survival studies focused on the sown perennial species (mainly chenopods); annuals do not (by definition) survive the summer. Because the densities of chenopod seedlings were low, the sown plots were searched for seedlings, and either all seedlings, or a subset of about 30, were tagged (marked with a large nail about 2 cm south of the seedling, the coordinates measured (in meters) from the plot edges, and their size recorded (as leaf stage: cotyledon, two-leaf emerging, two-leaf, four-leaf, etc.). At each visit, the survival of these tagged plants was recorded as well as height and width.

RESULTS

By March 1999, it was clearly visible that of the sown species the *Medicago* was readily found across all plots, and *chenopod* species were present but sparse. None of the other introduced species could be detected in the field at that time. There were far fewer germinations of the native species in the ripped and pitted treatments. Chenopod species were found only where the soil had been disturbed, i.e., 0.5 plants/m² for the non-fertilized, and 1.5 plants/m² for the fertilized-pelleted-pitted treatment. For the ripped treatment, the density was the same (0.5 plant/m²) for the fertilizer and non-fertilized plots, suggesting that some seed burial is needed for these winged seeds, but densities were too low to infer any other treatment effects.

Medicago spp. were much more abundant where the soil had been ripped, and not disturbing the soil gave very low densities. The pitted, ripped, and undistributed treatments gave densities of 1.3, 4.0, and 0.15, respectively. It is possible that the value for undisturbed conditions is inflated by confusion with native legumes which appear similar to the sown *Medicago* spp. Soil disturbance greatly reduced the emergence of the native seedlings. This is not unexpected. The native seed bank occurs in the very surface of the soil. Ripping, which had the greatest depressing impact, would have buried many seeds, and the ripping treatment affected the whole plot. Pitting, on the other hand, left more than half of the plot undisturbed (i.e., the area between the pits).

It is clear that the location of old vehicle tracks appears to greatly influence plant density, decreasing it in denuded, compacted areas, and greatly increasing it in adjacent depressions. By this effect, the location of old tracks could be seen even in the ripped treatment. The locations of old tracks were mapped. The application of soil sticker had no discernable effect on the density of germinations, either for all species in total (sown + natural) or for the sown perennials (none emerged in treatments with undisturbed soil surface, including the sticker treatments).

Fertilizer application had no effect on germination. For the different treatments, plant densities varied with pelleted fertilizer or no fertilizer, i.e., pitted (131.0 vs. 119.5), ripped (64 vs. 48.5), undisturbed (215.5 vs. 248.5). However, this was not the reason fertilizer was

applied, but to promote the growth of perennial seedlings. Too few seedlings survived (presumably because of lack of moisture) for the fertilizer to have an effect.

Very few seedlings survived until the 10 May (overall, 4.3% of the seedlings tagged), and even fewer were alive on 16 May. In the undisturbed soil surface treatment, no seedlings were found. There may well be other seedlings alive in the plots which were not tagged as part of this study. The poor establishment and survival of sown perennials in Year 1 is probably due to the poor season experienced at Al-Shegaya. Even though the total rainfall for Kuwait Airport was close to the median (97.6 mm vs. 101.9 mm), no rain fell until January and the rainfall at Al-Shegaya in March was likely much less than that at the Airport. This provided a short growing season, and insufficient time for good establishment. By May, there was only a sparse cover of native species (mainly *Stipa*) in the ungrazed enclosure.

CONCLUSIONS

Revegetation of areas under arid regions, such as the case of Kuwait, is difficult due to both the water shortage and poor quality of soils. A preliminary revegetation experiment was conducted in Al-Shegaya to demonstrate the possibility of revegetating arid areas and to produce a vegetative cover. Seeding and soil mechanical treatment was conducted in the area. Due to poor climatic conditions during the experimental period, the results were not satisfactory. A second year try will be conducted taking into consideration factors that influenced seed germination and seedling survivor.

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REFERENCES

- Annual Statistics, 1989. Public Authority for Agricultural Affairs and Fisheries Resources, Kuwait.
- Assessment and monitoring of desert ecosystems, pp. 1-356. *Proceedings: International Conference on Desert Development in the Arab Gulf Countries. Development in the Arab Gulf Countries, Vol. 1: p. 69-82. Scientific Research Report No. KISR 1327 B, Kuwait.*
- Halwagy, R., F.K. Taha, and S.A. Omar. 1990. *Advances in range management in arid lands.* Kegan Paul International, London.
- Humphreys, L.R. 1980. *A guide to Better Pastures for the Tropics and Sub-Tropics.* Adelaide, Australia.
- KISR. 1999. Soil survey and associated activities for the State of Kuwait. *Final Report*, 5 volumes. No. KISR 729, 928A, Kuwait.
- Omar, S.A.S., F.K. Taha, A.A. Nassef, and K. Al-Fili. 1983. Animal count in Kuwait's rangelands, Phase II.
- Omar, S.A.S., R. Misak, and N. Al-Awadhi. 1998. *Sustainable development in Arid Zones. Vol. 2. Management and improvement of desert rangelands, p. 359-737. Proceedings: International Conference on Desert Development in the Arab Gulf Countries.*
- Omar, S.A.S. 1986. Desert plants of Kuwait. Environmental Protection Council, Al-Qabas Prints, Kuwait (in Arabic).
- Omar, S.A.S. 1999. Impact of war on the rangelands of Kuwait. *Proceedings: International Congress on Range Management.* Townsville, Australia.
- Omar, S.A.S., and S.A. Shahid. 1999. Land degradation indicators in the arid environment of Kuwait. An oral presentation at the Second International Conference on Land Degradation, Khon Kaen, Thailand, 25-29 January 1999, *Extended Abstract*, p. 109-110.
- Omar, S.A.S., F. Al-Sdirawi, V. Agrawal, L. Hamdan, D. Al-Bakri, and F. Al-Shuaibi. 1986. Criteria for development and management of Kuwait's first National Park/Nature Reserve, Vol.1. Inventory and zoning, Kuwait Institute for Scientific Research, *Report No. KISR 2164*, Kuwait.
- Omar, S.A.S., F.K. Taha, A. Nassef, and K. Al-Fili. 1980. Livestock census of grazing animals in Kuwait's rangelands, Kuwait Institute for Scientific Research, *Report No. KISR156*, Kuwait.
- Omar, S.A.S., M. Razzaque, and F. Al Sdirawi. 1994. *Range management in arid zones.* Kegan Paul International, UK.
- Paul International, London, p. 221. rev. 4th ed. Australia: Wright Stephenson Company Ltd. *Production and de-desertification in Kuwait*, Kuwait Institute for Scientific Research, *Report No. KISR/PPI 025 FRA-R-P-7803*, Kuwait.
- Rangelands for Sustainable Yield. Kuwait Institute for Scientific Research, *Report No. 5408*, Kuwait.
- Stoddart, L.A., A. Smith, and T.W. Box. 1975. *Range management.* McGraw-Hill Book Company, London.
- Taha, F.K., M.A. Razzaque, and S.A.S. Omar. 1983. *Range management project. Phase II.* Kuwait Institute for Scientific Research.
- World Bank. 1998. *Rangelands development in arid and semiarid areas: Strategies and policies.* Natural Resources and Environment Division. World Bank, Washington, DC.

Desert Forages for Sustainable Rangeland Production in the Arabian Peninsula

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ABSTRACT

The native plant biodiversity of the Arabian Peninsula, which comprises over 3500 species, is being rapidly depleted. The primary cause is overgrazing, particularly by the large population of small ruminants (24 million, and growing steadily). Increasing amounts of supplementary feed in the form of alfalfa and Rhodesgrass is being produced to accommodate the shortfall from the rangeland. These species, introduced to the region, consume huge volumes of water, mainly applied through irrigation from groundwater. Groundwater reserves have fallen dramatically as salinity levels have risen. The combined effects have meant that the potential productivity of the land has fallen and, in some cases, it has had to be abandoned.

Some of the National Agricultural Research Systems of the Arabian Peninsula, working with the International Center for Agricultural Research in the Dry Areas (ICARDA), have taken steps to address the resulting degradation. This paper describes step-by-step a holistic approach that was begun in 1997 to address the problems. It started with the collection of indigenous knowledge and interviews with local Bedouin farmers in the United Arab Emirates; continued through a series of training programs for human resource development, germplasm collection missions in the UAE, the Sultanate of Oman, and the Republic of Yemen; the development of herbaria, databases and one large genebank in the Republic of Yemen, as well as a working collection in the UAE. Seed has been multiplied and evaluations for water-use efficiency and nutritive value are underway. Initial data shows that not only do the desert forages use less water than the introduced forages, but also their nutritive value is as good. Small enclosures have also been selected, in some of the countries, as sites for research on restoration and rehabilitation techniques. This research will not only benefit the Arabian Peninsula countries, but also all countries that are likely to face the increasing impacts of global warming, salinity and drought in the 21st century.

BACKGROUND

Climate

The Arabian Peninsula experiences extreme climatic conditions characterized by low, erratic rainfall, high evaporation rates, and amongst the highest temperatures on earth (Ghazanfar and Fisher, 1998). Added to this are high levels of soil and water salinity which concentrates rapidly under irrigation. Crop production in most areas is impossible without intensive irrigation, a practice which has proved unsustainable in many areas. The main form of agriculture is thus animal production in the form of open-access grazing of animals on communal rangelands. Closely linked to this is fodder production.

The climate, vegetation, and agricultural practices vary widely across the region, which comprises seven countries, viz. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates (UAE), and Yemen. Within these countries, there are very diverse ecosystems e.g., in the Sultanate of Oman, the north is dominated by the Oman Mountains and the Batina coastal plain, while in the south, the Dhofar Mountains receive light summer southwest monsoon rains from June to September and heavy showers from April to May and from October to November. This is in marked contrast to the rest of the country. Linking these two regions is the central desert, more commonly known as the Empty Quarter which extends into the northeast, where it is known as Wahibah Sands.

The Problem

Despite this diversity, the problem across ecosystems and countries is common. The native plant biodiversity of the Arabian Peninsula, which comprises over 3500 species (Ghazanfar and Fisher, 1998), is being rapidly depleted. Over 90% of the total land area now suffers from some form of desertification, and 44% is severely or very severely degraded. The primary cause is overgrazing. Since the late 60's, the region has experienced a sharp increase in numbers of animals, mainly because of improved veterinary services and the increased income that allows herdsmen to buy processed feed and baled hay. Herders have also become very reluctant to

sell surplus unproductive animals. In 1998, it was estimated that there were 24 million head of small ruminants, comprised mainly of sheep, goats, and camels.

Overgrazing not only lowers the productivity of these ecosystems, but it also results in a change in plant species composition. Palatable species are quickly taken out, leaving an ecosystem dominated by unpalatable species. In the Sultanate of Oman, Zaroug (1983) noted that in the Tawi Atair area, Dhofar, 50% of the area in 1982 was covered by an unpalatable, tall legume species locally known as 'mahlah'. He also noted the dominance of short grasses less capable of making use of moisture from monsoon mists. The palatable species in the Arabian Peninsula are disappearing fast. Overgrazing is seriously threatening the genetic resources and diversity of these important palatable forage species; species which in the past were, and could again be, the basis for a sustainable system of animal production. These species, which are well adapted to the extremes of environmental stress, also have considerable global importance in providing sources of tolerance to heat, salinity and drought, major problems that we are likely to face in the 21st century.

A viable, sustainable livestock industry requires not only a sustainable grazing regime, but also a sustainable system for the production of cheap fodder. Currently, in the Arabian Peninsula, the main fodder crops are alfalfa (*Medicago sativa*) and Rhodesgrass (*Chloris gayana*). These species do not occur naturally and are not adapted to the prevailing conditions of drought and salinity. They require vast quantities of water (up to 48,000 m³/ha/yr) usually derived from a groundwater source which, apart from being unsustainable, has resulted in many areas having to be abandoned due to problems of salinity. Indigenous grasses occurring in the natural vegetation, e.g., *Cenchrus ciliaris*, are, however, adapted to the local climatic conditions and have been shown to respond dramatically to very small amounts of irrigation. There is an urgent need to collect and conserve indigenous grasses and evaluate their potential as fodder crops under systems using minimal irrigation and water of relatively high salt content (Ferguson et al., 1998a). *Cenchrus ciliaris* is currently being successfully used as a fodder in parts of Australia and India and is collected from the wild throughout the Arabian Peninsula.

In addition to fodder production, there is a clear need to enhance the productivity of rangelands, either by restoration (planting or re-seeding with indigenous shrubs and trees) or by rehabilitation (planting or re-seeding with both exotic and indigenous shrubs and trees). This is not an easy or short-term task. Seed or cuttings of different palatable species must be collected, conserved and then evaluated in a range of different ecosystems, for establishment, ability to ultimately survive with no supplementary irrigation, and productivity.

A SOLUTION...AN APPROACH

The National Agricultural Research Systems (NARS) of the Arabian Peninsula, in collaboration with the Arabian Peninsula Regional Program (APRP) of the International Center for Agricultural Research in the Dry Areas (ICARDA), have taken steps to address the resulting degradation.

Farmer Participation

An essential first step in our approach was to find out what the local farmers perceived as being the most important forages. In May 1997, in the UAE, the Central Region of the Ministry of Agriculture and Fisheries and APRP convened a meeting at the Al-Dhaid Research Station, Sharjah, where local farmers brought samples of rangeland species preferred by their livestock. Two farmers explained the forage value and stress-resistance of the various species; then, with botanists from the Sharjah Natural History Museum and Desert Park and the Environmental Research and Wildlife Development Agency (ERWDA), Abu Dhabi, as well as published floras of the Arabian Peninsula (Chaudhary, 1989; Heemstra et al., 1990; Mandaville, 1990; Western, 1989), scientific names were put to 74 of the 85 species collected. The farmers were then asked to rank the plants in order of preference to the animals. With additional help from various range experts and botanists in the region, as well as personal observations, a first list of priority species was developed.

Training

Plant genetic resources work is in its infancy in the Arabian Peninsula. National scientists required training in germplasm collection as well as in how to store the germplasm in genebanks. Therefore ICARDA's Genetic Resources Unit (GRU) and the Arabian Peninsula Regional Program (APRP) organized, jointly with the International Plant Genetic Resources Institute (IPGRI), two training courses on 'Germplasm Collection and Maintenance' and 'Seed Production Techniques and Technology', both with an emphasis on forage and rangeland species.

In brief, the first course, on 'Germplasm Collection and Maintenance', was held at the Natural History Museum and Desert Park in Sharjah. A total of 23 lectures were given, in Arabic and English, covering a wide range of topics from species identification, planning a collection mission, to complementary conservation strategies and seed multiplication. Also included were under-utilized and neglected species, general genetic resource conservation, and germplasm health. Participants also visited sites and contrasting ecosystems for practical experience in germplasm collecting. The course which was attended by 14 participants from the various countries of the Peninsula. The other course on Seed Production held in the Sultanate of Oman followed a similar structure. These courses laid the

foundation for collaboration between APRP and the national programs in collecting potentially useful rangeland species.

In addition to these formal courses, a major objective of the subsequent collection missions was the "hands-on" training of counterparts from the respective Ministries in germplasm identification and collection techniques.

Collection

During 1998 and 1999, germplasm collection missions were carried out in the UAE and the Sultanate of Oman for the major indigenous forage grasses, legumes, shrubs and trees of the region, with the ultimate objective of utilizing the most promising germplasm for degraded rangeland rehabilitation and for irrigated fodder production, under systems requiring substantially less water than those currently used (alfalfa and Rhodesgrass) (Ferguson, 1998 b, c). Subsequent missions were also carried out in 1999 in the Republic of Yemen.

As indicated above, a major objective of the collection missions was the training of counterparts from the Ministry of Agriculture and Fisheries, UAE, and the Directorate of Agricultural Research, Oman, in germplasm collection techniques. In total, two scientists from the UAE and six scientists from the Sultanate of Oman were trained.

The mission in UAE, in early March 1998, targeted the higher rainfall zones which occur north of the Abu Dhabi to Al-Ain main road. Prior to the mission, target taxa had been prioritized according to discussions with farmers, local botanists, and an international consultant on rangeland development. In total 114 accessions were collected, representing 22 taxa from 27 sites (Table 1).

In the second mission, in Sultanate of Oman, in late March and early April 1998, the mission targeted the

accessions were collected in April 1998, representing 27 taxa from 18 sites (Table 2). All the seed was sent to the Genetic Resources Unit at ICARDA headquarters in Syria for in-trust 'blackbox' storage until suitable storage facilities are available within the Arabian Peninsula. (It should be noted that in Oman in the 1980's, again at the request of The Ministry of Agriculture and Fisheries, IPGRI conducted a collection mission for all local crops, but due to the lack of adequate storage facilities, all the germplasm was lost. This serious problem has yet to be remedied).

Database Preparation

During both expeditions, herbarium specimens were taken in order to identify unknown species, which may be of interest as browse species, and to define the distributional range of target species for which seed was unavailable. At each site, soil samples were taken to help define the ecological preferences of each species. All samples have been analyzed. In addition, indigenous technical knowledge was collected from farmers who were also asked to prioritize species for rangeland rehabilitation and fodder crops.

A database was compiled of all collection passport data and a photographic Flora produced to assist in rangeland species identification (Ferguson, 1998 a). In addition a database of 152 rangeland plants, which were brought to our attention by farmers, herders and scientists, has been developed. This includes information concerning biological characteristics, indigenous knowledge and potential use in forage production, rangeland enhancement and /or rangeland rehabilitation. This database has been used to produce a 'target species' list. The database includes 27 species of high priority (Table 3), 39 of medium priority, 60 of low priority, and 26 of unknown potential (but likely to be low).

Table 1. Rangeland species accessions collected in United Arab Emirates.

<u>Accessions</u> <u>No.</u>	<u>Genus</u>	<u>Species</u>	<u>Accessions</u> <u>No.</u>	<u>Genus</u>	<u>Species</u>
1	<i>Calligonum</i>	<i>crinitum</i> (ssp arabicum)	1	<i>Leptadenia</i>	<i>pyrotechnica</i>
1	<i>Cassia</i>	<i>italica</i>	18	<i>Panicum</i>	<i>turgidum</i>
11	<i>Cenchrus</i>	<i>ciliaris</i>	19	<i>Pennisetum</i>	<i>divisum</i>
5	<i>Coelachyrum</i>	<i>piercei</i>	1	<i>Rhanterium</i>	<i>eppaposum</i>
5	<i>Dichanthium</i>	<i>foveolatum</i>	1	<i>Savignya</i>	<i>parviflora</i>
8	<i>Dipterigium</i>	<i>glaucum</i>	2	<i>Sphaerocoma</i>	<i>aucheri</i>
1	<i>Farsetia</i>	<i>aegyptiaca</i>	2	<i>Sporobolus</i>	<i>ioclades</i>
2	<i>Heliotropium</i>	<i>kotschy</i>	5	<i>Sporobolus</i>	<i>spicatus</i>
1	<i>Indigofera</i>	<i>articulata</i>	15	<i>Stipagrostis</i>	<i>plumosa</i>
2	<i>Indigofera</i>	<i>sp.</i>	2	<i>Stipagrostis</i>	<i>sp.</i>
9	<i>Lasiurus</i>	<i>scindicus</i>	2	<i>Unidentified</i>	
			114	TOTAL	

northern regions, including the northern and eastern coastal plains, Wahiba Sands, the northern and eastern interior plains, and the Hajar Mountains. In total, 68

Table 2. Accessions of each species collected in Sultanate Oman (April, 1998).

Accessions No.	Genus	Species	Accessions No.	Genus	Species
2	<i>Asphodelus</i>	<i>tenuifolius</i>	8	<i>Lasiurus</i>	<i>scindicus</i>
1	<i>Calligonum</i>	<i>comosum</i>	1	<i>Lotus</i>	<i>garcinii</i>
1	<i>Calligonum</i>	<i>crinitum</i> (ssp <i>arabicum</i>)	1	<i>Ochradenus</i>	<i>arabicus</i>
7	<i>Cenchrus</i>	<i>ciliaris</i>	4	<i>Ochradenus</i>	<i>aucheri</i>
1	<i>Cenchrus</i>	<i>setigerus</i>	1	<i>Ochtochloa</i>	<i>compressa</i>
5	<i>Crotalaria</i>	<i>aegyptiaca</i>	3	<i>Panicum</i>	<i>turgidum</i>
2	<i>Cyperus</i>	<i>conglomeratus</i>	6	<i>Pennisetum</i>	<i>divisum</i>
5	<i>Dichanthium</i>	<i>foveolatum</i>	1	<i>Polygala</i>	<i>erioptera</i>
5	<i>Dipterigium</i>	<i>glaucum</i>	2	<i>Sporobolus</i>	<i>ioclades</i>
1	<i>Farsetia</i>	<i>linearis</i>	1	<i>Sporobolus</i>	<i>spicatus</i>
1	<i>Heliotropium</i>	<i>kotschyi</i>	1	<i>Stipagrostis</i>	<i>plumosa</i>
2	<i>Indigofera</i>	<i>intricata</i>	1	<i>Tephrosia</i>	<i>apollinea</i>
2	<i>Jaubertia</i>	<i>aucheri</i>	2	<i>Ziziphus</i>	<i>spina-christi</i>
1	<i>Kohautia</i>	<i>retrorsa</i>	68	TOTAL	

Table 3. List of high priority species

Grasses (10 species)		Shrubs and Trees (15 species)	
<i>Cenchrus</i>	<i>ciliaris</i>	<i>Acacia</i>	<i>ehrenbergiana</i>
<i>Cenchrus</i>	<i>setigerus</i>	<i>Acacia</i>	<i>gerardii</i>
<i>Coelachyrum</i>	<i>piercei</i>	<i>Acacia</i>	<i>nilotica</i>
<i>Dichanthium</i>	<i>foveolatum</i>	<i>Acacia</i>	<i>tortilis</i>
<i>Ochtochloa</i>	<i>compressa</i>	<i>Calligonum</i>	<i>comosum</i>
<i>Sporobolus</i>	<i>ioclades</i>	<i>Calligonum</i>	<i>crinitum</i> (subsp. <i>arabicum</i>)
<i>Sporobolus</i>	<i>nervosus</i>	<i>Ceratonia</i>	<i>oreothauma</i> (subsp. <i>oreothauma</i>)
<i>Sporobolus</i>	<i>virginicus</i>	<i>Convovulus</i>	<i>virgatus</i>
<i>Stipagrostis</i>	<i>plumosa</i>	<i>Cressa</i>	<i>cretica</i>
<i>Stipagrostis</i>	<i>sokotrana</i>	<i>Crotalaria</i>	<i>aegyptiaca</i>
Grass Shrubs (2 species)		<i>Dipterigium</i>	<i>Glaucum</i>
<i>Lasiurus</i>	<i>scindicus</i>	<i>Heliotropium</i>	<i>digynum</i>
<i>Panicum</i>	<i>turgidum</i>	<i>Maerua</i>	<i>crassifolia</i>
		<i>Prosopis</i>	<i>cinerea</i>
		<i>Rhanterium</i>	<i>epapposum</i>

Compiled according to observations and discussions with farmers, herders and scientists both in the UAE and the northern part of the Sultanate of Oman.

Seed Multiplication

With the priority species identified, a necessary next step in the approach is obtaining large quantities of seed and subsequent mechanized seed multiplication (Ferguson et al., 1998b). Following the first collections in UAE, several additional days were spent collecting bulk seed samples of *Panicum turgidum*, *Pennisetum divisum*, *Lasiurus scindicus*, *Cenchrus ciliaris*, *Dipterigium glaucum*, *Dichanthium foveolatum*, *Rhanterium epapposum*, *Stipagrostis plumosa*, *Coelachyrum piercei*, and *Calligonum comosum* from locations identified during the earlier collection mission. During October and November, with help from ICARDA's Seed Production Unit, who provided a scarifier and aspirator, scientists in the UAE were able to thresh the seed.

Gene Bank

A gene bank was established in the Republic of Yemen and others are being planned for the other countries that do not have them. In the UAE, all the seed was stored in vacuum-sealed packs and a small working gene bank was formed. This seed was used in our experiments.

EVALUATION

A next step in this research was to determine the water-use efficiency of the selected species. To this end, a line-source system, which provides a gradient of water, is being used to compare some of the priority species and the traditionally used forages. It is known that indigenous species are capable of surviving with less water than most introduced species, specifically Rhodesgrass and alfalfa, but, unlike the latter, the

productivity of the indigenous species as a function of the amount of water applied is unknown. Eventually, the most important criterion will be the weight of animal products produced per unit of water applied, under both optimum and sub-optimum water amounts for all the different forages and their mixtures.

It will also be important to determine the chemical composition and *in situ* degradation to estimate the nutritive value of the "new" forages in relation to Rhodesgrass and alfalfa. This is being done through a collaborative project with the UAE University in Al-Ain. Initial results show that *Cenchrus ciliaris* and *Coelachyrum piercei* are comparable with Rhodesgrass in having a similar crude protein content, a low neutral-detergent fiber (which provides an indication of better intake), and a low ash content (which provides an indication of the silica content which makes forages less palatable). In addition, *Cenchrus ciliaris* had similar dry matter digestibility to Rhodesgrass in both goats and camels. It was found, however, that camels were 50% more efficient at digesting the grasses than goats, which is a good example of the advantages of natural adaptation.

Small enclosures have also been selected, in some of the countries, as sites for research on restoration and rehabilitation techniques. Some excellent work has already been carried in a few AP countries, in particular, Kuwait and the Kingdom of Saudi Arabia.

CONCLUSIONS

By looking at desert rangeland plants in the Arabian Peninsula, ICARDA and the Arabian Peninsula NARS are seeking to make livestock production in the region sustainable. The work has potential impact in two directions: first, by rehabilitating the range itself to improve its present levels of productivity, and, second, by identifying new forages for cultivation which will use less water than those currently grown by farmers. The need to use less water is critical, as water use in the region has greatly exceeded sustainable supplies over the past 20 years (McCann, 1999). The result has been declining water tables and increased salinity. By seeking to maintain the resources of natural vegetation and water, we aim to enable animal production to continue into the future and provide food security and income for the people of the region. By conserving and

evaluating the genetic resources of the Arabian Peninsula, this research will not only benefit the constituent countries, but many countries that are likely to face the increasing impact of global warming, salinity and drought in the 21st century.

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REFERENCES

- Chaudhary, S.A. 1989. Grasses of Saudi Arabia. Ministry of Agriculture and Water, Riyadh, Saudi Arabia.
- Ferguson, M.E., I. McCann, and G. Manners. 1998a. Less water, more grazing. *Caravan* 8: 9-11.
- Ferguson, M.E., I. McCann, and G. Manners. 1998b. Seeds: the starting point for plant research. *Caravan* 8: 23.
- Ferguson, M.E. 1998a. Photographic flora of important indigenous forage species of UAE and Oman (Vols. I, II, III). Dubai, UAE.
- Ferguson, M.E. 1998b. Report on the collection of forage grasses, legumes, shrubs, and trees in the United Arab Emirates. ICARDA, Dubai, UAE.
- Ferguson, M.E. 1998c. Report on the collection of forage grasses, legumes, shrubs, and trees in the Sultanate of Oman. ICARDA, Dubai, UAE.
- Ghazanfar, S.A., and M. Fisher. 1998. Vegetation of the Arabian Peninsula. Kluwer Academic Publ., London.
- Mandaville, J.P. 1990. Flora of Eastern Saudi Arabia. Kegan Paul, London.
- McCann, I.R., and A.T. Moustafa. 1999. Agricultural water management in the Arabian Peninsula (This proceedings).
- Western, A.R. 1989. Flora of the United Arab Emirates, an introduction. United Arab Emirates University, Al-Ain.
- Zaroug, M.G. 1983. The status of the rangelands of the southern region of the Sultanate of Oman (Dhofar) and prospects for their conservation and sustained development. FAO, Rome.

Vetch Establishment under Supplementary Irrigation

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ABSTRACT

A field experiment was conducted during the 1997/1998 growing season at the University of Jordan Research Station, near Al-Muwaggar village, to evaluate the performance of vetch (*Vicia sativa* L.) grown alone or mixed with barley (*Hordeum vulgare* L.) under supplementary irrigation. The Al-Muwaggar site is characterized by low and erratic rainfall and a crusted surface soil. The treatments were randomly distributed in a split-plot design with four replications: (a) Diammonium phosphate (100 kg/ha) and/or sewage sludge (30t/ha) were placed in the main plot as follows: diammonium sulfate added alone, sewage sludge alone, DAP + SS together, control with nothing was added. (b) In the sub-plots, barley: vetch seeds were mixed in the following ratios: 100% barley; 0% vetch; 75% barley; 25% vetch; 50% barley; 50% vetch; 25% barley; 75% vetch; 0% barley; 100% vetch.

The highest grain yield (4 t/ha) was obtained from the application of sewage sludge with a seeding ratio of 25% barley: 75% vetch. While there were no significant interactions between the applications of DAP and/ or SS on straw yield, it was clear that the presence of barley in the mixture caused a sig-

nificant increase in straw yield, particularly when compared to pure vetch. The presence of barley in the mixture improves the herbage production. For example, under the control treatment, a seeding ratio of 75% barley: 25% vetch, the herbage production ranged from 4.8 to 6.0 t/ha compared to 3.6 t/ha for pure vetch. It can be concluded that vetch can be grown in low rainfall areas, but with supplementary irrigation. However, mixing vetch with barley can improve the production of herbage, grain, and straw.

INTRODUCTION

In Jordan, the scarcity of feed resources, primarily locally produced forages, is the major limitation to animal production. In 1989, about 550 thousand tons of grain were imported, consisting mainly of barley, corn (*Zea mays*), sorghum (*Sorghum bicolor*), and cereal bran. The area cultivated with vetch in the last 10 years (1988-'97) ranged from 1458 ha in 1988 to 1668 ha in 1997, with an average area of 1351 ha (Department of Statistics, 1988-'97). The total production ranged from 2218 tons in 1988 to 2892 tons in 1997 (Fig. 1).

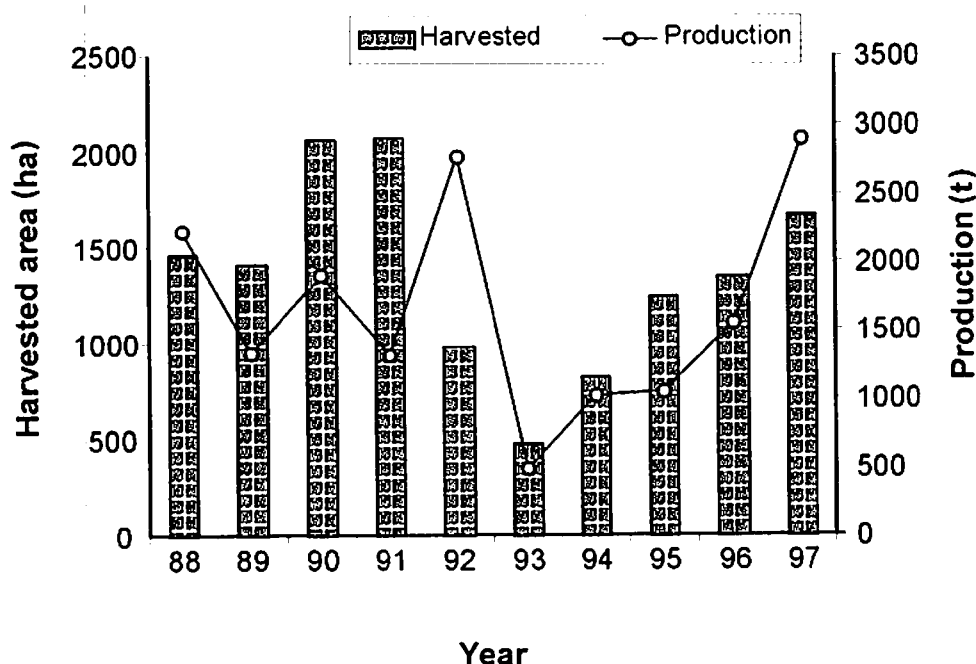


Fig. 1. Harvested area and production for annual forage legumes (bitter and common vetch) in Jordan.

Hay production from adapted legumes, such as vetch and pea (*Pisum sativa*), and from forage cereals, such as barley, triticale, and oats, has been suggested as one way of increasing feed from fallow land in traditional rainfed cropping areas (Osman and Nersoyan, 1986). However, growing either legumes or cereals in a pure stand is not considered ideal for haymaking. Therefore, growing cereal-legume mixtures is suitable for haymaking; in addition to that, mixtures are higher yielding than pure crops (Ababneh, 1983; Osman and Nersoyan, 1986). Vetch mixtures with barley are known for high dry matter yield and feed quality (Harb et al., 1986; Osman and Nersoyan, 1986). There are also advantages associated with the inclusion of a legume in a small grain crop. For example, Roberts et al. (1977) found that nitrogen (N) fertilizer requirements for wheat could be reduced by growing vetch in combination with wheat.

Semi-arid to arid areas of Jordan are large and the annual rainfall ranges from 100-200 mm. The major crop grown there for a long time is barley. In good years (1 out of 10), it can produce grain; however, in the bad years, it is usually grazed during March and April. If water can be made available, then why do not we grow other crops? The potential productivity of dryland farming is low and fluctuates from year to year, in relation to the seasonal variation in rainfall.

Average annual rainfall at Al-Muwaggar is about 150 mm; it is irregular, sporadic, and unpredictable, and fluctuates from year to year and within years. The area is characterized by having a crusted surface of soil, which reduces infiltration rate and hinders seedling emergence. These factors and others (i.e., frost) contribute to the low crop production in these areas. Similar to other areas of very low rainfall (below 200 mm) in Jordan, Al-Muwaggar has some *wadis* in which floodwater runs from place to place. Therefore, small earth dams were constructed to collect floodwater in order to use this water for irrigation of fruit trees, vegetables and field crops.

This present investigation was conducted to: study the performance of vetch crop grown alone or in mixture with barley under supplementary irrigation, and assess the effect of sewage sludge and/or diammonium phosphate application on yield of pure vetch or vetch-barley mixtures.

MATERIALS AND METHODS

This trial was conducted at Al-Muwaggar Agricultural Research Station during the 1997/1998 growing season. The station is located about 50 km southeast of Amman (38°5E, 31°53N). The climate is typical Mediterranean arid, with wet cold winters and hot dry summers (Taimeh, 1989). Rainfall varies from 80 to 200 mm, with annual average of 150 mm falling mostly during January and February. Soil is silty clay to silty clay loam.

Land preparation started in early October with a moldboard plow, then soil clods were broken down by

a rotary plow. Then, furrows 30-cm deep, 40-cm wide, and 100-cm apart, were opened using a furrow opener. Sewage sludge (SS) and/or diammonium phosphate (DAP) were added to the assigned plots at the bottom of the furrows and mixed with the soil. Any damage to the furrows was repaired by hand. Planting was carried out on 24 November 1997. Emergence was complete 20 days after sowing. Plots were irrigated for the first 2 weeks using sprinkler irrigation, and then irrigation was done by the furrows. Total amount of water received was about 350 mm (irrigation + rainfall).

Treatments were distributed in a split-plot design as follows: a) Main plots: DAP and/or SS; control with nothing added; DAP alone at a rate of 100 kg/ha; SS at a rate of 30 ton/ha; SS+DAP together. b). Seed mixture (a total of 120 kg/ha), with variable *barley-vetch percentage*: (0/100; 25/75; 50/50; 75/25; 100/0).

Samplings for fresh and dry matter were obtained from the two middle furrows at a length of 1 m. Before cutting, five readings were taken to determine stand height. Samples were taken when barley plants at the boot stage. Samples were weighted directly after cutting (fresh weight); then plant material was placed in a dry air oven (75°C) for 48 hours to determine dry matter yield. At maturity, total plots were harvested to determine straw and grain yield.

Data were statistically analyzed according to Little and Hills (1978). Mean separations for the main effects (DUNCAN) and for the interaction effects (LSMEANS) were estimated using SAS system for a split plot design (SAS Institute, 1985).

RESULTS AND DISCUSSION

Plant Height, Fresh and Dry Weight

Plant height of the stand ranged from 38 cm for pure vetch under control treatment up to 90 cm for vetch mixed with barley at a rate of 75% to 25% with the application of sewage sludge (Table 1). These results are much higher than those found by Ahmed (1997). He found that plant height ranged from 19 to 26 cm for common and narbon vetch, respectively. The highest amount of fresh yield (11.2 t/ha) was produced from growing barley and vetch in a mixture of 25% barley to 75% vetch with the application of 30 t/ha of sewage sludge. If vetch alone is considered, it is clearly shown that the lowest amount (3.6 t/ha) was produced under the control treatment (Table 2). This can be related to the plant height differences shown in Table 2.

Differences in dry matter production were not clear. However, growing vetch alone without DAP or sewage sludge gave 0.7 t/ha (Table 3), and yield was increased as the seeding ratio of vetch decreased from 100 to 50%. Other researchers proved that dry matter production of the mixture is higher than the legume alone (Osman and Nersoyan, 1986; Bawaleez, 1995). This is contradictory to Roberts et al. (1989). These results proved the potential to grow vetch in such areas with supplementary irrigation. Ahmed (1997) found that

herbage yield of common vetch grown at Muwaggar was about 0.5 t/ha. However, when animal manure was applied at a rate of 30 t/ha, yield was raised up to 1.5 t/ha, whereas Droushiotis (1985) showed that common vetch can produce 3 t/ha if cut at early flowering.

yield of legume-cereal mixture was 28-38% higher than that in the pure stand (Ababneh, 1983).

The significance is not that sharp; however, Table 5 shows that straw yield ranges from 3.7 to 12.7 t/ha for the different seeding ratios and DAP or SS application.

Table 1. Seeding ratio and treatments on plant height of barley-vetch mixtures grown under supplementary irrigation.

Barley - Vetch	Control	Diammonium Phosphate (DAP)	Sewage Sludge (SS)	SS + DAP
--%--	-----cm-----			
0:100	38.0b ¹	61.0a	69.0ab	50.3a
25:75	63.3a	77.3a	89.7a	72.0a
50:50	67.7a	76.7a	63.3b	58.3a
75:25	48.3ab	75.3a	70.7ab	59.0a
100:0	55.0ab	75.7a	66.7ab	71.3a

¹In each column figures followed by the same letter are not significantly different at P<0.05.

Table 2. Seeding ratio and treatments on fresh weight of barley-vetch mixtures grown under supplementary irrigation.

Barley - Vetch	Control	Diammonium Phosphate (DAP)	Sewage Sludge (SS)	SS + DAP
	-----t/ha-----			
0:100	3.6a ¹	7.7a	9.5ab	4.4b
25:75	6.0a	7.2a	11.2a	8.2ab
50:50	5.9a	7.4a	6.7b	4.9b
75:25	4.8a	9.0a	6.6b	9.6a
100:0	5.3a	6.0a	5.8b	5.9ab

¹In each column figures followed by the same letter are not significantly different at P<0.05.

Table 3. Seeding ratio and treatments on dry weight of barley-vetch mixtures grown under supplementary irrigation.

Barley - Vetch	Control	Diammonium Phosphate (DAP)	Sewage Sludge (SS)	SS + DAP
	-----t/ha-----			
0:100	0.7b ¹	1.4a	1.9a	1.2a
25:75	1.4ab	1.9a	2.5a	2.0a
50:50	1.8a	1.8a	2.2a	1.6a
75:25	1.3ab	1.9a	2.0a	2.0a
100:0	1.5ab	1.7a	1.8a	1.9a

¹In each column figures followed by the same letter are not significantly different at P<0.05.

GRAIN AND STRAW YIELD

Under sewage sludge application, growing 25% barley mixed with 75% vetch produced 4 t/ha of mixed grain (Table 4). However, when pure vetch is considered, the results indicated the possibility to produce 1.8 ton of grain/ha. Also, it was found that the application of 100 kg/ha of DAP gave 2.6 ton of vetch grain/ha. These results were much higher than that found by other researchers (Bawaleez, 1995; Ahmed, 1997). Grain

On the other hand, under the control treatment, without DAP or SS application, straw yield was increased from 1.5 to 7.5 t/ha as the vetch proportion in the mixture was reduced from 100% to 25%. Growing vetch alone without DAP or SS can produce 1.5 t/ha of straw; that was 50% higher than the straw yield found by Ahmed (1997).

Common Vetch to Reverse Long-Term Land Degradation and Alleviate Feed Deficits in Syria

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ABSTRACT

In West Asia, erosion-promoting crop rotations, due to demographic and economic pressures, are having detrimental effects on the environment and have generated serious problems associated with declining soil fertility and inadequate feed supply. In order to reverse this situation, the International Center for Agricultural Research in the Dry Areas (ICARDA) started to develop the cereal/vetch (*Vicia sativa*) rotation technology for resource-poor farmers in a fragile and harsh production environment in Syria. Starting 1982/83, a series of on-station trials were established at ICARDA's research farm at Tel Hadya about 35 km southwest of Aleppo. On-farm experimentation was conducted over a period of 15 years at El Bab, a town in Aleppo province in northwest Syria. A natural resource management approach that combines farmer knowledge and participation with current scientific knowledge was adopted.

Both on-station and on-farm research has demonstrated that vetch is well adapted to the farming systems of northwest Syria. On-station, barley grain yields were significantly higher after vetch grazing (3.13 t/ha) than after continuous barley (1.91 t/ha), lentil (2.37 t/ha), or fallow (2.59 t). Organic matter and total mineral nitrogen were highest with vetch and medic, and lowest with continuous cereal. On-farm, total crude protein output was twice as high from rotations that includes vetch; and barley/vetch rotation yielded most metabolizable energy.

Realising the benefit of this multifunctional technology, farmers began adopting the cereal/vetch rotation. The technology trials started in 1986 with a core group of eight farmers. The number of farmers growing vetch at El Bab increased in 1998 to 200 farmers in 20 villages, with an area of about 500 hectares. Efforts are on-going for the scaling-up of successful local experience with vetch, a crop that clearly adds to the productive potential of the soil while enhancing, rather than depleting, soil quality.

INTRODUCTION

For centuries, rainfed crops and livestock in West Asia were integrated in an efficient and sustainable use of natural resources. Grazing pressure on native pastures was adequate to allow maintenance of species diversity and a high turnover of biomass to meet animal needs.

Cheap and plentiful amounts of fertile land were available, allowing the region to be a major world provider of grain (Watson, 1974).

Population increases, however, have altered this equilibrium. To meet increasing demands for food and feed, the cereal/fallow rotation has turned to continuous cereal and rainfed cereal cropping has extended to marginal land. As a result, the area devoted to grazing is becoming smaller, with more animals grazing fewer hectares, and large feed deficits are projected by 2020 (Nordblom and Shomo, 1995). Erosion-promoting crop rotations, due to demographic and economic pressures, are having detrimental effects on the environment and have generated serious problems associated with declining soil fertility and inadequate feed supply for livestock.

In northwest Syria, for example, pressure on agricultural land is forcing farmers to use non-sustainable cultural practices, such as cereal monoculture (Jones and Singh, 1995). In just ten years, the fallow area in El Bab district decreased from more than 40% (Tully, 1984) to about 10% (Pape-Christiansen, 1997). This intensification is associated with cereal yield depression and increased pest pressure. Barley monocropping encourages a seed gall nematode (*Anguina tritici*) locally called Abu Ulaiwi, which devastates barley yields (Bahhady et al., 1997).

All of these changes raise grave concerns for the maintenance of the resource base and for the continued productivity of the farming systems of the region. It is against this background that the International Center for Agricultural Research in the Dry Areas (ICARDA) is working with national agricultural institutions in an endeavor to increase food production and the welfare of the farming community. One strategy for increasing agricultural production and maintaining the resource base in West Asia has been to introduce forage legumes into the cropping rotations (Cocks and Thomson, 1988). In this context, a particular research effort was devoted to common vetch (*Vicia sativa* subsp. *sativa*).

Common vetch is an ancient crop. Historical records of its cultivation start with the Romans (White, 1970). It was used in Roman agriculture in monoculture, both as a green manure crop and cut as fodder for cattle, and in mixed forage crops, and was excellent for succeeding grain crops. Common vetch has recently returned to favor and gained popularity as a crop. It can be grown for fodder, hay, green manure, or seed production. This paper reviews the on-station and on-farm research which led to development of the cereal/vetch

rotation technology for resource-poor farmers in the fragile and harsh production environments in Syria.

MATERIALS AND METHODS

As ICARDA began to develop the barley/vetch technology, it was felt that it should be applied on-station to evaluate the biological potential of cropping systems. On-farm trials were simultaneously conducted. Five long-term rotation trials undertaken in a number of locations in Syria and involving a vetch/cereal rotation are presented.

Barley Rotation, Breda

A trial was established in the 1982/83 season at Breda, northern Syria. It comprised six 2-course rotations of barley (*Hordeum vulgare*) with fallow, with barley or with one other crop; peas (*Pisum sativum*), vetch (*Vicia sativa*) or lathyrus (*Lathyrus sativus*), or mixtures of these legumes with barley. These rotations were combined in an incomplete factorial design with six fertilizer regimes, to give a total of 22 treatments. There were three replicates (see Jones and Singh, 1995, for further details).

The site is located at: Lat. 35° 56' N, Long. 37° 10' E, Elev. 300 m. It has a typical Mediterranean environment with cool wet winters and hot dry summers. The soil is a typical Calciorthid with a clay-loam texture, and a pH of 8.3 (1:1 water). Olsen-P at the start of the trial was 3 ppm, and organic carbon was 0.47%.

Durum Wheat Rotation, Tel Hadya

A two-course durum wheat based-rotation trial were established in 1983-'84 at Tel Hadya, ICARDA's research station, 30 km south of Aleppo in northwest Syria (Lat. 36° 01' N, Long. 35° 56' E, Elev. 284 m). The site has a typical Mediterranean environment with cool wet winters and hot dry summers. The climate of the site is discussed in detail by Kassam (1981). Soil texture was a silty-clay (*Calcixerollic Xerochrept*, Ryan et al., 1997) with a pH of 8.1, Olsen-P at the start of the trial of 13 ppm, and a depth varying from less than 75 cm to more than 200 cm.

Durum wheat was rotated with fallow (W/F), wheat (W/W), lentil (W/L), chickpea (W/C), watermelon (W/WM), medic pasture (*Medicago* spp.) (W/M), and vetch (W/V). Four levels of nitrogen were applied on the wheat (0, 30, 60, 90 kg ha⁻¹) and three intensities of grazing of wheat stubble (heavy, moderate, and zero) were superimposed in a split-strip design (for further details see Harris, 1995).

Wheat/Barley Rotation, Tel Hadya

The experiment began in the 1985-'86 season and treatments evolved over time. Seven rotations were established from 1985-'86 to 1990-'91 using wheat (White et al., 1994). The trial was modified in 1991 to accommodate strips in the cereal phase, including barley and wheat. The trial was modified in 1993-'94 from a

wheat-based to a completely barley-based trial. Seven rotations are compared: barley/medic (10 ewes/ha), barley/vetch for hay, barley/vetch for seed and straw, barley/vetch lamb grazing, barley/lentil, barley/fallow, and barley/barley. Plots in the cereal phase were randomly split and then continued as two sub-plots with the same management throughout the trial: one receiving N fertilizer and the other half not receiving N. The rotations were randomly allocated within each of the three complete blocks.

Wheat Rotations, Kamishly

The experiment began in the 1986/87 season at the Hemo experiment station, near Kamishly in northeast Syria (Lat. 37° 03' N, Long. 41° 13' E, Elev. 270 m). The site has a more continental Mediterranean environment than in northwest Syria; however, wet winters and hot dry summers prevail. Soil texture was deep clay loamy with a pH of 7.5, soil organic matter ranged from 1.2% in the upper layer to 0.5% in the deeper layer, Olsen-P at the beginning of the experiment of 9.2 ppm, and a soil depth not less than 3 m.

Six rotations were established; wheat (*Triticum aestivum*) rotated with: A mixture of medics (*M. rigidula* 35%, *M. noeana* 30%, *M. rotata* 30% and *M. polymorpha* 15%) grazed at 5 sheep/ha (CML), 9 sheep/ha (CMM), 12 sheep/ha (CMH), Common vetch (CV), Fallow (CF), and Wheat Sham 3 (CC). There were three replicates with treatments being randomly allocated within blocks. Fertilizer N was applied to the cereal phase according to soil test results.

On-Farm Trials, El Bab

The trial started in October 1986 near El Bab, a town in Aleppo Province in northwest Syria, and ran through the 1992-'93 season. Trials were replicated on six to eight farms. The soils are mostly cracking clays (*Vertisols*); many plots had shallow (<20 cm) soils, although some had medium (20-40 cm) and deep (>40 cm) soils. A rain gauge was installed at one farm. Rainfall was below average (266 mm) in four of the seven years. Trials compared fallow (F) or barley (B) with common vetch (V) or chickling (C), each in rotation with barley. The rotations were therefore barley-fallow (B-F), barley-barley (B-B), barley-vetch (B-V), and barley-chickling (B-C). Nitrogen as ammonium nitrate (30-60 kg N ha⁻¹) was hand-broadcast on half of the barley crop. Nitrogen and rotation were 'stripped' across each other within each phase and each farm. On each farm, the rotations were established on about 4 ha, half being sown to feed legumes, continuous barley or left fallow, and half to barley each year (For further details, see Christiansen et al., 1997).

RESULTS

Plant Productivity

The introduction of vetch into rotation consistently increased cereal yield compared to continuous cereal. On-station, cereal grain and straw yields after the vetch

were higher than that of cereal after cereal at Tel Hadya (Tables 1, 2), Breda (Table 3), and Hemo (Table 4). The cereal/fallow rotation outyielded the cereal/vetch in three of the four on-station sites. Grain and straw yields were also greater for the barley/vetch rotation than for the barley/barley or barley/fallow rotations in on-farm at El Bab (Table 5). Surveys conducted in 1997 and 1998 on farmers' fields confirmed the beneficial effect of introducing vetch in the rotation. Cereal

yields after vetch was significantly higher than that of cereal after barley (Table 6).

Although yields of all crops and rotations varied greatly from year to year depending on rainfall, rotations including vetch gave a significant yield advantage over continuous barley. Yields of the barley-fallow rotation were much less variable than those of the barley-barley rotation, with the barley-vetch rotation intermediate.

Table 1. Barley mean yields when grown in rotation at Tel Hadya.

Year	Fallow	Lentil	Vetch for Seed and Straw	Vetch for Hay	Vetch for Grazing	Medic	Barley	Mean
-----t/ha-----								
Grain								
1993 - 4	3.08	2.62	2.65	2.65	2.78	3.23	2.18	2.74
1994 - 5	2.53	2.27	2.89	3.05	2.79	2.99	1.88	2.63
1995 - 6	2.11	1.99	2.27	2.68	2.32	2.57	1.73	2.24
1996 - 7	2.67	2.58	3.14	3.67	3.29	3.32	1.84	2.93
SE				(a) 0.15				-
Nitrogen								
0	1.89	1.81	2.32	2.61	2.46	2.69	1.19	2.14
60	3.30	2.93	3.16	3.42	3.13	3.37	2.62	3.13
SE				(b) 0.10 (c) 0.063				0.024
Mean	2.59	2.37	2.74	3.01	2.79	3.03	1.91	2.63
SE				0.092				-
Straw								
1993 - 4	4.45	3.33	3.82	3.82	3.90	4.42	2.71	3.78
1994 - 5	2.72	2.18	3.23	3.41	3.15	3.43	1.86	2.85
1995 - 6	2.83	2.39	3.03	3.88	3.30\	3.84	2.12	3.06
1996 - 7	3.14	3.01	4.11	5.31	4.72	4.54	2.20	3.86
SE				(a) 0.24				-
Nitrogen								
0	1.97	1.80	2.69	3.14	2.89	3.14	1.26	2.41
60	4.60	3.66	4.41	5.07	4.64	4.97	3.19	4.36
SE				(b) 0.17 (c) 0.093				0.035
Mean	3.29	2.73	3.55	4.10	3.77	4.06	2.22	3.39
SE				0.15				-

Standard Errors (S.E.) to compare: (a) rotations within years; (b) rotations at the same or different levels of fertility and (c) fertility within rotation.

Table 2. Grain yield of durum wheat in rotation 1985-'92 at Tel Hadya.

Year	Fallow	Wheat	Wheat in Rotation with:					S.E.
			Lentil	Chickpea	Watermelon	Vetch	Medic	
-----t/ha-----								
1985 - 86	2.57	1.38	2.04	2.00	2.71	2.13	1.32	0.162
1986 - 87	1.92	1.01	1.65	1.35	1.96	1.62	1.18	0.098
1987 - 88	4.11	0.87	3.91	2.94	3.61	3.93	3.24	0.245
1988 - 89	1.80	0.31	0.94	0.40	1.04	0.98	0.29	0.118
1989 - 80	1.14	0.55	0.73	0.62	1.60	0.74	0.50	0.074
1990 - 81	1.56	0.97	1.25	0.76	1.64	1.17	0.93	0.086
1991 - 82	2.70	1.92	2.21	2.19	2.77	2.31	2.24	0.123
Mean	2.26	1.00	1.82	1.46	2.19	1.84	1.39	0.051

Table 3. Rotation effects on barley grain yield at Breda.

Year	Rainfall	Barley/vetch	Barley/fallow	Barley/barley	Mean
	-----mm-----				
			-----t/ha-----		
1983 - '84	204	0.84	1.24	0.51	0.86
1984 - '85	268	1.79	1.73	1.76	1.76
1985 - '86	208	1.84	2.32	1.09	1.75
1986 - '87	245	1.21	1.35	0.91	1.16
1987 - '88	399	3.05	3.16	1.97	2.73
1988 - '89	180	0.63	0.78	0.42	0.61
S.E.			±0.089		±0.051
			(±0.077a)		(±0.044b)
Mean		1.56	1.76	1.11	1.48
S.E.			±0.045		

Means over two fertilizer regimes, no fertilizer and NP applied in alternate years to current barley crop. Unbracketed S.E.S are for comparisons between all values in the adjacent line, column or matrix except for comparisons between cycles, when bracketed values apply; (a) for comparisons between values from the same combinations of series and rotation; (b) for comparisons between the same series, e.g., between 1/1, 2/1, and 3/1.

Table 4. Yields of wheat grain grown in rotation at Hemo Experiment Station, Kamishly.

Year	Rainfall	Wheat/Medic Grazing Pressure			Wheat in Rotation with:		
		Low	Medium	High	Fallow	Vetch	Wheat
					-----t/ha-----		
1987	331	1.21	1.05	1.31	1.35	1.15	1.23
1988	719	1.49	1.32	1.24		1.38	1.39 1.30
1989	243	0.10	0.11	0.18		1.52	0.17 0.05
1990	309	0.96	1.02	0.91		2.14	1.07 0.91
1991	307	1.25	1.40	1.41		2.00	1.76 1.06
1992	439	3.19	2.86	3.13		3.24	2.65 1.72
1993	577	4.01	4.34	3.99		4.42	3.91 1.21
1994	330	1.05	1.25	1.64		2.79	1.11 0.76
1995	632	3.73	3.35	3.34		3.39	3.08 1.34
1996	497	3.07	3.18	3.15		3.54	2.75 1.80
S.E.					0.18*		

Table 5. Dry matter mean yields for barley grain and straw harvested from different rotations at El Bab.

Rotation	Year							Mean
	86/87	87/88	88/89	89/90	90/91	91/92	92/93	
				-----t/ha-----				
Rotation				Grain				
Barley/vetch	0.83	1.46	1.04	0.92	1.39	1.13	1.54	1.19
Barley/chickling	1.11	1.64	1.06	0.86	1.45	1.11	1.53	1.25
Barley/fallow	0.95	1.38	1.20	1.13	1.48	0.99	0.74	1.12
Barley/barley	1.01	1.30	0.74	0.74	1.20	0.85	0.60	0.92
SE				±0.079				±0.041
Nitrogen								
N-	0.80	1.34	0.99	0.85	1.35	1.01	1.04	1.05
N+	1.15	1.55	1.03	0.97	1.40	1.03	1.17	1.19
SE				±0.048				±0.012
Rotation				Straw				
Barley/vetch	2.20	2.68	1.93	1.60	1.85	1.16	1.52	1.85
Barley/chickling	2.57	2.95	2.06	1.56	1.54	1.17	1.58	1.92
Barley/fallow	2.28	2.47	1.88	2.07	1.95	1.07	0.66	1.77
Barley/barley	2.40	1.96	1.46	1.35	1.78	0.84	0.56	1.48
SE				±0.14				±0.066
Nitrogen								
N-	1.84	2.25	1.71	1.42	1.65	1.01	0.98	1.55
N+	2.89	2.78	1.95	1.87	1.91	1.11	1.18	1.96
SE				0.089				±0.025

Table 6. Farmers' field cereal yields in different rotations at El Bab.

	1996/97	1997/98
	-----kg/ha-----	
Deep Soil		
Barley after vetch (deep soil)	1574	2874
Barley after barley (deep soil)	945	2239
Wheat after vetch (deep soil)	897	3241
Wheat after barley (deep soil)	648	859
Shallow Soil		
Barley after vetch (shallow soil)	1068	1946
Barley after barley (shallow soil)	521	996

Forage Production and Animal Performance

Grain, straw and hay yields from vetch in a 6-year on-farm experiment at El Bab are given in Table 7. Over the entire series of years yield of feed from both phases of the rotation was highest from the barley/vetch than the barley/barley or barley/fallow rotations. Total outputs of crude protein, the main limiting factor in animal performance in west Asia, were twice as high for the barley/vetch compared to the barley/barley or barley/fallow rotations. The barley/vetch rotation gave the highest output of metabolisable energy. There were no N x rotation treatment interactions; therefore, the main effect of N fertilization with 30 - 60 kg N ha⁻¹ in the cereal phase was to increase dry matter production by about half a ton per year, for all treatments.

Biological Sustainability

Total soil N levels were significantly higher in vetch rotations than with fallow or continuous wheat cropping (White et al., 1994). Soil organic matter levels in vetch rotations were also significantly higher than in the other systems, except for *Medicago*.

Economic Viability

The inclusion of vetch in the rotation raises gross revenue. Based on an 8 years data from a long-term crop rotation trial established in northeast Syria, a whole-farm linear programming model was designed to assess interactions between crop, pasture, and livestock activities, prices, and household requirements and resources.

Table 7. Dry matter mean yields for legume grain, straw and hay harvested from various rotations at El Bab.

Rotation	86/87	87/88	88/89	89/90	90/91	91/92	92/93	Mean
	-----t/ha-----							
	Grain							
Barley/vetch	0.69	0.86	0.18	0.24	0.39	0.28	0.44	0.44
Barley/chickling	0.59	1.10	0.37	0.20	0.47	0.28	0.48	0.50
SE				±0.061				±0.027
	Straw							
Barley/vetch	1.98	3.44	1.05	1.42	3.09	0.66	1.10	1.82
Barley/chickling	1.71	3.00	1.02	0.54	2.00	0.48	0.66	1.34
SE				±0.12				±0.047
	Hay							
Barley/vetch	1.09	3.75	0.84	0.89	0.78	0.75	0.82	1.27
Barley/chickling	0.89	3.16	0.77	0.51	0.47	0.44	0.49	0.96
SE				±0.101				±0.05

Average lamb liveweight gains during grazing of vetch for seven years on five farms (275 mm average rainfall), mostly with shallow soils where the potential for seed and straw production was low, compared to on-station results for 13 years at the Tel Hadya station (330 mm average rainfall), where the potential for production is higher due to deep soils capable of holding moisture. Lambs aged 2.5 to 3 months on farms averaged a growth rate of 184 g day⁻¹.

Predicted income from fallow-wheat and vetch-wheat rotations is lower than from lentil-wheat, but the fallow-wheat rotation is more stable. Where vetch pasture cannot be sold for use by other flocks, vetch-wheat with sheep is more profitable than without sheep. Only vetch hay, seed, and straw can be sold in this model. In an on-farm experiment at El Bab, the barley/vetch rotation provided a higher gross income than continuous cereal or fallow rotations (Fig. 1).

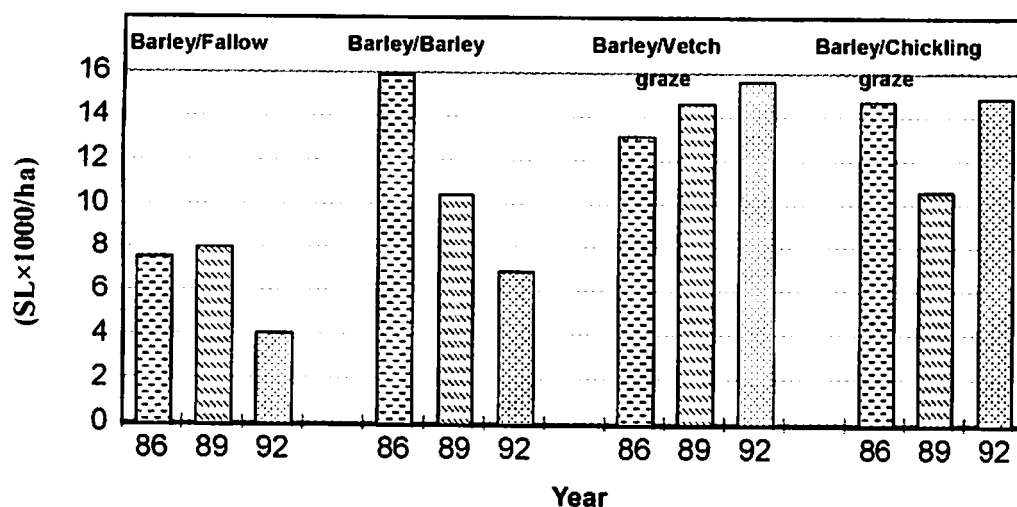


Fig. 1. Gross revenue of rotations, 1986-'92, El Bab.

DISCUSSION

In the long-term cereal/vetch rotations described here, both on-station and on-farm trials confirmed the beneficial effect of introducing vetch in rotation with cereals. Some soil factors were clearly influenced by the rotations, particularly those involving the supply of N and C sequestration. There was increased soil N content and a better N economy for rotations including vetch compared with continuous cereal or cereal fallow. This is consistent with results from Jones (1998), who found that vetch reduces or obviates the need for N fertilizer in the cereal phase. As N is the major input in cereal production, eliminating this need would greatly contribute to sustainability. Inclusion of vetch also resulted in an increase in soil organic matter, thus enhancing soil quality. The C and N buildup can reduce N needs for the alternating cereal crop and improve soil structure (Ryan, 1998).

Vetch not only improved soil quality but also a valuable forage source for sheep. Dry matter production from rotations including vetch was higher than that of the cereal/cereal and cereal/fallow rotation. In another experiment (Jones, 1988), productivity from a barley-vetch rotation exceeded that from a barley-barley rotation by 39% without fertilizer, and by 15% with fertilizer. Calculations based on crop contents of crude protein and metabolizable energy indicates theoretical sheep-carrying capacities 46-57% higher in barley-vetch compared with barley-fallow rotations. This will help alleviating the increasing feed deficit (Nordblom and Shomo 1995) and reduce the pressure on the resource bases for traditional livestock rising.

Another advantage for vetch is its diverse utilization options. It can be grazed, grown for fodder, hay, green manure or seed production. Some farmers at El Bab believe that the grazing option makes better sense than growing legumes for seed and straw, especially on shallow soil. Grazing eliminates the need for weeding and this is important in the El Bab area where no selective herbicides are available for elimination of broadleaf

weeds in forage legumes; it is also less expensive than hand-harvesting; and it shortens the crop's exposure to weather risk. Other farmers chose to harvest seed and straw at maturity.

In contrast with the numerous papers proving the benefits and recommending the use of forage and pasture legumes (Carter, 1978; Robson, 1990; Crespo, 1991) for West Asia, the adoption by farmers is far below expectations. This raises the issue of potential versus practical sustainability (Harris, 1998). Long-term are experiments are worthwhile only if the technologies under scrutiny have real potential for uptake by farmers; otherwise, we are considering only potential sustainability.

Parallel to the on-station experiments to evaluate the biological potential of vetch, on-farm investigations were undertaken. A participatory research approach was adopted at El Bab to demonstrate that the barley/vetch is valuable to farmers and to overcome constraints to adoption at the farm level. Farmers collaborated with researchers throughout the research process, resulting in frequent modifications of design and methods to take account of their needs.

Based on the recommendations of an extensive survey (Tully, 1984), ICARDA started to develop the cereal/vetch rotation in the El-Bab area, in 1986. At that time, continuous wheat and, especially, barley cropping was exhausting the land, and causing an unbroken cycle of pests and diseases. Both were reducing yields. The work started in 1985/86 by establishing on-farm trials. They aimed to involve farmers in studies to quantify the benefits of using common vetch to replace the fallow year in the barley-fallow rotation or to introduce common vetch into continuous barley monoculture.

The improvement of soil fertility induced by vetch cultivation leads to higher cereal yield. The barley/vetch rotation produced significantly higher barley grain yield than the barley/lentil and barley/fallow rotations. Surveys conducted in 1997 and 1998 on

farmers' fields confirmed the beneficial effect of introducing vetch in the rotation. Cereal yields after vetch was significantly higher than that of cereal after barley. In the 1997/98 season, in what was generally not a good year for cereals in Syria, a farmer from El Bab, obtained a yield of around 3.4 t/ha from his barley fields following vetch, against 2.8 from those where this practice was not followed. In general, he has been seeing yields 20% above those of his neighbors in recent years. Even more significant were the benefits that farmers saw in their barley when forage crops interrupted the gall nematode cycle monoculture that has become quite widespread in recent years.

These results made vetch attractive to farmers. Vetch seed production was, however, a bottleneck to the wide adoption of vetch. Hand harvesting is not economical because labor is scarce and therefore expensive at the time of the harvest. To respond to need expressed by farmers ICARDA started to test locally constructed rollers to make an even seedbed and mowers to cut and swath the mature crop. The availability of the rollers and mowers added to farmers' growing enthusiasm about vetch.

By solving the seed production bottleneck, the vetch rotations proved profitable and reached critical mass. The number of farmers growing vetch increased in 1998 to 200 farmers in 20 villages, with an area of about 500 hectares. In spring 1998, a farmer has invested in three mowing machines to harvest the vetch.

The approach adopted at El Bab, combining scientific evidence, a participatory approach for technology development, and dissemination and listening to farmers' views on constraints to adoption proved successful. The technology could help to combat rural poverty and to conserve and regenerate the deteriorated resource base of small farms. Efforts are on-going to scale up this successful technology.

REFERENCES

- Bahhady, F.A., S. Christiansen, E.F. Thomson, H. Harris, K.M. Eskridge, and A. Pape-Christiansen. 1997. Performance of Awassi lambs grazing common vetch in on-farm and on-station Trials. *In: Proc. Regional Symposium on Integrated Crop-Livestock Systems in the Dry Areas of West Asia and North Africa*; 51-63 (Ed., N. Haddad, R. Tutwiler, and E. Thomson). ICARDA, Aleppo, Syria.
- Bahhady, F., A. Ferdawi, E.F. Thomson, M. Singh, and S. Christiansen. 1994. On-farm trials comparing forage legume/barley rotation to fallow/barley rotations and continuous barley in north-west Syria. p. 53-67. *In: Pasture, Forage and Livestock Program, Annual Report*. ICARDA, Aleppo, Syria.
- Carter, E.D. 1978. A review of the existing and potential role of legumes in farming systems in the Near East and North African Region. Report to ICARDA, Waite Agric. Res. Institute, South Australia. 120p.
- Christiansen, S., M. Bounejmate, F. Bahhady, E.B. Thomson, B. Mawlawi, and M. Singh. 1997. On-farm trials with forage legume/barley compared to fallow/barley rotations and continuous barley in Northwest Syria. *Proc. workshop on "The Challenge of Production System Sustainability: Long-Term Studies in Agronomic Research in Dry Areas"*. ICARDA, Aleppo, Syria, 8-11 December 1997.
- Cocks, P.S., and E.F. Thomson. 1988. Increasing feed resources for small ruminants in the Mediterranean Basin. p. 51-66. *In: Increasing Small Ruminant Productivity in Semi-arid Areas*. (Ed., E.F. Thomson and F.S. Thomson). Kluwer Academic Publishers: Dordrecht.
- Crespo, D.G. 1991. A survey of the types of legumes suitable for animal production in the Mediterranean region. *In: Legume Genetic Resources for Semi-arid Temperate Environments*. (A. Smith and L. Robertson, Ed.), p. 258-280. ICARDA, Aleppo, Syria.
- Harris, D. 1998. Potential versus practical sustainability: the importance of uptake and impact. *In: Jones, M.J. (Ed.). The Challenge of Production System Sustainability: Long-term Studies in Agronomic Research in Dry Areas. Abstracts of presentations and Workshop Conclusions*. ICARDA, Aleppo, Syria.
- Harris, H. 1995. Long-term trials on soil and crop management at ICARDA. *Adv. Soil Sci.* 447-469.
- Hillman, G. 1975. The plant remains from Tel Abu Hureyra: a preliminary report. *Proc. Prehist. Soc.* 41: 70-73.
- Jones, M.J. 1991. The role of forage legumes in rotation with cereals in Mediterranean Areas. *In: "Legume Genetic Resources for Semi-arid Temperate Environments"*. (A. Smith and L. Robertson, Ed.), p. 195-204. ICARDA, Aleppo, Syria.
- Jones, M.J., and M. Singh. 1995. Yields of crop dry matter and nitrogen in long-term rotation trials at two sites in northern Syria. *J. Agric. Sci. (Cambridge)* 124: 389-402.
- Kassam, A.H. 1981. Climate, soil and land resources in North Africa and West Asia. *Plant and Soil* 58: 1-29.
- Nordblom, T.L., and F. Shomo. 1995 Food and feed prospects to 2020 in the West Asia/North Africa region. ICARDA Social Science Paper No. 2. ICARDA, Aleppo, Syria.
- Pape-Christiansen, A. 1997. Socio-economics of land use changes in northern Syria: the impact of irrigation and perennial crops on farming systems. *Unpublished Ph.D. Thesis*, University of Hohenheim.
- Robson, A.D. 1990. The role of self-regenerating pasture in rotation with cereals in Mediterranean Areas. p. 217-236. *In: The Role of Legumes in the Farming Systems of the Mediterranean Areas*. (A.E.

- Osman et al., Ed.), Kluwer Academic Publishers, Dordrecht.
- Ryan, J., M. Bounejmate, S. Masri, G. Estephan, and S. Christiansen. 1998 Management of a long-term barley/legume grazing trial: nitrogen and carbon effects. Amer. Soc. Agron. Meetings, Baltimore, (MD), Oct. 18-23. *Agron. Abst.*, p. 42.
- Ryan J, S. Masri, S. Garabet, J. Dickmann, and H. Habib. 1997. Soils of ICARDA's agricultural experiment stations and sites: Climate, classification, physical and chemical properties, and land use. ICARDA, Aleppo, Syria.
- Tully, D. 1984. Land use and farmer strategies in Al-Bab: the feasibility of forage legumes in place of fallow. Farming Systems Program Report No. 12. ICARDA, Aleppo, Syria. 68 pp.
- Watson, A. 1974. The Arab agricultural revolution and its diffusion. 700-1100. *J. Econ. Hist.* 34 No 1.
- White, K.D. 1970. Roman farming. Cornell University Press, Ithaca, NY.
- White, P.F., N.K. Nersoyan, and S. Christiansen. 1994. Nitrogen cycling in dry Mediterranean zones: changes in soil N and organic matter under several crop/livestock production systems. *Aust. J. Agric. Res.* 45: 1293-1307.
- Zohary D., and M. Hopf. 1988 Domestication of plants in the old world. Clarendon, Oxford.

Cactus to Prevent and Combat Desertification?

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ABSTRACT

The increasing interest in cacti is based on their ability to produce useful products on arid and semi-arid land and to prevent long-term degradation of ecologically weak environments. Beside their efficient crassulacean acid metabolism (CAM), they have developed *phenological, physiological, and structural adaptation to arid environments*. They generate three to five times more biomass per unit of water than C4 and C3 plants, respectively. They grow on marginal lands and provide fruits and instantly available source of stored energy, fiber, vitamin, and water at the disposal of the livestock. This source of a survival ration is stored *in situ* and remains evergreen all year around. Cacti grow in deserts and are drought-tolerant. Like other CAM plants, they are capable of developing high productivity in water-stress regions. It is a useful feedstuff for arid zones and an emergency feedstock in case of drought. For this purpose, it is used in different ways (grazing, cutting, silage) and helps in better using other available feed resources of arid environments, such as straw and fodder shrubs. Two success stories are cited, one in central and southern Tunisia, and the other from the desert area of southern Peru. They witness the important role that *Opuntia* species plays. Indeed, in these two examples, it is shown that is possible to revert the desertification trend and restore the vegetation cover by using spineless cactus.

INTRODUCTION

The future of the arid and semi-arid zones of the world depends on the development of sustainable agricultural systems and on the cultivation of appropriate crops. Suitable crops for these areas must successfully *withstand water shortage, high temperature, and poor soil fertility*. Cacti, particularly *Opuntia*, fit most of these requirements, and are important to the economy of arid zones, for both subsistence and market-oriented activities (Barbera, 1995). They play a positive ecological role in soil conservation projects and produce fruits and vegetables for human consumption, forage/fodder for livestock, biomass for energy purposes (fuel or biogas), cochineal for carmine production, and many other by-products (beverages, vegetarian cheese, drugs, cosmetics, etc.). They also provide shelter and food for various wildlife species living in arid environments. The use of cactus dates back to pre-Hispanic times in America, where it played an important role in the agricultural economy of the Aztec Empire. Recently,

plantations have been developed in many countries of Africa, America, Asia, and Europe.

CACTUS, A MULTI-PURPOSE PLANT

The increased interest in cactus is partly because of its ability to produce useful products on arid and semi-arid lands. It is also useful in preventing long-term degradation of ecologically weak environments. Recently, Nobel (1991) suggested that *Opuntia ficus indica* might be advantageously cultivated over substantial part of the earth's surface, mainly in those regions where a doubling in atmospheric CO₂ levels is expected.

Opuntia spp. presents various alternatives to its exploitation (Table 1).

- (i) **Forages:** They grow in severely degraded land (900,000 ha) where few other crops can. They are also highly palatable, digestible, and reduce the need for supplying water to animals; however, they must be combined with other feeds to balance the daily diet, as they are *poor in proteins*, though rich in carbohydrates and calcium.
- (ii) **Vegetable:** They are consumed fresh mainly by Mexicans; however, Mexican exports to non-traditional markets (Europe, Asia) are increasing.
- (iii) **Fruit:** A sustainable horticultural system is required to achieve high yields and high quality. The potential market for this product is large, but little exploited. Aggressive marketing strategies and post-harvest technologies are required. *Opuntia* spp. requires extensive labor, an important consideration in developing countries.
- (iv) **Cochineal:** Carmine acid, a natural red dye accepted by health authorities worldwide, is obtained. Yields vary according to the production system, i.e., plant density, and irrigation and fertilization systems. Cochineal industry is profitable and requires intensive use of labor. However, the market demand for this product fluctuates, making investment decisions difficult.
- (v) **Industrialization:** There is a potential market for fruit and nopalitos to produce concentrated foods, juices, liquors, semi-processed and processed vegetables, food supplements and the cosmetics industry. This market requires research and investment.
- (vi) **Medicinal Applications:** There are promising results for the treatment of gastritis, diabetes, hyper-cholesterolemia, and for obesity.

The most important economical use of cactus pear is as a fruit crop. In modern plantings, it is planted as a *monoculture* or *intercropped* with traditional crops in

the dry areas of Mexico, Italy, Chile, Bolivia, Argentina, Tunisia, and South Africa. Mexico and Italy are the main producers. Ten to 30 ton/ha fruit and 100-150 ton/ha of forage are obtained. The fruit is rich in sugar and vitamins and its relatively high sugar content permits the manufacture of products as marmalade, jelly, juice, and compote. Its nutritive value may be compared to apple, apricots, and oranges (Pimienta-Barrios et al., 1993).

Table 1. Actual and potential uses of *Opuntia ficus indica*.

<u>Food</u>	<u>Medical Uses</u>
Fruits	Flowers for diuretic purposes
Nopalitos	Cladodes for diabetes
Fruit juice	Mucilages
Oil extracted from seeds	
Miel de tuna	<u>Agronomical Uses</u>
Queso de Tuna	Soil fixation
Jellies and marmalades	Soil mulching
	Soil water supply
<u>Energy Production</u>	Hedges
Alcohol	Wind-breaks
Fresh biomass	
<u>Cattle Feeding</u>	<u>Coloring Uses</u>
Forage, Fodder	Betacyanin in fruits,
Fruit wastes	Carminic acid (red cochineal dye)

Source: Inglese et al., (1993).

HOW CACTUS CAN PREVENT AND COMBAT DESERTIFICATION?

The Plant Characteristics

The species of the *Opuntia spp.* subgenus have developed phenological, physiological, and structural adaptations to arid environments. Asynchronous reproduction, CAM metabolism, combined with structural adaptations, such as succulence, allow this plant to continue assimilation of carbon dioxide during long periods of drought and reach acceptable productivity levels, even in years of severe drought. In addition, it has other attributes:

- Biomass generation per unit of water is about three times higher than for C4 plants and five times higher than for C3 plants.
- Under optimal conditions, C3, C4 and CAM types of plants produce similar amounts of dry matter per unit area, but under arid and semi-arid conditions, CAM plants are superior.
- *Opuntia spp.* can develop in severely degraded soils, which are inadequate for other crops. They are well equipped to respond to global environmental changes. Their root characteristics combat wind and water erosion and favor growth in degraded areas.
- *Opuntia spp.* has an asynchronous development of the various plant organs and therefore some plant parts are not affected, whatever the stress.

Structural Adaptation to Arid Environments

The spineless cactus is a dicotyledonous perennial with pads, which are modified stems. The plant is leafless, but spines are modified leaves for xerophytism. Wax and a thick epidermis cover the pads, and limit evaporation. The stomata are deep and, when in stress environments and the temperature or the light intensity rises, they usually close for the largest part of the day.

Opuntia ficus indica is characterized by a shallow, fleshy root system, with horizontal spreading root. Under drought conditions, fleshy side roots develop from the taproots to take up soil moisture at lower levels. Nevertheless, in all kinds of soil, bulk masses of absorbent roots are found in the upper soil layers at a maximum depth of 30 cm, and spreading 4 to 8 m horizontally (Sudzuki Hills, 1995). The roots of Cactaceae differ from other plants, as they develop xeromorphic characteristics, enabling the plants to survive prolonged periods of drought: The fine roots can be found covered with a layer impermeable to water, or the roots abscise in order to avoid water loss in dry soil. Roots can respond to drought tolerance in three ways (Sudzuki Hills, 1995):

- Restricting the root surface and decreasing their permeability to water.
- Rapidly absorbing the small quantity of water supplied by light rains via "rain roots", which develop within a few hours after a shower and disappear as soon as the soil dries up, or via a reduction in the

root surface from which water flows off.

- Decreasing shoot transpiration due to root high negative potential.

On the basis of the above, these drought-resistant water savers may have high hydraulic resistance which would, in turn, decrease water flow to the shoot. Cacti absorb water through their roots and combine it immediately with a hydrophilic mucus compound from which the water evaporates very slowly. This hydrophilic compound is stored in the fleshy mesophyll cells of the pad. The plants also possess a closed oxalic acid metabolism that also contributes to water conservation in the plant (De Kock, 1983). The stem-like epidermis is one-cell-thick layer, with outermost wall impregnated with and covered by a wax of a fatty substance called cutin. The waxy, rough surface around the epidermal cell serves a number of functions. The cuticle prevents the escape of water vapor from the plants, repels surface water, and reflects much of the sun's radiation. The chemistry and structure of the cuticle cannot be digested by small organisms that could try to enter a cladode (Gibson and Nobel, 1986). The pad can lose as much as 60% of its total water content before the cells collapse (De Kock, 1983). The precise function of the mucilage is not known; however, it is generally believed that it helps to retain water inside the cactus (Gibson and Nobel, 1986).

Spines and trichomes have many functions. The most popular idea is that spines defend the plant from being eaten by animals and help to restrain water loss (Levitt, 1980); however, the most important function remains their ability to condense water from the air (Buxbaum, 1950). Moreover, spines help to reduce day-time stem temperature, and their presence also diminishes light interception by the cladode (Nobel, 1983). Spineless cactus has, on occasions, been referred to as "camels of the plant world", "nature's fodder bank", and

"living fodder banks". Cacti possess the exceptional characteristics of being able to store large quantities of water in their succulent organs. A shower of only few mm of rain can be efficiently utilized by spineless cactus. This is made possible by its relatively shallow spreading root system and its ability to still absorb water from the soil at a stage when other crops can no longer do so (De Kock, 1983).

Physiological Adaptation to Arid Environments

Cacti "grow in deserts" and are drought-tolerant. They possess a highly specialized photosynthetic mechanism that allows them to be more efficient than any grass or legume in converting water to dry matter (Russel and Felker, 1985; Nobel, 1989). Nobel and Harstock (1984) believed that the cultivation of cactus, which requires little or no irrigation, might get greater agronomic importance in the future, in the arid or semi-arid areas. Like other CAM plants, cacti are capable of developing high productivity in water-stressed regions. Recognition of the high potential productivity of certain CAM species may increase their cultivation in various areas in the future. Because of their water-conserving nature, suitable lands for CAM species are too harsh for most C3 and C4 species, and therefore increasing cultivation of CAM species will not cause displacement of other crops. Research work may enhance the productivity and food value of various agaves and cacti. Although their annual biomass productivities can be substantial, it can further improve in regions with water limitations if care is taken to optimize shoot area indices (Nobel, 1991).

Water use efficiency (WUE) generally averages 0.5-1.5 mmol CO₂ per mol H₂O for mature leaves of C3 plants, 1.0-2.0 for C4 plants, and 4-10 for CAM plants (Le Houérou, 1984; Nobel, 1991). De Kock (1983) already demonstrated the fact that showed that spineless cactus utilizes limited water better than atriplex or

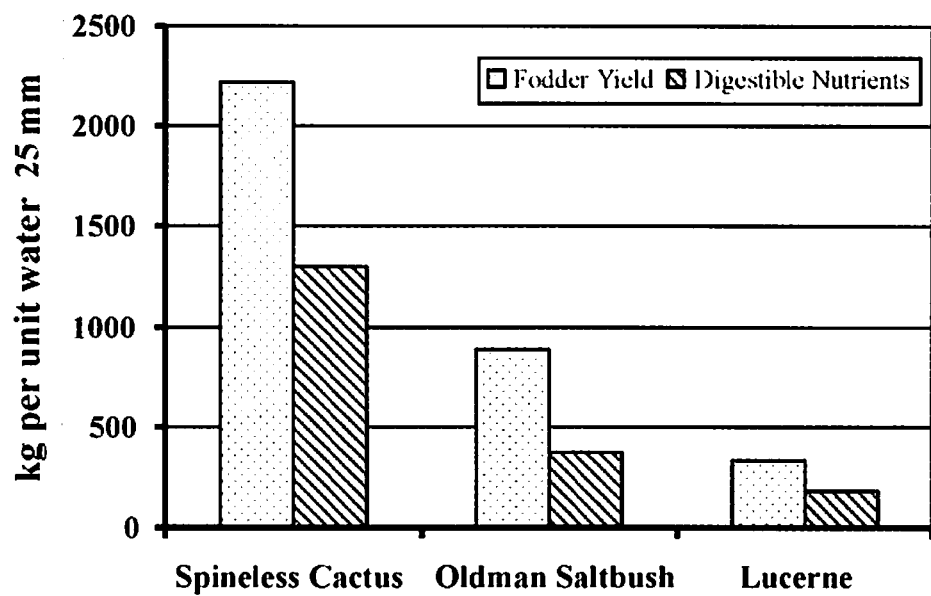


Fig. 1. Fodder yield and digestible nutrients produced by spineless cactus, *Atriplex nummularia*, and lucerne per unit of water (adapted from De Kock, 1991).

alfalfa (Fig. 1). The stomatal opening, predominantly at night, when leaf and stem temperatures are lower than during daytime, leads to less water loss by CAM plants per mol of CO₂ taken up than for leaves of C3 and C4 plants. Moreover, many CAM plants are succulent and can store considerable amounts of water in their shoots. Water storage added to the high WUE greatly extends the periods of net CO₂ uptake (Nobel, 1991). Most net CO₂ uptake by CAM plants occurs at night, when photosynthetic photon flux density (PPFD) is zero, so their net CO₂ uptake cannot be related to the instantaneous PPFD (Nobel, 1991).

Aboveground productivity of deserts worldwide is estimated at about 1 ton per ha per year, although mono-specific stands of various herbaceous species can attain double this productivity in deserts; CAM species, because of their higher water-use efficiency, can have up to five-fold higher productivity (Nobel, 1989). Under rainfed conditions and with no fertilizer application, spineless cactus yields vary between 20 and 100 tons of cladodes per year, for an average rainfall of 150 and 400 mm per year, respectively (Fig. 2). These yields are extremely high in comparison to other plant species.

invaluable in the livestock husbandry of arid areas and an ideal as a complement to fodder saltbush (*Atriplex spp.*) in terms of feed composition, nutritional value, and soil requirements. Both share the combination of high rain-use efficiency and water-use efficiency with very high drought tolerance (De Kock, 1980; Le Hou  rou, 1992).

Cactus is not a balanced feed and should rather be considered as a cheap source of energy. Cladodes have a low crude protein content, and consequently need to be supplemented by protein sources (including *Atriplex spp.*). They are also low in phosphorus and sodium. It is often recommended the following ways of utilizing cactus pear for feeding livestock:

- *Grazing of cladodes in situ.* Although this is the simplest method, it is not the most efficient and care should be taken so that the animals do not over-graze and deplete the plants.
- *Cutting of the harvested cladodes into small pieces or strips and feeding them in a confined area to limit unnecessary wastage.*
- *Making silage.* The cladodes are cut into smaller pieces and mixed with hay or low-quality alfalfa. If

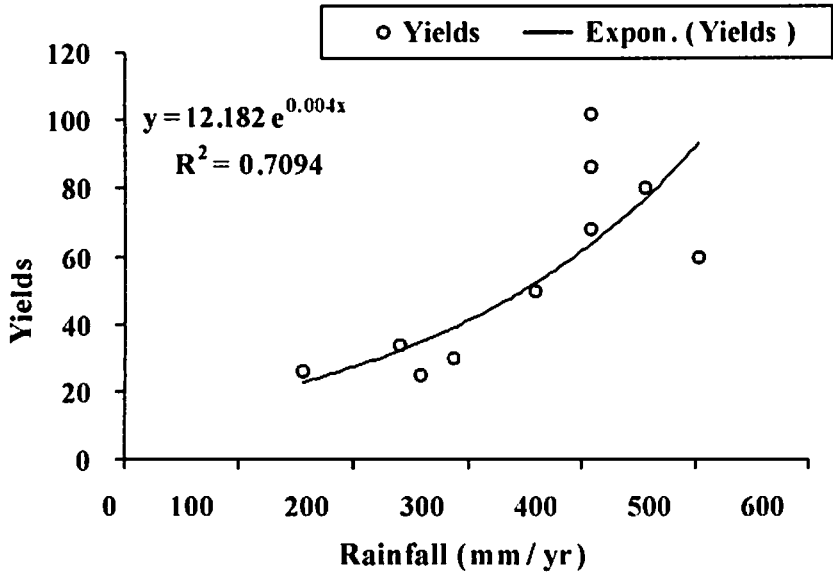


Fig. 2. Cactus yield according to rainfall in Tunisia (adapted from Montjauze and Le Hou  rou, 1965).

Cactus, a Living Fodder Bank, Reduces Rangeland Pressure

The spineless cactus cropped area is estimated at over 1 million ha, out of which 300 to 400 thousand ha are in Tunisia. Large areas are encountered in South Africa, Algeria, Mexico, and Brazil. It is used all year around or as emergency feedstock in case of drought. During drought cacti remain succulent. In many arid areas (Tunisia, Mexico, South Texas, South Africa, etc.), farmers use cactus extensively as an emergency forage that is harvested from both wild and cultivated populations to prevent the disastrous consequences of frequent and severe droughts. Thus, spineless cactus has proved

- no fruits are included, it is necessary to add molasses. Silage must be airtight.
- *Supplementation in case of emergency.* Cactus, fed in any form, will keep the animals alive for long periods. De Kock (1983) emphasizes the desirability of supplementing cactus pear with a protein-rich supplement of alfalfa or hay (200 g in winter and 100 g in summer) with cactus fed *ad libitum*. A lick of equal parts by mass of bone meal, salt and fodder lime is recommended by De Kock (1983) to supplement the phosphate and sodium.

Cactus Reduces Pressure on Water Points

Water is scarce in arid zones and watering animals during summer time and drought spells can be burdensome. Animals spend a lot of energy before reaching water points. Moreover, rangeland degradation in the surrounding area of water points is serious. Therefore, the high water content of cactus pads helps solving animal watering in dry areas. The succulent pads can then serve as a source of drinking water for stock. Experiments have shown that sheep kept indoors can do without water for more than 500 days if they have daily access to sufficient quantities of spineless cactus (De Kock, 1983). The data obtained in our laboratory show that water intake is nil when cactus intake by sheep is about 300 g of dry matter (Fig. 3). Water consumed by animals decreased from 2.4 L for the control diet to 0.1 L when the level of spineless cactus was 300 g DM or more (Ben Salem et al., 1996). Animals stopped drinking water at high levels of cactus intake. Terblanche et al. (1971) reported similar findings.

supplementing cactus with a *triplex*, *acacia*, or ammonia/urea-treated straw are developed below.

Poor Quality Roughage Supplementation with Cactus

Poor quality roughage may be supplemented with cactus. Indeed, the intake of straw increases significantly with the increase of the amount of cactus in the diet (Nefzaoui et al., 1993; Ben Salem et al., 1996). Cactus is also a good supplement to ammonia or urea-treated straw, since it provides the necessary soluble carbohydrates to the efficient use of the non-protein nitrogen (N) in the rumen (Nefzaoui et al., 1993). To study the effect of using large amounts of cactus (*Opuntia ficus indica*, var. *inermis*) in order to enhance non-protein N from ammonia or urea-treated straw, six groups of six Barbarine sheep were subjected to diets including cactus *ad libitum* and two levels (300 and 600 g) of untreated, urea or ammonia-treated straws (Table 2). Results showed that cactus voluntary intake could be

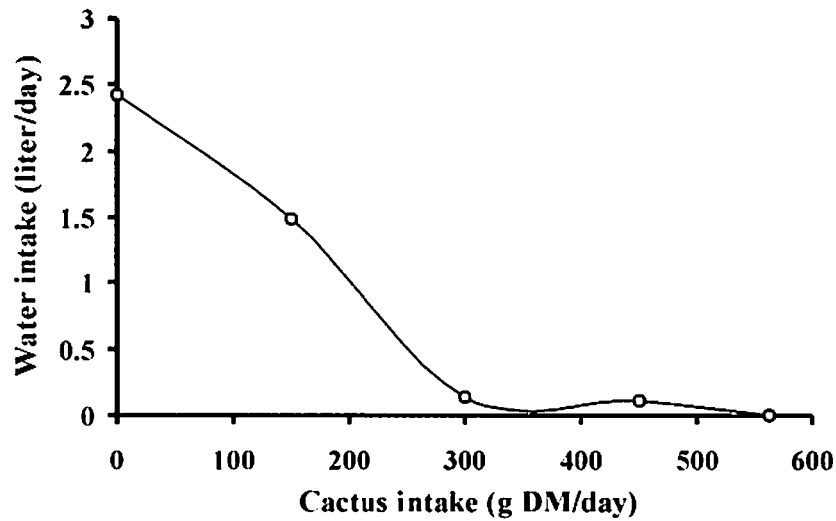


Fig. 3. Feeding cactus helps solving watering problem (Ben Salem et al., 1996).

Cactus Helps Other Feed Use

Experiments conducted in Tunisia have shown the benefit of integrating cactus with other resources in the feeding systems in arid zones. Some examples of

high (450 g DM) and remain important when daily straw ingestion increased from 300 to 600 g. Diets containing 64% of cactus caused no digestive disturbance.

Table 2. Straw supplementation with spineless cactus.

	Level of Straw					
	300 g straw d ⁻¹			600 g straw d ⁻¹		
	US ¹	ATS	UTS	US	ATS	UTS
Dry Matter Intake, g						
Opuntia	445	447	425	432	462	439
Straw	254	242	249	494	466	486
Diets <i>in vivo</i> Digestibility, %						
Organic Matter	67	64	63	66	69	72
Crude Protein	41	48	43	45	61	77
Crude Fiber	37	30	29	46	49	52
Nitrogen retained	-0.2	-0.2	-0.6	0.8	2.8	3.9

¹US: untreated straw, ATS: ammonia-treated straw, UTS: urea-treated straw.

Source: Nefzaoui et al. (1993).

Data indicated that it is possible to cover sheep maintenance requirements for energy by using diets based on cactus given *ad libitum* with 300 g of straw per day. With high levels of straw (600 g/day), it is possible to cover 170 to 190% of the maintenance energy requirement. To cover N maintenance requirements, straw should be treated. Therefore, cacti may be used as a major component of diets containing cereal straws; it is only necessary to add appropriate supplements in order to overcome the N deficiency and to bring the fiber needed for normal rumen functioning.

Atriplex, a Nitrogen Supplement to Cactus
In a first experiment (Nefzaoui and Ben Salem, 1996a), Barbarine sheep whether swere randomly allotted into three equal groups, and fed diets based on (80% of the diet) cactus (*Opuntia ficus indica* var. *inermis*) and atriplex (*Atriplex nummularia*). Limited amounts of wheat straw (180 g. d⁻¹) and commercial mineral and vitamin supplements (30 g.d⁻¹) were distributed.

The diets dry matter intake was similar for all groups. Digestibility coefficients of organic matter (OMD) and crude protein (CPD) of the three diets were relatively high, averaging 68, 74%, and 75%, respectively (Table 3).

In contrast, fiber digestibility was low, as the soluble carbohydrates of cactus might have depressed rumen cellulolytic activity. The diets covered about 1.7 times the sheep energy and digestible crude protein (DCP) requirements. Diet 1 covered 1.65 and 2.3 times the energy and DCP requirements of sheep, respectively. Thus, it provides excess N and should be supplemented with an energy source such as barley grain. Diet 2 is relatively well balanced in both energy and N, while Diet 3 has excess energy and needs to be supplemented with an N source (non-protein N, like urea).

Energy and sheep N requirements may be matched using diets based on these two feeds. The level of cactus in the diet may reach up to 55% on a DM basis, without any digestive side-effects. It is advisable that small amounts of fibrous feed (straw, hay) be fed to animals before cactus. A better efficiency of the diets can be obtained if the mineral balance is improved.

In another experiment, the effect of N supplement (urea, soybean meal, *Atriplex halimus*, *Atriplex nummularia*) on voluntary of intake cactus-based diets, and growth of Barbarine yearlings was investigated (Nefzaoui et al., 1996b). Four iso-nitrogenous and iso-energetic diets were offered to four groups of six Barbarine yearlings for 60 days in summer 1995 (Table 4).

Table 3. Nutritive value of diets.

Diets Parameter	Diet 1	Diet 2	Diet 3
Total intake, g DM d ⁻¹	941(70)	930(72)	983(73)
Cactus intake	197	353	550
Atriplex intake	554	391	236
Straw intake	160	159	167
Diet OMD, %	67.7	69.3	74.4
Diet CPD, %	74.5	76.6	75.5
Retained N, g d ⁻¹	4.1	3.9	4.1
Feeding value ²			
Energy	167	174	184
N	230	190	167

¹The values () correspond to intakes stated in g of dry matter (DM) per kg of LW^{0.75}. ²Feeding value is expressed in % of sheep maintenance requirements in energy (DOMi: digestible organic matter intake) and N (DCPi: Digestible crude protein intake)

Source: Nefzaoui and Ben Salem et al., 1996.

Table 4. Feed intake and liveweight gains.

Diets Parameter	Diet 1	Diet 2	Diet 3	Diet 4
Intake (g DM/d):				
Cactus	241	252	241	228
Atriplex halimus	0	224	0	0
<i>Atriplex nummularia</i>	0	0	225	0
Soybean meal	0	0	0	57
Barley	308	243	243	243
Hay	149	142	147	150
Urea	8	0	0	0
Total intake	706	862	857	679
Average daily gains (g/d)	55	58	74	70

Source: Nefzaoui et al. (1996).

For all diets, freshly cut cactus was fed *ad libitum* in addition to a limited amount of hay (170 g d⁻¹). Diets were supplemented, respectively, with 8 g d⁻¹ urea (D1), 770 g d⁻¹ *Atriplex halimus* (D2), 740 g d⁻¹ *nummularia* (D3), and 65 g d⁻¹ soybean meal (D4) (Table 5). Results showed that cactus-based diets might be supplemented efficiently by nummularia, urea, and *A. halimus* led to low growth rates in comparison to soybean meal or *A. Nummularia*-supplemented diets.

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groups were fed various diets, e.g., R00, R21, R22, and R23 (Table 5).

Because of cost, hay was distributed in a restricted and limited amount. The intake of acacia is low (250 g DM/day) because of its high content in condensed tannins (7% DM). These tannins also cause low digestibility of the acacia crude proteins. Such diets, need to be supplemented with an appropriate N source. For feeding cactus pads, we recommend the following simple rules:

- *Cactus is an unbalanced diet* and should be fed in association with fibrous feedstuffs (straw, hay, shrubs, etc.). It is also needs to be supplemented with an appropriate and cheap N source.
- *Cactus is rich in soluble carbohydrates and Ca and poor in phosphorus*. Therefore, it is recommended to (i) avoid decreasing rumen cellulolytic activity by adding molasses, (ii) limit the amount of grain in the diet for the same reason, (iii) feed animals fibrous feeds (straw, hay) before cactus. Moreover, a special mineral supplement is required (equilibrium Ca/P ratio), to bring sufficient amounts of sulfur (S).

Table 5. Diets nutritive value of various diets.

Diets Parameter	R00	R21	R22	R23
Feed intake, g DM/day				
Cactus	0	167	246	267
Acacia	241	373	211	177
Diet digestibility, %				
Organic matter	67.7	76.5	73.9	74.6
Crude protein	45.8	49.4	34.8	16.9
Crude fiber	62.8	80.5	77.4	79.9
Retained N., g/day	2.77	2.73	0.46	-1.07
Feeding value*				
Energy	147	151	131	116
Nitrogen	75	67	35	10

*Feeding value is expressed in % of sheep maintenance requirements in energy (DOMi: digestible organic matter intake) and N (DCPi: Digestible crude protein intake)

Source: Nefzaoui et al. (1996b).

supplemented efficiently by nummularia, urea, and *A. halimus* led to low growth rates in comparison to soybean meal or *A. Nummularia*-supplemented diets.

The voluntary intakes were 694, 844, 858, and 674 g DM per day, for diets D1, D2, D3, and D4, respectively. The average daily live-weight gains were 55, 58, 74, and 70 for D1, D2, D3, and D4 respectively. Such diets using low proportions of cereals (28%) and forage (17%) are recommended to cope with feed deficiency in arid and semi-arid areas prevailing in North Africa.

Cactus and Acacia

In this example, *Acacia cyanophylla*, a widespread introduced shrub, was used to supplement cactus-based diets. Indeed, Acacia is rich in crude protein (about 13% of DM). For this purpose, four Barbarine sheep

Cactus: Efficient Species in Reducing Water and Wind Erosion

Marginal lands are fragile ecosystems which are subjected to ploughing and indiscriminate vegetation removal that resulting in large-scale degradation and destruction of the vegetative cover. The disappearance and scarcity of several plant species indicate the magnitude of genetic and edaphic losses.

To revert the desertification trend and restore the vegetative cover in those areas, appropriate integrated packages are utilized for rangeland monitoring, and in livestock and natural resources conservation. Spineless cactus (*Opuntia ficus indica*), a drought and erosion-tolerant plant, is being advantageously uses to slow and direct sand movement, enhance the restoration of the

vegetative cover, and avoid the water destruction of the land terraces built to reduce runoff. Two success stories should be cited, one in central and southern Tunisia where cactus plantations provide a large amount of fodder for livestock and play a key role in natural resources conservation; the other from the Peruvian Desert in Arequipa, where a private company (La Joya Verde) initiated large scale plantation for those purposes and to produce red dye from cochineal.

Cactus to Combat Desertification in Central and South Tunisia

Land terraces are easily damaged by water runoff. Cactus helps by its deep and strong rooting system. Two rows of cactus pads are planted on the inner side of the terraces. The rooting system is enhanced by the availability of the water collected at the base of the terrace. Roots are widely spread on the elevated land part and deeply in the soil to ensure stability of the terraces. In addition, cut and carried pads provide sufficient feed resources during dry spells. Cactus can be used in combination with cement barriers or cut palm leaves to stop wind erosion and sand movement. It fixes the soil and enhances the restoration of the vegetative plant cover.

Oasis of *Opuntia* in Peru's Arequipa Desert

On the most recent successful stories in marginal land and desert rehabilitation is the case of the Desert of Arequipa in southern Peru. It has never rained, and no wildlife existed until a private company called "La Joya Verde" converted the area into a green productive oasis of spineless cactus. Water was made available from the underground in limited quantities, but sufficient enough to drip-irrigate *Opuntia*. An efficient rapid and low-cost technique of establishing cactus was developed, where, instead of digging the sandy soil, a set of cactus pads were put in an iron frame and covered with sand. The frame is later removed. These plantations were commercially used to produce red dye from cochineal. Furthermore, cactus pads left over after cochineal husbandry were composted and used as organic fertilizer to improve the soil. This success story shows how marginal lands in arid environment can be turned economically productive.

REFERENCES

- Barbera, G. 1995. History, economic and agro-ecological importance. In: Agro-ecology, cultivation and uses of cactus pear, Barbera, G., P. Inglese, and E. Pimienta-Barrios, (Eds.) *FAO Plant Production and Protection Paper* 132: 1-12 p.
- Ben Salem, H., A. Nefzaoui, H. Abdouli, and E.R. Orskov. 1996. Effect of increasing level of spineless cactus (*Opuntia ficus indica* var. *inermis*) on intake and digestion by sheep given straw-based diets. *Animal Science*, 62: 293-299.
- Buxbaum, F. 1950. Morphology of cacti. Abbey Garden Press. Calif., USA.
- De Kock, G.C. 1980. Drought resistant fodder shrub crops in South Africa. In: H.N. Le Houérou, (Ed.) *Browse in Africa Symposium*. Addis Ababa, 1980. Int. Livestock Center for Africa. Addis Ababa, Ethiopia.
- De Kock, G.C. 1983. Drought resistant fodder crops. In: Le Houérou, H.N. (Ed.), *Browse in Africa*. The current state of knowledge. 30 p.
- Gibson, C.A., and P.S. Nobel. 1986. The cactus primer. Harvard Univ. Press, Cambridge. 286 p.
- Inglese, P., G. Barbera, and T. La Mantia. 1993. Research strategies and improvement of cactus pear (*Opuntia ficus indica*) fruit quality and productivity. p. 24-36. In: "Proc. 4th Annual Texas Prickly Pear Council, August 13-14, 1993, Kingsville, Texas.
- Le Houérou, H.N. 1984. Rain use efficiency: a unifying concept in arid-land ecology. *J. Arid Environ.* 7: 213-247.
- Le Houérou, H.N. 1992. The role of *Opuntia* cacti in the agricultural development of Mediterranean arid zones. *Proc. 2nd Intern. Cong. "Prickly Pear and Cochineal"*. 22-25 Sept., 1992. Santiago, Chile.
- Levitt, J. 1980. Response of plants to environmental stress, Vol. II. Water radiation, salt, and other stresses; 2nd ed. Academic Press. New York.
- Monjaoui, A., and H.N. Le Houérou. 1965. Le rôle des *Opuntia* dans l'économie agricole Nord Africaine. *Bulletin Ecole Nationale Supérieure d'Agriculture de Tunis*. (8&9): 85-164
- Nefzaoui, A., A. Chermiti, and H. Ben Salem. 1993. Spineless cactus (*Opuntia ficus indica* var. *inermis*) as a supplement for treated straw. p. 130-133. 7th Meeting of the FAO Sub-Network on Mediterranean Pastures and Fodder Crops. Greece (Chania), April 21-23, 1993.
- Nefzaoui, A., and H. Ben Salem. 1996. Nutritive value of diets based on spineless cactus (*Opuntia ficus indica* var. *inermis*) and atriplex (*Atriplex nummularia*). In: "Native and Exotic Fodder Shrubs in Arid and Semi-Arid Zones", Regional Training Workshop, Tunisia, 27 Oct. - 2 Nov. 1996.
- Nefzaoui, A., H. Ben Salem, and L. Ben Salem. 1996. Nitrogen supplementation of cactus based diets fed to Barbarine yearlings. In: "Native and Exotic Fodder Shrubs in Arid and Semi-Arid Zones", Regional Training Workshop, Tunisia, 27 Oct. - 2 Nov. 1996.
- Nobel, P.S. 1983. Spines influence on PAR interception, stem temperature, and nocturnal acid accumulation. *Amer. J.N. Bot.* 70(8): 1244-1253.
- Nobel, P.S. 1988. Environmental biology of agaves and cacti. Cambridge Univ. Press, New York.
- Nobel, P.S. 1989. Productivity of desert succulents. *Excelsa* 14: 21-28.
- Nobel, P.S. 1991. Tansley review No 32. Achievable productivities of certain CAM plants: basis for high values compared with C3 and C4 plants. *New Phytol.*, 119: 183-205.

- Nobel, P.S., and T.L. Harstock. 1984. Physiological responses of *Opuntia ficus indica* to growth temperature. *Physiologia Plantarum* 60: 98-105.
- Pimienta-Barrios, E., G. Barbera, and P. Inglese. 1993. Cactus pear (*Opuntia* spp., *Cactaceae*) International network: An effort for productivity and environmental conservation for arid and semi-arid lands. *Cactus Succulent J.*, 65(5): 225-229.
- Russel, C.E., and P. Felker. 1985. The prickly pear (*Opuntia* spp., *Cactaceae*): a source of human and animal food in semi-arid regions. *Econ. Botany* 41: 433-445.
- Sudzuki-Hills, F., 1995. Anatomy and Morphology. p. 28-35. In "Agro-ecology, Cultivation and Uses of Cactus Pear". Barbera, G., P. Inglese, and E. Pimienta-Barrios (Ed.), FAO/Plant Production and Protection Paper 1312.
- Terblanche, I.L., A.M. Mulder, and J.W. Rossouw. 1971. The influence of moisture content on the dry matter intake and digestibility of spineless cactus; *Agro-animalia* 3(2): 73-77.

Feed Block Supplementation under Drought Conditions: Mashreq - Maghreb Project Experience

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ABSTRACT

In West Asia and North Africa region, the feeding strategies used for sheep during drought period are to maximize survival rates and minimize a reduction of reproductive performance. There is considerable amount of agro-industrial by-products available in the region. These by-products are, however, not efficiently used in animal feeding. Opportunity in WANA region exists to fill part of the gap between the supply and demand for feed resources through efficient utilization of these by-products. Experience of the Mashreq/Maghreb (M&M) Project has shown that feed blocks manufactured from urea and agro-industrial by-products can be used as a supplement for improving the productivity of ruminants which depend on low quality roughage as their main diet. The results of several on-station and on-farm experiments has shown that using feed blocks as supplementary feed resulted in considerable improvement in the performance of sheep.

Many national programs have developed, within the framework of the Mashreq/Maghreb Project, various feed-block formulae by using locally available agro-industrial by-products. In some countries (Iraq and Jordan) the feed block technology was successfully disseminated and adopted by sheep owners and manufacturers (NGOs, private sector) through, an efficient methodology associating researchers, extension service, policy-makers, and end-users.

Socio-economic and impact studies conducted in both countries indicates a high rate of acceptance of this technology, while the adoption rate ranges between 15.3% in Jordan to 38.3% in Iraq by sheep owners. There is a good prospect for feed blocks to be used as a strategic supplement for small ruminants in WANA region.

INTRODUCTION

The greatest single constraint to small ruminant development in dry areas of the WANA region is the shortage of good feed resources, which can meet their nutrient requirements. This is mainly due to a decline in the production of green forages because of the priority given to cultivation of land in food crops, which also extended to marginal lands. Another factor is the deterioration of rangelands, which were subjected to increasing pressure by livestock. On the other hand, considerable amounts of crop residues are available

now in the region, due to expansion of food crops (+37%), especially cereal grain (wheat and barley) (Nordblom and Shomo, 1993). But the use of these crop residues in ruminant feeding is limited because of their low energy digestibility (35-45%) and low protein content (3-4%), (Leng et al., 1991). Frequent incidence of drought in the region further aggravates the situation and widens the gap between the supply and the demand for feed resources.

The measures undertaken by many governments in the region are to import feed grain (mainly barley) and other feedstuffs for feeding the exist animal population. Whereas considerable amount of agro-industrial by-products (e.g., date pulp, sugarbeet pulp, tomato pomade olive cake, brewer grains and molasses) are available in the WANA region (Salmon, 1996; Hadjipanayiotou, 1997). But these by-products are not efficiently used in ruminant feeding. Opportunity in WANA exists to fill part of the gap between the supply and the demand of the feed resources through efficient utilization of these by-products. The past experience from inside and outside the region has shown that feed blocks manufactured from urea and agro-industrial by-products proved to be a top supplement and a good management tool for improving ruminant productivity which depend on low quality forages as their basal diet (Leng et al., 1991; Habit et al., 1991; Hadjipanayiotou et al., 1994; Salmon, 1996).

FEED BLOCK SUPPLEMENTS

Feed block supplements originated in South Africa and then spread to Australia and United Kingdom as means of providing small, safe amounts of urea, energy, and minerals to cattle and sheep kept under extensive conditions (Tops, 1975). The Food and Agriculture Organization (FAO) of the United Nations promoted feed-block technology in sugar-producing countries in West Africa and South Asia (Sensuous, 1986). Also, more than 60 countries have received assistance from FAO to develop the manufacture and distribution of blocks of molasses - urea and other agro-industrial by-products as feed for livestock. In the late eighties, ICARDA's Mashreq Project (UNDP/AFESD, Iraq, Jordan and Syria) revived interest in feed-block technology as an alternative feed source for sheep in the region.

Recently the national programs in Iraq and Jordan in operated with M&M Project "Development of Integrated Crop/Livestock Production in Low Rainfall

Areas of WANA" sponsored by the Arab Fund for Economic and Social Development (AFESD) and by the International Fund for Agricultural Development (IFAD), coordinated by the International Center for Agricultural Research in the Dry Areas (ICARDA), and implemented in partnership with the national programs of the M&M countries (Iraq, Lebanon, Jordan and Syria, and Algeria, Libya, Morocco and Tunisia, respectively), and the International Food Policy Research Institute (IFPRI) has successfully implemented a project to produce and disseminate feed block technology among sheep owners in both countries (Salman, 1997; Mammoth, 1998).

Manufacture

The Iraqi methodology in formulation and manufacturing of feed blocks is considered as major development in the region and outside the region (Salman, 1996). This methodology is simple and does not need sophisticated equipment to be imported from outside. Different formulae of feed blocks were manufactured by M&M national programs with different levels of urea, binders, and varieties of agro-industrial by-products, which are available locally (Table 1). Inclusion of high-moisture date pulp and olive cake, which is available in commercial quantity, gave excellent blocks regarding hardness and compactness (Salman, 1996, 1997; Mamdouh et al., 1997).

FEED-BLOCK SUPPLEMENTATION-SHEEP PERFORMANCE

Several on-station and on-farm experiments were conducted by the M&M national programs to evaluate the potential of urea feed block as a supplementary feed for sheep at different stages of production (growth, fattening, mating, pregnancy and lactation). These experiments were designed to use the feed blocks as a supplement under existing feeding systems of sheep owners in WANA region.

Awassi Ewes Grazing Cereal Stubble

Sheep owners in dry areas of the WANA region do not use any supplementation to ewes grazing cereal (wheat and barley) stubble, a period which coincides with the long mating season. The lengthy mating season, together with no supplementation, may be responsible for low conception, lambing and twinning rates (Salman, 1996). The results of on-station and on-farm experiments (Table 2) have shown that using feed block as supplementary feed during cereal stubble grazing resulted in considerable improvement in ewe weight gain (52-360%), conception rate (11-44%), lambing rate (25-33%) and twinning rate (15-18%) compared to the farmer's practice, i.e., no-supplement (Salman, 1998). Salman (1996) stated that the improvement in the reproductive performance of Awassi ewes due to

Table 1. Some formulae of feed blocks manufactured in Magreb-Mashreq countries.

Ingredients	Formulae No.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 ¹	16 ²
Urea	10	10	7	6	7	7	8	7	7	4	7	6	7	7	5	5
Molasses	40	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wheat bran	30	10	30	38	34	32	20	25	30	10	27	27	25	22	30	32
Rice bran	-	-	-	-	-	22	15	-	5	5	-	-	15	5	5	-
Feed flour	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-
Date pulp	-	-	-	-	-	-	38	35	-	-	35	-	-	20	12	46
Olive cake	-	20	35	36	-	-	-	-	-	-	-	-	-	-	-	-
Beet pulp	-	-	-	-	32	-	-	-	22	-	-	-	-	-	-	-
Brewer grain	-	-	-	-	-	-	-	-	-	-	-	45	-	-	9	-
Poultry litter	-	-	-	-	-	20	-	5	5	35	5	-	22	15	15	-
Ground straw	-	-	-	-	8	-	-	-	-	-	8	-	-	-	-	-
Ground corn cobs	-	-	-	-	-	-	-	10	10	-	-	5	10	10	-	-
Ground reed	-	-	-	-	-	-	10	-	-	34	-	-	-	-	-	-
Quicklime	-	-	12	7	12	12	10	12	14	6	12	10	7	10	10	8
Cement	15	15	-	7	-	-	-	-	-	-	-	-	-	-	-	-
Bentonite clay	-	-	-	-	-	-	-	-	-	-	-	-	7	4	-	-
CaSO ₄	-	-	-	-	2	2	2	2	2	1	2	2	2	2	1	1
Salt	-	-	5	5	5	5	5	5	5	4	5	5	5	5	5	3
Minerals premix	5	5	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Whey	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-

¹Mating Feed Blocks. ²High-Energy Feed Blocks.

Recently the Iraqi national team of M&M Project developed new feed block formulae according to sheep physiological stages (Table 1). These formulae (Salman, 1998) were used by sheep owners during mating (Mating Feed Blocks) and during hand-feeding period (High-Energy Feed Blocks).

feed blocks can be considered the important aspect of this technology in dry areas of the WANA countries where sheep depend heavily on cereal stubble grazing during the mating season.

Table 2. Feed-block supplementation vs. reproductive performance of Awassi ewes (on-station).

	Exp. 1			Exp. 2		Exp. 3		
	Control	Feed Block 1	Sunflower Seed meal	Control	Feed Block 2	Control	Feed Block 2	Feed Block 3
No. of ewes	29	28	30	27	27	32	32	30
Days on test	82	82	82	82	82	82	82	82
Initial weight (kg)	39.5	39.6	39.4	46.3	46.3	42.2	42.8	42.1
Weight gain (g/d)	30	51	44	-35	5	3	26	32
B.C. Score at mating	2.13	2.33	2.23	2.36	2.72	2.42	2.46	2.52
Conception rate (%)	86	93	87	78	89	81	94	97
Lambing (%)	93	100	93	89	115	84	109	117
Twinning (%)	10	7	6.6	11	26	3	16	21
Supplement intake (g/d) -		144	150	-	227	-	259	280

Supplementation Feed: Hand-Feeding Period.

Hand-feeding period (November to January) is considered the most critical time for sheep in the M&M countries because of the shortage of grazing (Salman, 1996). Currently, sheep depend on whole barley grain and stored straw as their main diet. There is great interest among sheep owners in replacing costly barley grain with other cheaper feed resources. The Iraqi national team developed new formulae of feed blocks to meet the demand of the sheep owners. These formulae, called high-energy feed blocks (HFB), depend on high moisture date pulp or sugar beet pulp as the main ingredients. Such block during hand-feeding period, which coincides with ewes' late pregnancy and early lactation was, tested by on-station and on-farm experiments (Salman, 1999).

The results of these experiments (Table 3) showed that using HFB resulted in a significant replacement of costly barley grain (50-100%). Salman (1996) indicated that the main reason behind the success of feed block technology in Iraq was that majority of sheep owners used feed blocks during hand-feeding period. Also, such blocks can be used as a strategic supplement during this period because it compensates for the shortage of cereal grain and minimizes the use of roughage.

TECHNOLOGY DEVELOPMENTS

The M&M Project methodology and mechanisms of developing and dissemination of feed block technology, which was successfully implemented and adopted by Iraqi and Jordanian national teams, links researchers with both extension services and manufacturers (private sector, NGO's), policy-makers and end-users (sheep owners) looking for the sustainability of this technology (Mamdouh et al., 1997; Haddad et al., 1997), also spread the technology in the region.

In Iraq, 21 manufacturing plants were established during the last 4 years. These plants produced, until the end of 1998, more than 2700 tons of different formulas of feed blocks distributed among 7302 sheep owners (Salman, 1998).

Socio-Economics

Over the past 5 years (1992-1996), a large number of sheep owners have been exposed to feed block technology through implementing demonstrations, trials on farmers' flocks, and extension presentations. It was necessary to follow up the farmers to study the effect of technology that the Project was trying to transfer to sheep owners and providing feedback for further developments of improved technology.

Table 3. High energy feed blocks vs. the performance of Awassi ewes during hand-feeding period (on-farm, Mosul area).

	Nazazh		Al-Jemff		Beasheeka	
	Control	Feed Block	Control	Feed Block	Control	Feed Block
No. of ewes	20	20	15	15	27	27
Days on test	85	85	72	72	70	70
Initial ewes wt. (kg)	51.9	52.5	48.5	47.6	45.2	44.8
Final ewes wt. (kg)	37.4	37.1	40.5	42.6	36.1	36.7
Lambs birth wt. (kg)	3.1	3.1	3.2	3.1	3.2	3.0
Lambs wt. at weeks (kg)	12.3	13.4	13.2	11.7	8.2	8.1
Milk yield (g/ewe/d)	242	385	500	362	330	330
Feed intake (g/ewe/d)						
Whole barley grain	412	-	712	356	890	305
Straw	265	500	370	370	N.D.	N.D.
Feed Block	-	347	-	416	-	445
Feed cost (l. Dinas/head)	2326	1442	3341	2614	3364	2976

A special questionnaire was established for that purpose and administered to sheep owners participating in the project in Iraq and Jordan during 1996. A random sample of non-participating sheep owners was included in the surveys as a check for a comparison of farmers acceptance, and adoption rate, and technology performed constraints to adoption were identified. The survey was restricted to the target area of the M&M Project (low rainfall areas).

Results of a sample survey of 149 sheep holders in Iraq indicate that 94% of the participants in field demonstrations have used feed blocks for at least one time. The adoption rate was 36% among the attendee's field days, whereas only 4.2% of non-participants had adopted the feed block technology. As a result, the adoption rate was 38.3% of all sheep holders (Shideed et al., 1998).

In Jordan, the results of a sample survey of 78 sheep holders exposed to feed block technology (Table 4) indicate that 61% non-participants had accepted the technology and 13% among them adopted it, while the adoption rate among the sheep holders exposed was 15.3% (Mamdouh et al., 1997).

Table 4. Feed-block technology adoption according to participation category in Iraq and Jordan, 1996 .

Type of Participation	Iraq				Jordan							
	Exposed				Exposed				Accepted			
	Once				Continuous				Adopted			
	No	%	No	%	No	%	No	%	No	%	No	%
Participants in demonstration	46	31	43	94	25	58	8	103	6	8	2	
Participants in field days.	31	21	11	36	6	55	16	20.5	14	18	-	-
Non participants	72	48	3	4	1	33	54	69.2	48	61	10	13
Total	149	100	57	38.3	32	56	78	100	68	87	12	15.3

CONCLUSIONS

The success of feed block technology in Iraq and Jordan is considered as one of major achievement of ICARDA's M&M Project in the region. This is mainly due to wide ranges adoption of the technology by manufacturers and sheep owners. It is well established that using feed blocks improved the performance of sheep during stubble grazing and considerably reduced feed cost during hand feeding period. The methodology of making FB is simple and does not need sophisticated equipment. Also, feed blocks can be made by making use of a wide variety of by-products, which are available locally. There is a good prospect for feed blocks to be used as a strategic supplement for small ruminants in other WANA countries. This is mainly due to similarity in animal feeding systems and availability of by-products, which are not efficiently and economically used in animal feeding. Also, the experience of feed-block making can be available inside the region.

REFERENCES

- Habib, G., S. Basit Alishah, G. Wahidullah, and J. Ghuffranullah. 1991. The importance of urea-molasses blocks and by-pass protein in animal production. The situation in Pakistan. p. 133-145. *In* Isotope and Related Techniques in Animal Production and Health, International Atomic Energy Agency, Vienna.
- Haddad, N., E. Al-Karablieh, and E. Bailey. 1997. Development and transfer of improved technologies for integrated crop-livestock production in low rainfall zones. ICARDA.
- Hadjipanayiotou, M. 1994. Urea block made of variety of by-products and of binders. *Livestock Research for Rural Development*. 6: 20-29.
- Hadjipanayiotou, M. 1997. The role of crop residues and agro-industrial by-products in filling the deficit of animal feed stuffs in the Middle East Regional Symposium on Integrated Crop-Livestock Systems in the Dry Areas of West Asia and North Africa. 6-8. Nov. 1995. Amman, Jordan.
- Leng, R.A., T. R. Preston., R. Sansoucy, and P.L.G. Kanju. 1991. Multi-nutrient blocks as a strategic supplement for ruminants. *Wld. Anim. Rev.* 67: 11-19.
- Mamdouh, Q., 1998. Utilization of improved agricultural by-product blocks in feeding of small ruminants. Ministry of Agriculture NCARTT, Jordan.
- Mamdouh, Q., and A. Balawneh. 1997. Impact of animal technology assessment in Jordan. ICARDA-Mashreq-Maghreb Project.
- Mamdouh, Q., and A. Taymeh. 1996. Investments in by-products in Jordan. Ministry of Agriculture, NCARTT. Amman, Jordan.
- Nordblom, T.L., and F. Shomo. 1993. Livestock and feed trends in West Asia and North Africa: past, present and future, p. 15-30. *In* Agriculture in Mediterranean Countries. 1:5. Options Méditerranéennes CIHEAM. Paris.
- Salman, A.D. 1996. The role of multi-nutrient blocks for sheep production in integrated cereal-livestock farming system in Iraq. 2nd FAO Electronic Conferences on Tropical Feed. Livestock Feed Resources within Integrated Farming Systems.

- Salman, A.D. 1997. The potential of by-product feed blocks in Tunisia. ICARDA-West Asia Regional Program.
- Salman, A.D. 1998. Effect of feed blocks supplementation on the reproductive performance of Awassi ewes grazing cereal stubble. *In* Livestock Production and Climatic Uncertainty in the Mediterranean. International Symposium. Agadir, Morocco, Oct. 22-24, 1998.
- Salman, A.D. 1999. Using feed blocks manufactured from agro-industrial by-products as supplementary feed for ruminants. Workshop on Feed Block Technology and its Impact on Improving Animal Performance. Baghdad 22-24 March, 1999.
- Sansoucy, R. 1986. The safe manufacture of molasses and urea blocks, *Wild. Anim. Rev.* 57: 40-48.
- Shideed, K.H., and A.D. Salman, 1996. Production, utilization, economic assessment, and adoption of by-products feed blocks in Iraq. Regional consultancy report. ICARDA, Mashreq/Maghreb Project.
- Topps, J.H. 1975. Block and liquid feeding for supplementing pasture and roughages. *In*: Simplified Feeding for Milk and Beef. U.S. Feed Grains. Council and University of Aberdeen, April, 1975.

Private Rangeland Intensification in Egypt's Northwest Coast

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ABSTRACT

The farming system and traditions of the Northwest Coast of Egypt are undergoing rapid change due to coastal development for tourism. Most of the land-mass is a plateau 100-200 m above sea level adjoining a narrow coastal strip, with winter rainfall averaging approximately 140 mm at the coast and falling to < 80 mm per annum 60 km inland. Although the mean annual rainfall is low, it is sometimes of high intensity and the rocky surface of the plateau generates major quantities of rainfall runoff, and over the course of millions of years a network of deeply incised *wadis* were created. The deep but gullied soils found in the *wadis* represent about 6% of the total arable surface area of the region and they are the focus of land reclamation techniques to intensify agricultural production using runoff farming and tree crops.

Two major development projects in the past decade-GTZ Qasr Rural Development Program (QRDP) and the Government Egypt/World Bank Matrouh Natural Resource Management Project (MRMP) have reduced poverty and generated income in the Bedouin community by shifting the farming system from small ruminant livestock and subsistence winter crop production to a more intensified mixed farming centered on horticultural crops, primarily figs and olives. A small and more recent project, from 1996 to 1999, showed how a well-developed watershed (*Wadi Ramla*) could be further developed by exploiting unused terraces in the watershed to transplant properly grown seedlings of arid-land adapted fodder shrubs.

The project used GIS as a tool for identification of the locations that are suitable for planting, having more soil and accessibility to moisture than on the plateau, but not competing with more economic crop production on the reclaimed areas of the *wadi*. It focused on privately owned land to control animal access using traditional methods and property rights to avoid the need for fencing. In this pilot scheme during 1998/99, approximately 59,000 plants were transplanted on a total of 26.2 ha in eight selected locations of *Wadi Ramla* using several species (*Periploca angustifolia*, *Atriplex nummularia*,

Acacia cyanophylla, *Atriplex canescens linearis*, *Cassia sturtii*, *Colutea istria*, and *cactus*).

The plants will be ready for use in two more years. This method offers greater prospects for successful rangeland intensification than under open access conditions on the plateau because the investment focuses on privately owned land on more numerous sites with many farmers. A goal for the future will be to promote the use of direct seeding that builds upon this methodology and reduces the costs associated with the nursery production of seedlings and the transplantation program.

INTRODUCTION AND RATIONALE

This report is a summary of a survey made between 9 May and 31 August 1998 and follow-up actions during 1998 and 1999 to identify the potential for range improvement in the *wadi* "tips". These tips can be considered as the beginning of the hydrographic network of a *wadi*. Every *wadi* and its watershed extend over hundreds or thousands of hectares. *Wadi* beginnings, the so-called *wadi* tips, are physically connected to the privately owned fruit plantations further down the *wadi* stream. These areas have sufficient soil and water for shrubs but not enough for fruit trees.

The reasons for selecting the *wadi* tips as a focus for range rehabilitation with adapted arid land genetic resources are: (1) the higher rainfall and runoff for shrubs in the *wadi* tips compared to the open grazing lands, (2) the private status of *wadi* tips which avoids the need for fences, and (3) the greater probability of success by investing in smaller but more numerous sites with more farmers.

The Project used a geographic information system (GIS) as a tool for identifying the potential for improvement in order to: (1) accurately localize on a digitized map of the area the places that are suitable for planting, having more soil and accessibility to moisture than on the plateau, but not competing with more economic crop production on the reclaimed areas of the *wadi*; (2) attach information to these localized sites in the form of a database; and (3) extract, correct, and easily update the information in this database. The project focused on privately owned land to control animal access using traditional methods and property rights to avoid the need for fencing.

The concepts leading to this survey were to: (1) conserve the natural environment as much as possible, and (2) minimize the costs of improving these areas. These basic principles had some influence on the shape of the database and on how to use the sites that were surveyed. The goal of the project was to improve private rangeland in the region of Marsa Matrouh in the Northwest Coast of Egypt. The specific objective of the study was to identify the potential for range improvement in a specific type of location: the *wadi* tips.

METHODOLOGY

It was decided to organize the GIS application in the shape of coverage of points, which could be overlaid on a digitized topographic map of the region. Each point represented a registered tip (localized on the map with the Global Positioning System or GPS coordinates), and information on the tip can be obtained by a simple click on the map.

The Survey Form

The first step in this survey was to identify the information to be collected in the field. This information was organized within a form (on paper) to fill out when visiting each site, such that it was ready to be entered into the computer database. The description of this form is as follows:

Site Identification and Location

Tip Number: A number was given to each site visited; Date: The date of the observation was registered; Wadi Name: The name of the wadi was written on the form; Coordinates (x, y): The GPS coordinates (in metric units) of each site were taken using UTM (Universal Transverse Mercator) projection, zone 35; Film and Photograph Number: One or two photographs of each site were taken, and the film and photograph numbers were registered. These photographs were scanned and entered into the computer.

Site Description

Geomorphology: The type of area in a tip was divided into classes: the wadi stream (1), the slope on the left side of the wadi stream (2), the slope on the right side (3), the slopes on both sides (4), the wadi head (5), the interfluvium between small wadi gullies (6), the whole tip (7), or the adjacent area on the plateau (8); Area: The area of the site (m²); Soil Texture: Some classes for soil texture were defined: clay (1), clay loam (2), loam (3), sandy clay loam (4), sandy loam (5), loamy sand (6), fine sand (7), or coarse sand (8); Soil Type: Additional information on the soil was obtained under four classes: calcareous (1), gypseous (2), saline (3), or calcareous and saline (4); Soil Depth: Three classes of soil depth were defined: less than 20 cm (1), 20 to 50 cm (2), or more than 50 cm (3); Slope: The slope of the considered area of the tip (%); Aspect: The orientation of the site was defined as: north (1), northeast (2), east

(3), southeast (4), south (5), southwest (6), west (7), or northwest (8); Coverage % by Rocks: Quick estimation with regard to the whole site registered; Coverage % by Stone, Gravel, Bare Soil, and Perennial and Annual Vegetation: Same as previous; 1st, 2nd, 3rd, and 4th Dominant Annual: Latin names of the species; 1st, 2nd, 3rd, and 4th Dominant Perennial: Same as previous; Comment on Vegetation: General brief comment; Indication of Biodiversity: Three classes of biodiversity: low (1), medium (2), and high (3). 'Low' biodiversity means less than 20 species; 'medium', 20 to 40 species; and 'high', more than 60 species; Species of Interest: Latin name of the most interesting species; Presence of Cistern: Yes or No was used to describe this field.

Ownership

Farmer's Name: Name of the owner of the registered site; Relation Between the Owner of the Tip and the Owner Downstream: Three classes were defined: the owner of the tip is himself the owner of the *wadi* bed downstream (1), he is a relative of the owner of the *wadi* bed (2), or there is no relationship between the two owners (3); Farmer's Interest in the Project: Three classes were defined: interested in the project (1), cannot keep animals away (2), or not interested in the project (3); Farmer's Comment: Brief comment on the use of his land by the project.

Site Interpretation

Civil Work Needed: Six options were used: terracing (1), ripping (2), banks (3), stone dikes (4), plantation holes (5), or none (6); Surveyor's Comment: Final brief comment on the possible use or not of the site.

Equipment for Information Collecting

The expertise on soil, vegetation, rangeland, and the ability to communicate with the farmer was provided by a team of scientists. A GPS, camera, soil auger, range finder, car, and driver were used. Two experts in GIS used MapInfo Professional 4.0 and Esri Arc View 3.0a software on a laptop computer. Also, a digitized map (1/25000) of contour lines, hydrography, and roads for the study area was used, in addition to a scanner to digitize the photographs.

Approach to Data Collection

Field

Each tip of a chosen *wadi* was visited, and all the needed information collected. First, the information on the location was taken (recording the coordinates, taking photos, etc.) and then the site was described (geomorphology, area, soil, vegetation, etc.). An attempt was then made to meet the farmer and, if possible, to solicit his opinion regarding the improvement of the land. Before the team moved to the next tip on the map, a decision was taken on the possibility of using this site.

Fieldwork

The information in the form was entered in the computer after each field trip to ensure accuracy. When the team felt that all the sites had been visited in the chosen *wadi* (*wadi ramla*), the fieldwork stopped. A quick classification of the sites was made, with regard to the surveyor's comment, as follows: good site to plant shrubs (1), medium site (2), site where improvement is not possible (3), and site to keep as is because of its biodiversity or in which seeds could be collected (4).

RESULTS

General Comments on the Field Experience

The survey showed that it is possible and needed to improve huge areas in the *wadis*. Not only the tips must be considered, but also other areas that have potential inside the *wadis*. Some areas that were registered in the database are not really tips; they are places which can be improved as rangeland inside the *wadis*. Examples of these are "ripped" areas, huge areas of slopes between the plateau and the wadi stream, and huge interfluvies between *wadi* branches.

The farmer's comment is probably the most important parameter in this kind of survey. The farmer can agree to improving a site already registered, but can also lead the team to a site that he wants to improve. A good link with the farmer and a thorough explanation of the aim of the Project are the key to success in improving the land. Once the farmer is involved, he will take care of the land during the growth of the shrubs, and will use it afterwards. Most farmers were interested in the Project, but there were different kinds of interest:

- Some were interested in improving their land as rangeland. They were able to keep the animals out of the plantations, and didn't ask for money. The reason is that the registered site was unused land and they knew it would produce an extra income for them.
- Some were interested but couldn't keep the animals out of the area during growth, so they asked for fences or money to take care of these areas.
- Some showed interest but the team suspected that they were interested only in clearing their land so as to plant other species (fruit trees or barley) after a few years, even if the site under consideration was not suitable for these species.

Therefore, an accurate assessment of the interest and willingness of the owner is necessary to have an acceptable rate of success in the long term. The farmer can also offer solutions for improving the land by advising on the kind of plants that do or do not grow in the area. For example, a farmer told the team that *Atriplex* did not grow on his land, while another farmer showed the team three well-grown cactus plants on part of his sandy land, suggesting the use of this land for

growing cactus. Thus, it is useful not only to select the proper adapted species to plant by using the knowledge of a rangeland or ecology specialist, but also to benefit from the ideas and experience of the farmer.

Results Extracted from Database

Initially, six *wadis* comprising 160 sites were registered: Ramla (116 sites), Magid (38), Medouar (3), Abu Groof (1), Hashem (1), and Saloufa (1). More than 30 farmers were met (27 of whom were in *Wadi Ramla*). After realizing the extent of the time needed to achieve results, it was decided to focus the survey on *Wadi Ramla*. Even in *Wadi Ramla* alone, the team did not achieve all what it had hoped for, mainly because of the time needed to meet all the farmers in the area. However, of the 116 registered sites in *Wadi Ramla*, there was a general consensus among the owners that in 47 of the sites there was potential for improvement. Actually, 82 of the 116 sites were suitable for rangeland plantings, and 44 of them were commented on by the farmers (i.e., the farmers commented on more than half of the suitable areas).

In 30 of these 44 sites, farmers agreed with the aim of the Project: to improve their land by planting fodder shrubs for feeding their animals. In seven of the sites, the farmers were interested, but were unable to keep the animals away for 2 years to allow enough time for the shrubs to grow; thus, they needed fences. However, the aim of the survey was to minimize the improvement cost of these sites; therefore, these sites were placed in a different category. If the Project could afford the cost of fences, these sites would be considered. In another seven of the 44 sites, the farmers were not interested in the improvement of their land, either because the land would be used for barley or fruit trees (even if not suitable for this type of use) or it will be sold for construction.

It is thus evident that, in the suitable sites, nearly two-thirds of the owners agreed with the aim of Project, although the sites represented only one-quarter of all the sites (30 out of 116). Out of the 30 sites, 17 belonged to a *wadi* tip, 5 were slopes, 4 were ripped areas, and 4 were unclassified. Nineteen sites had an area of at least 1 ha.

Rangeland Test Areas in Wadi Ramla

Eight sites, where Project activities could begin, were selected from the sites with good and medium potential registered in the database, and where the farmer had given his approval.

The sites were to be prepared and cultivated as demonstration fields. They were re-checked in the field to obtain additional information in order to formulate the workplan. The plan described the types of plants that match the properties of soil and other related characteristics of the chosen sites. It also described their density, spacing, and number of plants. The contracted plant nursery was visited to ensure the availability of

the seedlings in good condition, sufficient numbers and in proper timing. Other nurseries were also visited to ensure an abundance of plantations from different sources.

On the basis of previous studies and preliminary visits to the sites, the method of cultivation and preparatory (mostly civil) work were planned. This work was executed either by the farmer himself or by hired laborers and/or machinery. Technical assistance and follow-up were always provided. The seedlings were planted in pits (50 × 50 × 50 cm), dug at distances predetermined for each site in the work plan. In the ripped areas and sandy soils, no preparatory work was recommended.

Immediately after rain showers, the seedlings were transferred to the sites according to plan (Table 1). After taking off the poly-bag, each seedling was planted at about two-thirds the depth of the pit. The earth was accumulated adjacent to the rim of the pit down the slope as a crescent-shaped barrier.

There was a problem with the accuracy of the GPS. The main consequence is that some sites were not positioned accurately on the map, sometimes with an error of about 100 m. The digitized maps were not completed on two maps because of the bad quality of the copies used for digitizing. Time was lost because of the difficulty in contacting the farmers; they were not at either home or living far from the sites. This was the main problem because farmers were one of the main sources of information for the database.

Database Changes from Field Experience

Since it became apparent during the survey that time was insufficient to register all the information on the cisterns, only the presence or absence of a cistern was entered in the database. The other information (volume or distance to the site) was omitted. The field describing the needed civil engineering work was not well defined at the outset because it was not the intention of the project to spend much time in improving these

Table 1. Type and number of seedlings planted at the eight sites in Wadi Ramla.

Site No.	Size	Description	Target Species	Plants/ha	Spacing Density	Transplanted Species	Plants Cultivated
	-ha-			-x 10 ³ -	-m-		-x 10 ³ -
134	2.00	Rocky, loamy soil	<i>Periploca angustifolia</i>	3.3	1 × 3	<i>Atriplex nummularia</i>	6
135	2.50	Ripped, destined	<i>Atriplex nummularia</i>	2.5	2 × 2	<i>A. nummularia</i> + <i>Periploca angustifolia</i>	4 + 1
104	5.00	Deep sandy soil (lower part)	Cactus blocks, bordered with <i>Acacia cyanophylla</i>	2.0	1 × 5	<i>Cactus</i> (without borders)	10
126	3.00	Calcareous, sandy clay loam soil	<i>Atriplex nummularia</i>	2.5	2 × 2	<i>A. nummularia</i> + <i>Acacia saligna</i>	7 + 1
94	6.00	Deep, sandy loam soil. Roman camp	<i>Atriplex nummularia</i>	2.5	2 × 2	<i>A. nummularia</i>	7.5
93	6.00	Deep, sandy loam soil. Saline locations	<i>Atriplex nummularia</i>	2.5	2 × 2	<i>A. nummularia</i> + <i>Acacia saligna</i>	8.5+1
42	1.00	Deep sandy loam soil	<i>Cassia sturtii</i>	2.5	2 × 2	<i>Colutea isteria</i> + <i>Cassia sturtii</i> + <i>A. nummularia</i> + <i>Acacia saligna</i>	5+ 0.5 + 2.5 + 1
4a	0.35	Calcareous, loamy sand.	<i>Periploca angustifolia</i>	3.3	1 × 3	<i>Colutea isteria</i> + <i>Periploca angustifolia</i> + <i>A. nummularia</i>	1.5 + 1.5 + 1
Total	26.2						59

RECOMMENDATIONS AND CONCLUSIONS

Initially, only the wadi tips were registered. With time, all spots suitable for rangeland in the wadis were also registered. It was also advised to discontinue studying every small tip although they were registered at the beginning of the survey; this is why there are slopes, ripped areas, and other types of sites in the database, not only wadi tips. There were problems with the different comments on how to improve each site. Recording the names of the plants was a problem; therefore, the team needs a person who is knowledgeable about the local vegetation.

areas. The cost of this work would have been expensive for the low income of the farmers. In fact, the team nearly always chose the option "plantation holes" to improve the land; thus, this field was deleted. The field describing the interesting species in terms of biodiversity was problematic because it depended on the presence of specialists.

After having changed the extent of the survey to study not only the wadi tips but also other sites suitable for rangeland in the wadis, a classification of sites by type was needed. Therefore, a field named "Typesite" with four classes: tips (1), slopes (2), ripped areas (3), or other (4) was added. A field of information was also

added to the database for the interpretation of the possible use of the sites: good site for range improvement (1), medium site (2), nothing to be done in the site (3), or keep the site for biodiversity and collection of seeds (4).

The final form of the GIS consisted of seven types of coverage: 1) The contour lines of the area, every 5 m; 2) The hydrographic network; 3) The roads (highways, roads, and tracks); 4) The airport of Matrouh; 5) The sites registered. This is coverage of points. A click on each point provides information on a tip. A photograph of the site can be displayed by clicking on a point; 6) The selected sites; 7) Four areas that were recommended to be protected for their biodiversity.

What is Needed to Continue Such Surveys

Knowledge

A team of 2-3 persons, who are either specialists, or who would be trained, is needed to cover a number of subject: soil, rangelands, ecology, GIS analysis, and ability to communicate with the farmers. It is recommended that the same team be continuously available in the field to ensure homogeneity of the database. It is also advisable to involve the same team in the second step of the survey; selection and planting of seedlings. This way, coordination would be better than if one team was conducting the survey to identify potential and another team applying the recommendations.

Field Equipment

The needed equipment includes: car and driver; an easy to use GPS with quick acquisition of position and with navigation options to return easily to a registered site; digital camera; soil auger; and range finder to measure distances and areas as precisely as possible.

GIS equipment

The following hardware is needed: laptop computer to check positioning in the field with a minimum of two GB hard disk, 32 MB RAM, and P 150 processor; a Zip drive to store the survey data; and a CD-ROM to store the final database. The software needed is: ESRI ArcView version 3.0 to visualise data and make queries; MapInfo Professional version 4.0 to digitize maps, create coverage's, manage data collected, etc.; ERDAS Imagine, in case the remote sensing data of the area has to be added to the GIS as an additional layer; and JASC Paint Shop Pro version 4.12 (available as shareware) for photograph manipulation. Also needed are maps of the area on a 1:25000 scale to be digitized, or maps already digitized with contour lines (5 m × 5 m), the hydrographic network, and roads (highways, roads, and tracks).

Information to Collect: the Ideal Form

The following are the main fields to be collected based on the initial experience of the team:

- The main fields of information to locate and identify a site must be kept: site number, date, *wadi*

name, x and y coordinates, and film/photograph number.

- Description of the site: type (tip, ripped area, etc.), geomorphology, area, soil information (soil texture and soil depth, and possibly precise information on salinity, presence of crust, etc.), slope, aspect, % of coverage of the soil (rock, bare soil, vegetation, etc.), main species of annuals and perennials, an indication of biodiversity if needed, a comment on vegetation if needed, and the presence of a cistern if supplemental irrigation is needed.
- Information on the owner: name, relation with the owner downstream, comments, and a simple classification of these comments in order to easily extract the information.
- Analysis of the sites: A comment on the site and a brief classification of the site (good, medium, etc.). A field can also be added on the type of plants to be grown (it was not done in this survey but is recommended) and, perhaps, the rate of success in order to monitor and evaluate, some years later, the work done in this type of environment.

Advantages and Possible Applications

This type of GIS application has many advantages for this kind of survey:

- The data is precisely located in time and position.
- It is easy to extract data by simple queries in the database with GIS software *if the data is properly entered*. Maps can be generated in barely half an hour by queries. However, it is essential when first setting up the database to define exactly what might be required to be extracted from the database. If this procedure is done properly, GIS can be an important decision-making tool for project managers.
- The database is easily updated, for example, when returning to a registered site, new data can be entered, the site reassessed, and its progress monitored. Queries in the database can also reveal possible reasons for the success or failure of a particular site or area by overlaying information on soil, landowners, etc.
- The information in the database (text, numbers and photographs) is conveniently stored on a CD ROM or tape.
- An assessment of the requirements for the GIS must be thoroughly discussed before beginning the survey, using the same kind of methodology, to identify the different fields of information to be registered in the database.

Observations and Remarks about Establishment

A visit to the planted sites in late May led to a number of observations. These were visual observations and not real evaluations with exact assessment of plant development.

1. There was either complete failure or good success at the sites. Five out of the eight locations showed survival rates of around 75%; the rest were close to zero.
2. Only *Atriplex halimus* and some *Acacia* were well propagated, the rest seemed to have disappeared.
3. In one spot where there had been hardly any survival due to the fact that the seedlings had been planted without removing the poly-bags, most of the plants recovered well and will certainly survive the next winter.
4. *Atriplex* is an excellent indicator of soil depth and water availability in some places. It is better and more exact than a soil survey for assessing soil conditions. Plant height and volume are, in some specific locations, very well reflected in natural conditions of growth.
5. Complete failures are presumably due to one or a composition of the following shortcomings: (i) *insufficient soil moisture-holding capacity*, (ii) *plantation pits are too close to each other*, (iii) *soil was not wet enough at the date of transplantation*, (iv) *no plant development in saline soils*, and (v) *poor transplantation management* (the excavated soil of the pits had not been placed down-slope of the pit) resulted in the surface runoff water not being caught in many cases.
6. There were no traces of animal movement in any of the sites. Farmers obviously kept their promise to keep the planted areas free of flocks.
7. The amount and distribution of rainfall was below average in the winter of 1998/99, as well as in the beginning of 1999/2000.

Underground Vetch (*Vicia sativa* spp. *amphicarpa*): Potential Pasture and Forage Legume for Dry Areas

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ABSTRACT

Subterranean vetch (*Vicia sativa* spp. *amphicarpa* [Dorth.] Aschers & Graebn.) is native to disturbed grasslands of the Mediterranean basin, where heavy grazing, seasonal drought, and erosion act as strong selection forces. It produces two pod types, *above-ground* and *5 cm below* the soil surface. Unlike subterranean clover (*Trifolium subterranean* L.), which buries its seeds after flowering above-ground, subterranean vetch flowers and forms pods beneath the soil surface on under-ground stems. The aerial pods are produced after vegetative development ceases, while the under-ground pods are produced in ontogeny. The ability of this unusual vetch to survive in marginal lands with low rainfall (about 250 mm per year), and to produce nutritious herbage and pods, are important characteristics which help address rehabilitation of degraded rangelands and increase feed production for small ruminants.

Research at the International Center for Agricultural Research in the Dry Areas (ICARDA) has assessed the productivity of herbage and seed of under-ground vetch, its ability to grow in rotation with barley in the marginal low-rainfall areas, and its capacity to regenerate after heavy grazing. Drier conditions in 1989 favored earlier under-ground flowering; the number of under-ground pods was higher than that of aerial pods. Grain yield of barley (var. Atlas) was around 2.0 t ha⁻¹ after under-ground vetch and only 1.2 t ha⁻¹ after barley. Grazing under-ground vetch had no effect on the productivity of the succeeding barley crop. The aerial and under-ground pods serve two distinct functions; aerial pods increase the dissemination within suitable habitats, while under-ground pods increase the probability of plant survival under adverse conditions such as drought and heavy grazing. Potential use of under-ground vetch serves two purposes, namely, the rehabilitation of marginal lands and production in rotation with barley.

INTRODUCTION

Subterranean or under-ground vetch (*Vicia sativa* spp. *amphicarpa* [Dorth.] Aschers. & Graebn.) is native to disturbed grassland of the Mediterranean basin, where uncertainties such as heavy grazing, seasonal drought and erosion act as strong selection and persistence forces (Nazim and Dorlu, 1970; Nazim and Donald, 1970; Ehrman and Cocks, 1990; Abd El Moneim and Saxena, 1995). It produces pods containing seeds above

and below the soil surface (Rumbaugh, 1979). Unlike subterranean clover (*Trifolium subterranean* L.), which produces flowers above-ground and, after pollination, the developing fruits and seeds are buried in the soil by their elongating peduncles or primary flower stalk, subterranean vetch flowers beneath the soil surface on under-ground stems.

Flowers and pods are dimorphic, the aerial flowers having the typical blue-purple colour of common vetch (*Vicia sativa* spp. *sativa*), while the under-ground flowers are white, non-chlorophyllous, and much smaller. Under-ground pods have fewer and larger seeds than the aerial pods, and the seeds are usually pale compared with greenish-black in aerial pods. The aerial seeds are produced after vegetative development ceases, while the subterranean seeds are produced early in ontogeny (Rumbaugh, 1979; Saxena et al., 1993; Abd El Moneim and Saxena, 1995); subterranean chickling (*Lathyrus ciliolatus* Guss. Syn. *L. saxatilis* L.) is also dimorphic and is endemic to Syria and found only on volcanic soils (Ehrman and Maxted, 1990; Abd El Moneim and Saxena, 1995).

Subterranean vetch is common in the heavily grazed grasslands of West Asia, where rainfall is lower than 250 mm per year (Ehrman and Maxted, 1990; Abd El Moneim and Saxena, 1997). It may, therefore, be useful for improving the productivity of dry grasslands in West Asia and other Mediterranean areas where climatic conditions are similar (e.g., North Africa, Australia, and Chile). It also grows wild in fallows and in hilly and mountainous parts of the Mediterranean region, preferring soil mixed with sufficient stones or gravel to provide good aeration (Saxena et al., 1993). It grows well in microhabitats that are relatively dry and too cold for other vetches (*Vicia* spp.), which make it a potential pasture or forage legume in cereal/pasture rotations (Cocks and Abd El Moneim, 1991).

While the few studies that dealt with under-ground vetch focused on morphology, relatively little is known about the productivity, agronomy, ecology and utilization of such kinds of "*amphicarpous*" species. Therefore, the objectives of this study were (i) to evaluate different ecotypes of subterranean vetch (collected by the first author from their natural habitats) in west Syria, and (ii) to study its productivity and ability to grow in rotation with barley under rainfed conditions.

MATERIALS AND METHODS

Location

The experiments were conducted at Tel Hadya (35° 55' N, 36° 55' E, altitude 362 m), 35 km south of Aleppo, in northwest Syria. Tel Hadya has an estimated mean annual rainfall of 342 mm (Dennett et al., 1983) and a growing period of 6.5 months. The climate is Mediterranean, and rain normally falls from October until May (meteorological data are given in Table 1). The soils are well-structured, reddish-brown clays, classified as a fine, thermic, montmorillonitic Calcixerollic Xerochrept merging into a Chromic Calcixerert (Ryan et al., 1997).

Based on the results obtained from these two experiments, a third experiment was started in 1989/90, in which clipping (simulated grazing) was replaced by actual grazing by sheep, and subterranean vetch was grown in rotation with barley, where it was allowed to regenerate naturally to give a ley-farming system, i.e., pasture legume/barley/self-regenerated pasture. In this third experiment, a randomized block design was used with three replicates. Plot size was 10 × 10 m. The experiment was sown on 29 November 1989 at 60 kg ha⁻¹ with scarified seed of *V. sativa* spp. *amphicarpa* (# 2416/2569) and 18 kg P ha⁻¹ was applied as superphosphate. The treatments were grazing all the above-ground herbage on 15 February, 15 March, 15 April,

Table 1. Meteorological data for the Tel Hadya site where the subterranean vetch trials were conducted.

Season	Air Temperature			Frost Days	Rainfall
	Mean		Absolute Minimum		
	Maximum	Minimum			
	----- C -----				
1988 - 89	25.5	10.2	- 9.9	52	234
1989 - 90	25.0	9.8	- 8.9	54	233
1990 - 91	25.2	10.7	- 6.4	35	290
1991 - 92	23.6	9.2	- 8.8	57	352
1992 - 93	24.3	9.5	- 8.7	50	290

Experiments

In 1988/89 season, two experiments were conducted. In the first, scarified seeds of four accessions (genotypes) of subterranean vetch, originating from Syria, were sown in a split-plot design with three replicates, the main plots being the four genotypes and the sub-plots being the time of clipping (simulated grazing) treatments (clipping on 5th March, 1st April, and no clipping). Individual plot size was 9.0 m². The experiment was sown with an Øyjord experimental drill within 10 days after the first autumn rains. Seeding rate was 60 kg ha⁻¹, and all plots received a basal dressing of 40 kg P₂O₅/ha.

The plants were clipped 5.0 cm above the soil surface in an area of three 0.5 m² quadrates at each clipping date. Herbage was dried at 85 °C for 24 h to determine dry matter yield. The under-ground seed yield was measured at full maturity of under-ground pods by removing five cores with a total surface of 336 cm² to a depth of 15 cm. The cores were collected in the quadrates from which the herbage had previously been harvested.

In the second experiment, the same genotypes were used with the same experimental design, but with different treatments applied to the sub-plots, e.g., at 50% flowering (above-ground) the plots were clipped at 5 cm (*severe*), 7.5 cm (*moderate*), and 10 cm (*light*) above the soil surface, and also plots were left without clipping. The seed yield was measured as described previously.

and plots left without grazing. Barley plots (var. Atlas 46) were also planted at a rate of 100 kg ha⁻¹.

Four quadrates (50 × 50 cm) were cut to ground level from each plot of subterranean vetch before it was grazed to determine the herbage yield before grazing. At full maturity, the under-ground seed production was measured using cores of 20-cm depth with a total surface area of 336 m². Above- and under-ground pods were threshed, cleaned by hand, and weighed to estimate seed yield.

After cultivation to a depth of 5 cm, barley (Var. Atlas 46) was sown on 10 December 1990 over the whole experimental area at a rate of 100 kg ha⁻¹ and given 18 kg P ha⁻¹ as in the previous year. During the barley phase, the seed bank of subterranean vetch was measured before planting barley and after harvesting it. After the barley phase (1991/92), the under-ground seeds of the vetch germinated after the first autumn rain, giving a pasture. Herbage yield was measured when 50% of the plants had above-ground flowers. In this experiment, we are referring to 1989/90 as establishment year, 1990/91 as the barley phase, and 1991/92 as the self-regenerated vetch year. Analysis of variance of the data was conducted according to Steel and Torrie (1980).

RESULTS AND DISCUSSION

Clipping Trials

The plants clipped in early April produced more herbage and under-ground seeds than those clipped in the beginning of March (Table 2), with variation

between genotypes and clipping dates. The under-ground seed bank at early clipping (1st March) varied from 278 to 580 kg ha⁻¹, whereas, at early April, it varied from 330 to 580 kg ha⁻¹. Late clipping in April also prevented aerial seed production (the flowers were removed) and the plants were able to partly respond by increasing the yield of subterranean pods.

Severe clipping to 5.0 cm also prevented the production of aerial pods, and the plants responded by producing subterranean pods, which contained seeds. The seed bank, under severe clipping, varied from 275 to 370 kg ha⁻¹ according to the genotypes, indicating that genotypes respond differently (Table 3). Light clipping produced more subterranean seeds than moderate clipping.

The drier conditions in 1988/89 favored earlier subterranean flowering, and subsequently the proportion of subterranean pods was greater. Following the prolonged drought in early 1989, a large proportion of the plants produced only subterranean pods, indicating that the plants were able to persist under drought and severe clipping. The four genotypes tested also showed a high level of cold tolerance throughout the 52 frost nights, with absolute minimum temperature as low as of -9.9 C.

subterranean vetch produced up to 0.9 t dry herbage and 0.5 t under-ground seeds per hectare under April clipping. These results confirm the conclusion that subterranean vetch is adapted to dry conditions and persists well under heavy grazing and is likely to make a valuable contribution to pasture in dry areas.

In contrast to annual medics (the common pasture species), the high proportion of under-ground seeds (>90%) will result in almost complete protection from grazing. The subterranean flowers and pods are less exposed to damage by mammals and insects than comparable above-ground structures. The 80 to 95% hard-seededness of seeds produced under-ground (Fayad, 1993) was also an added advantage to this unusual vetch as a new pasture plant that could self-regenerate after a cereal crop. These results were sufficiently promising to use the subterranean vetch in rotation with barley under rainfed conditions.

Rotation Trial

During the establishment year, when subterranean vetch was grazed by sheep, herbage yield was 830, 750, and 900 kg ha⁻¹ compared with 2020 kg ha⁻¹ obtained from the non-grazed plot. The under-ground seed bank after grazing was 82, 225, 301 kg ha⁻¹, when grazed by

Table 2. Herbage and underground seed yields of subterranean vetch genotypes as affected by clipping time, 1989-90.

Genotypes IFLV am#	Herbage					Under-ground Seed				
	<u>5</u>	<u>1</u>	Without clipping	Mean	SE ±	<u>5</u>	<u>1</u>	Without clipping	Mean	SE ±
	Mar.	Apr.				Mar.	Apr.			
-----kg ha ⁻¹ -----										
2416	975	1387	1600	1320	158	352	580	1030	654	52
2660	735	887	1400	1007	120	314	500	1162	659	59
2647	545	577	1090	737	66	294	330	560	395	36
2650	660	910	1100	890	82	278	460	730	489	39
Mean	728	940	1297	988	-	309	467	870	549	-
SE ±	58	95	155	109	-	29	40	75	29	-

Table 3. Underground seed yield of subterranean vetch genotypes as affected by clipping height, 1989 - 90.

Genotypes IFLV am. #	Clipping Height (cm ⁻¹)			Without Clipping	Mean	SE ±
	<u>5.0</u>	<u>7.5</u>	<u>10.0</u>			
				-----kg ha ⁻¹ -----		
2416	370	480	615	1380	711	40
2660	310	420	590	1280	650	58
2647	322	390	480	1250	610	55
2650	275	302	510	1000	521	42
Mean	319	398	545	1227	622	-
SE ±	22	35	50	127	47	-

Seed production of *Medicago rigidula* L, a self-regenerated pasture plant, was reduced to 0.4 t ha⁻¹ by the dry conditions of 1990/91 (Christiansen et al., 1996). It produces up to 1.0 t ha⁻¹ in normal conditions of Tel Hadya (Cocks, 1990). Even in 1988/98, however

sheep on 15 February, 15 March, and 15 April, respectively, compared with 458 kg ha⁻¹ from non-grazed plots. Barley after barley produced significantly less yield than barley grown after subterranean vetch (Table 4). Grazing time of under-ground vetch had no effects

on the productivity of barley. Early grazing of vetch greatly affected the yield of under-ground seeds. The seed bank varied from 82 kg ha⁻¹ for February grazing, compared to 225 and 301 kg ha⁻¹ for grazing in March and April, respectively.

The differences in vetch seeds found buried in the soil at the beginning and the end of the barley phase would give an indication of germination and

can secure for its progeny favorable sites previously occupied by the parental plants. These findings are in agreement with those of Koller and Roth (1964) on *Gymnarrhena micrantha*, which also produces aerial and subterranean fruits that differ markedly from subterranean vetch.

Table 4. Effect of grazing date on it herbage yield of subterranean vetch in the establishment year.

Parameter	Grazing Date				Barley	SEM±
	15.02	15.03	15.04	No grazing ¹		
	-----kg ha ⁻¹ -----					
Herbage yield (1989/90)	830	750	900	2020	-	57*
Seed bank (Sept. 1990)	82	225	301	458	-	27*
Barley biological yield (1990/91)	4300	4200	4000	3900	3100	215*
Barley grain yield (1990/91)	1966	2035	1925	1900	1200	98*
	(V/B) ²	(V/B)	(V/B)	(V/B)	(B/B)	
Seed bank (Sept. 1991)	75	205	290	400	-	97*
Herbage yield (1991/92)	3200	3900	3800	4000	-	320 (N.S.)

¹Total biological yield above-ground. ²Barley (B) after Vetch (V). *Significant at 0.05 probability level. N.S.= Non-significant. ³Yield of succeeding barley as compared to barley after barley, vetch seed bank at the start and the end of barley phase, and dry herbage yield of self-regenerated vetch.

hardseededness of buried seeds during the barley phase. In the third year, the under-ground seeds germinated (self-regeneration) after the first rain. The result was a dense pasture without any external inputs. The productivity of the self-regenerated pasture varied from 3.2 to 4.0 t ha⁻¹ dry herbage, and it could be grazed by sheep in the spring.

Like other legumes, subterranean vetch is valued for its nitrogen-fixation ability, its nodules being large and effective. Therefore, the barley yields after subterranean vetch, were much higher than barley after barley. The high herbage yield of self-regenerated vetch of 1991/1992 establishes the potential of this unusual vetch as a pasture plant. Unlike annual medics (*Medicago* spp.), which are naturally found in undisturbed habitats and can be buried deeply by conventional tillage, which prevents seedling emergence, one of the major advantages of subterranean vetch is that it can tolerate a moderate level of soil disturbance during the barley phase because of the large size of the under-ground seeds.

The results clearly showed that subterranean vetch can regenerate naturally and form productive pastures when grown in rotation with barley. These experiments have resolved one of the important problems preventing introduction of ley-farming: a suitable annual legume has been identified which adapted both to the soil and climate of north Syria and to the ley-farming system as well.

The under-ground flowering may be an adaptation to habitats where a dry period follows the flowering season, as it is reproductively advantageous for a plant to have some of its seeds already buried in a dry soil. It obviously is a mechanism by which an annual species

CONCLUSIONS

The production aerial and under-ground pods by subterranean vetch serve two distinct functions: aerial pods increase the dissemination within suitable habitats, while under-ground pods increase the probability of survival under adverse conditions such as drought and heavy grazing.

The subterranean "amphicarpous" vetch is a typical Mediterranean species which is common in poor marginal lands. It provides a new opportunity for use in rehabilitation of marginal lands and in a ley-farming systems with rotation of barley in areas that are too dry for production of other vetches and medics (*Medicago* spp.). It produces more than 50% of its pods under-ground, leaving a good seed bank for self-regeneration. It is tolerant to drought and cold, and has good persistence under heavy grazing, thus providing particularly valuable forage under marginal land conditions. As available lines of this crop, however, have relatively low herbage yield, improvement work at ICARDA is being done to incorporate increased herbage yield through hybridization and selection program.

The need to cope with the increasing feed requirements of the expanding livestock population in West Asia and North Africa (WANA) necessitates the introduction of such kinds of pasture and forage legumes into the farming systems in these areas. In such areas, under-ground vetch could replace fallow in a way that a ley farming system could be established. Aside from high feed production, the forage legume in the ley farming system would have a tremendous impact on cereal production through symbiotic nitrogen fixation.

REFERENCES

- Abd El Moneim, A.M., and M.C. Saxena. 1995. Demand for meat and milk in WANA increases urgent need for feed from forage legumes. *Diversity*. 2: 120-121.
- Abd El Moneim, A.M., and M.C. Saxena. 1997. Developing cultivated forage legumes for improved yield and quality to feed livestock in the dry areas. p. 205-213. In N. Haddad et al. (Ed.) Improvement of crop-livestock integration system in West Asia and North Africa. *Proc. Regional Symposium on Integrated Crop-Livestock Systems in the Dry Areas of West Asia and North Africa*. Amman, Jordan. 6-8 Nov. 1995. ICARDA, Aleppo, Syria.
- Cocks, P.S. 1990. Dynamics of flower and pod production in annual medics (*Medicago* spp.) II. In swards at low and high density. *Aust. J. Agric. Res.* 41: 923-931.
- Cocks, P.S., and A.M. Abd El Moneim. 1991. A system approach to the evaluation of pasture and forage legumes in West Asia. p. 281-296. In A. Smith, and L. Robertson (Ed.) Legume genetic resources for semi-arid temperate environments. *Proc. Inter. Workshop on "Genetic Resources of Cool-Season Pasture, Forage, and Food Legumes for Semi-Arid Temperate Environments*. Cairo, Egypt. 19-24 June 1997. ICARDA, Aleppo, Syria.
- Christiansen, S., A.M. Abd El Moneim, P.S. Cocks, and N. Singh. 1996. Seed yield and hard seededness of two amphicarpic pasture legumes (*Vicia sativa* spp. *amphicarpa* and *Lathyrus ciliolatus*) and two annual medics (*Medicago rigidula* and *M. noeana*) *J. Agric. Sci.* 126: 421-427.
- Dennett, M.D., J.A. Rodgers, and J.D.H. Keatinge. 1983. Simulation of a rainfall record for the site of a new agriculture development: an example from northern Syria. *Agric. Meteor.* 29: 247-258.
- Ehrman, T., and P.S. Cocks. 1990. Ecological of annual legumes in Syria. *J. Appl. Ecol.* 27: 247-258.
- Ehrman, T., and N. Maxted. 1990. Eco-geographic survey and collection of Syria. *Vicieae and cicereae (Leguminosae)*. FAO/IBPGR *Plant Genetic Res. Newsletter* 77: 1-8.
- Fayad, E.S. 1993. Studies on the potential of subterranean vetch (*Vicia sativa* spp. *amphicarpa* Dorth) as a pasture plant for dry areas. (In Arabic, with English summary). *M.Sc. Thesis*. University of Tishreen, Lattakia, Syria.
- Koller, D., and N. Roth. 1964. Studies on the ecological and physiological significance of amphicarp in *Gymnarrhena micrantha* (compositae). *Amer. J. Bot.* 51: 26-35.
- Nazim, A., and N. Durlu. 1970. Subterranean vetch seed enhances persistence under grazing and severe climates. *J. Range Manage.* 23: 61-63.
- Nazim, D., and R.C. Donald. 1970. A vetch producing both subterranean and aerial seeds. *Agron. J.* 62: 55-56.
- Rumbaugh, M.D. 1979. A very unusual vetch. *Utah Sci.* 40: 40-42.
- Ryan, J., S. Masri, S. Garabet, J. Diekmann, and H. Habib. 1997. Soils of ICARDA's agricultural experimental stations and sites: climate, classification, physical and chemical properties, and land use. *Tech. Bull.* ICARDA, Aleppo, Syria.
- Saxena, M.C., A.M. Abd El Moneim, and M. Ratinam. 1993. Vetches (*Vicia* spp.) and chicklings (*Lathyrus* spp.) in the farming systems in West Asia and North Africa and improvement of these crops at ICARDA. p. 2-8. In J.R. Garling and M.W. Perry (Ed.) Potential for *Vicia* and *Lathyrus* species as new grain and fodder legumes for southern Australia. *Proc. Vicia/Lathyrus Workshop*, Perth, Western Australia.
- Steel, R.G.D., and J.H. Torrie. 1980. *Principles and procedures of statistics: biometrical approach*. 2nd Ed. Mc Graw-Hill. New York.

Kochia: Fodder Crop to Combat Desertification

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ABSTRACT

Kochia is a good option to prevent and combat desertification, because the main priorities for rural development are water and forage availability. *Kochia scoparia* L. Schrad belongs to the family *Chenopodiaceae*. It was established in America in the early 1900's and it has been growing in Mexico for the last 25-30 years. *Kochia* grows well in a great variety of climates and soil, so it represents a good option as a fodder crop. This paper deals with the evaluation of *Kochia* under different climates and soils in Mexico in the last 15 years, considering agronomic, nutritional and socioeconomical aspects.

Kochia has a short vegetative cycle, i.e., 70 day to the time for cutting (at beginning of flowering stage); it has low water requirement (30-50 cm); and high yields (50-80 ton/ha) of green matter; it has high protein content (18-26%) and good palatability and is has a ratio cost/benefit of 1:5 to 1:7. *Kochia* is a good option for soils with salinity problems; due to its low water requirement, it can be helpful in reducing aquifer over-exploitation. It is necessary to reinforce research on animal behavior with different concentrations of *Kochia* in the ration and to establish an interdisciplinary team of researchers, working together with producers and cattle breeders, in order to utilize *Kochia* safely and efficiently.

With respect to the scarcity of forage crops, especially during the dry season, *Kochia* represents a good option as supplementary forage because it grows quite consistently under adverse ecological conditions. Many countries around the world are struck by devastating droughts, livestock business is seriously affected, and, most of the time, cattlemen do not find adequate alternative food supplies, especially at low costs of production.

INTRODUCTION

In Mexico, in the last decades, livestock production faces serious problems for the feeding of animals, a situation that is reinforced by strong periods of drought, erratic rainfall, high costs for pumping water, a marked index of overgrazing, and the upward erosion of the soils. This induces the scarcity and expensiveness of feeding products that constitute a strong obstacle for present and future production of meat, milk and eggs, indispensable elements in the feeding of 100 million Mexicans.

In Mexico, 62 percent of the territory (113 million hectares) is devoted to animal production; in 70% of that area processes of overgrazing are occurring, which cause shortages of forage and death of the livestock. In

the costs generated by the livestock production, 70 to 80% are contributed to feeding.

The objective of this paper is to present results of 15 years research and demonstration by considering three aspects: agronomic, nutritional, and socioeconomic of *Kochia* (*Kochia* L. Schrad var. *Emerald*) of the *Chenopodiaceae* family, as a fodder crop to face the urgent necessity of forage production. *Kochia* is an annual plant, high in protein, with good palatability, and well adapted to diverse ecological conditions. *Kochia* is receiving attention by farmers and scientists because it represents a good option as a grazing or forage crop; it can also be ensiled or baled.

ECOLOGICAL POTENTIAL

The *Kochia* species and varieties found in different parts of the world are the following: *Kochia scoparia* (L) Schrad, reported in People's Republic of China, former Soviet Union, USA, Canada, Syria, Saudi Arabia, Greece, Italy, Spain, Morocco, Argentina, England, Egypt, India and Mexico (Anaya, 1996; Zahran, 1986; and Griffin, 1990); *Kochia melanoptera* Bunge, People's Republic of China, Soviet Union, USA; *Kochia prostrata* (L) Schrad var. *Canescens* Moq, People's Republic of China; *Kochia prostrata* (L) Schrad var. *Villosissima* Bong and Mey, People's Republic of China; *Kochia iranica* Lity ex Bronn, People's Republic of China, Iran; *Kochia pyramidata*, Australia; *Kochia planifolia*, Australia; *Kochia sedifolia*, Australia; *Kochia georgei*, Australia; *Kochia tomentosa*, Chile; *Kochia gregori*, Chile; *Kochia triptera*, Chile; *Kochia enchylaenoide*, Chile; *Kochia indica*, India; *Kochia californiana*, USA (Anaya, 1996).

Kochia represents a good option for forage production. The following aspects relating to research and production should be considered (Anaya, 1992):

- Reinforced research on adaptation of *Kochia* to different climate and soil conditions in order to measure the potential yield of forage and seed; this should be connected with plant breeding.
- Evaluation of its quality as forage and the behavior of different animal species with varying *Kochia* concentrations in the ration.
- Analysis of the real socioeconomic potential of *Kochia*.
- The urgent and necessary creation of interdisciplinary teams of researchers and producers in order to use *Kochia* safely and efficiently.

Kochia could be sown in 70% of the national territory due to its capacity of germination under low temperatures, its deep root system, its adaptability to scarce

precipitation, and its resistance to salinity. Mexico is suffering the effects of salinity in different areas because soil productivity is diminishing; more than one million hectares under irrigation are affected. It tolerates pH's between 5.0 and 9.0 and also grows well in stony soils, for what its cultivation could be carried out so much under rainfed conditions as in irrigated zones (Osuna, 1984; Osuna, 1985; Farias, 1985; INIFAP, 1986; Carmona et al., 1993; Contreras, 1987 and Anaya, 1993).

Kochia is distinguished by its low water consumption since, with only 200 to 300 millimeters, it produces 50 to 70 tons of green forage per hectare (10 to 15 tons of dry matter per hectare), which means that with 180 to 200 liters of water per kilogram of dry matter could be obtained. Forages like alfalfa require, for the same amount of dry matter, of 1000 to 1200 liters of water, or from 5 to 6 times more (See Table 1).

In the Valley of Mexico, between June and October 1998, three different clippings were taken at 45, 60 and 75 days after the seeding date. When the first clippings were made on August 15th, Kochia was 55-cm tall and yielded 3,400 kilograms of dry matter per hectare with a protein content of 27%. At the second set of clippings, taken on August 30th, plants were 85-cm tall and yielded 7,500 kilograms of dry matter per hectare, with the protein content of 23%. At the third clipping on September 15th, plants were 115-cm tall with a yield of 10,500 kilograms of dry matter per hectare; this time the protein content was 18% (Anaya, 1999).

The following aspects in the ecological improvement with Kochia have been observed:

- Reinstatement of the vegetative cover in rangelands.
- Stopping environmental degradation by controlling erosion and overgrazing.

Table 1. Yield of Kochia in the first cutting (70-80 days) in Mexican states.

<u>Location</u>	<u>Rainfall in Growing Period</u> --mm--	<u>Irrigation</u> --mm--	<u>Dry Matter</u> --t/ha--	<u>Crude Protein</u> --%--	<u>Protein</u> -kg/ha-	<u>Water Use Efficiency</u> -l/kg/DM-
Calculalpan, Tlaxcala	280		16	20	4480	175
Tecamac,	260		13	21	2930	200
Libres, Puebla	300		12	21	2520	250
Montecillo,	310		14	26	3640	221
Jalpa, Zacatecas	250		13	18	2340	192
Sayula, Jalisco	290		14	20	2800	207
Oaxaca, Oaxaca	270		13	19	2470	208
Colon, Qro.	280		12	19	2280	233
Leñn, Guanajuato	320		17	21	3570	188
Tlahuac,	300		14	23	3220	214
Texcoco,	320		14	21	2940	228
Temamatla,	300		15	18	2700	200
Tizayuca, Hgo.	240		11	21	2310	218
Cuitzeo, Michoacan	330		15	22	3300	220
Comarca, Lagunera		600	18	24	4320	333
Dgo.		500	20	23	4600	250
Montecillo,		400	16	22	3520	250
Cd. Obregon, Sonora		450	16	21	3360	281
Colon, Qro.		500	20	20	4000	250
Mixquic, Teotihuacan		550	17	23	3910	239

According to Diaz, (1995), under salinity conditions in the Mexico Valley, seeding dates are related with the capacity of Kochia to extract salts during the dry season (October to April). Kochia can extract 8.7 ton/ha with a yield of 24 ton/ha of dry matter. Kochia accumulates larger amounts of minerals than conventional hays, particularly when grown on saline soils, which increases water consumption by animals. Diaz (1995) also mentions Kochia's efficiency in the use of water; Kochia requires 278 liters producing 1 kilogram of dry matter, while alfalfa requires 1185 liters to produce one kilogram of dry matter.

- Recovery of soil fertility by increasing the deposition of organic matter.
- Modification of the albedo.
- CO₂ fixation.
- Entrance of energy to the ecosystem.

ANIMAL NUTRITION

Very interesting results concerning production, chemical analysis, and digestibility of Kochia compared with alfalfa were shown (Sherrod, 1971; Finley, 1971; Sherrod 1973).

- Protein content of Kochia compared well with that of alfalfa.
- Kochia digestibility of energy and protein was similar to that of alfalfa hay.
- Kochia yield was 11327 kg/ha of dry matter.

Díaz (1995) studied the effect of maturity on nutritive value of Kochia and found that, when harvested at or before full bloom, it was quite similar in digestible nutrient intake to alfalfa when harvested at 20% bloom. Kochia is forage with good palatability, which allows using it as a source of protein in diets and balanced food (Anaya, 1999). Several experimental treatments were evaluated using diets with different levels of Kochia and alfalfa on Creole lambs. The daily increments of weight were of 290 to 300 grams, which indicates that the results were similar statistically but with a reduction of 40% in the costs of lamb nutrition and production in the diet with Kochia (Rodríguez, 1988; García et al., 1989; Trejo, 1997).

In research carried out in Chapingo, Mexico, five combinations of Kochia/alfalfa were evaluated for food of Creole rabbits in phase of development and fattening. Results pointed out no difference between the treatments for the consumption of total food (308 to 432 kilograms) and nutritious conversion (3.70 to 4.74 kilograms of food for kilogram of meat) during a period of 30 days (Ramírez y Méndez, 1998; Santana, 1991). Studies to evaluate the efficiency for production and quality of milk of Creole goats in Kochia as a substitute of alfalfa in the "Comarca Lagunera Region" of Coahuila and Durango states, indicates that Kochia could be considered as an ingredient in diets, up to 40% (Flores, 1992).

In Hidalgo State, conditions of aridity and semi-aridity induced the installation of productive modules with Kochia in an integral approach. The benefited population of animals was 1,057 cattle, 7,650 sheep, and 5,100 goats. With the implementation of the project, the index of grazing improved in 1.66% upon passing of 0.06 to 1 animal unit per hectare with the introduction of Kochia and different vegetation to pasture land; and in 3.33% upon passing of 0.03 to 1 animal unit per hectare with the introduction of special pasture for goats (Gobierno del Estado de Hidalgo, 1995).

ECONOMIC POTENTIAL

In USA, Mexico and Canada, cattlemen have found which a grazing program that includes Kochia can provide low cost/high benefits with relatively little effort in producing the forage (Fuehring, 1984; Foster, 1980; Coxworth, 1988; Anaya, 1999). In Mexico, the distribution of rains shows a strong period of drought, which indicates shortage of forage and death of livestock. It is necessary to consider that Kochia requires approximately 70 days from the seeding to the moment of court (to 5% of flowering). Also, its wide adaptation

and resistance to low temperatures allows its cultivation and the readiness of green forage almost all year by means of the establishment of periodical seeding dates.

The seasonality of production of fodder crops, and as favorable forages can increase prices up to 300 to 400%, suggest that Kochia as an excellent option for producing forage. In a hectare, the cost of production until packing does not exceed the 3,400 pesos per crop. Under good conditions, the production could be 100 tons of green forage per hectare per harvesting, and one could obtain four harvestings per year. Suppose that four harvestings are obtained per year with a yield of 70 tons per hectare per crop of green forage. A price for Kochia of 90% of the value of alfalfa in conditions of relative abundance of the forage is assigned. If the price of alfalfa is of 2,000 pesos (10 = \$1) per ton of dry matter, the Kochia could be sold for 1,600 pesos per ton of dry matter (Reyna, 1994).

Kochia contains 80% moisture. Supposing that the production per harvesting is of 14 tons of dry matter for hectare, in four harvestings, 56 tons of dry matter per hectare will be obtained. When dried, the income will be of 92,600 pesos and the cost of production, including the packing, would be of 13,600 pesos per hectare per year. Relating the value of the production against the costs, it is observed that the revenues are of 79,000 pesos per hectare per year; the relationship benefit/cost is of 5.8:1, which means that for each invested peso, 5.8 are obtained.

IMPACT IN THE SOCIAL WELLBEING

With 56 tons of dry matter per hectare per year, the readiness of forage for 12 animals units is guaranteed for one year. An animal unit means the necessary forage for the food and production of one cattle of 450 kilograms of weight or its equivalent in another type of animal.

The consumption of milk recommended by the World Organization for the Agriculture and the Feeding (FAO) is of 180 liters for person per year, or 450 milliliters per day. Thus, if 11 cattle (50% Holstein) fed with Kochia will produce around 15 liters per day, this makes a total of 165 liters per day. For a family of 6 members, the necessities of milk are of 2.7 liters per day, which means that there is a surplus of 162.3 liters per day (Trejo, 1997). If sold at 3 to 3.5 pesos per liter of raw milk, the revenues for sale would be of 489.9 to 568.1 pesos per day, or of 14.00 to 16.23 wages, which they cooperate to cover the costs of production, as well as the investment and the saving (Trejo, 1998).

Using Kochia as a source of protein in the diet of the livestock guarantees the readiness of milk, meat, egg and their derived products; this means an appropriate feeding for the inhabitants and better levels of life, supporting the sustained development of the family economies and the prevention and control of desertification.

CONCLUSIONS

Kochia is adapted to a great variety of ecosystems; it resists frost, and it is tolerant to drought and salinity. It is a good option as a fodder crop and as a protein supplement in animal nutrition. Cattlemen may use this fodder crop for diverse animal species by restricting it to less than 40% of the ration as a source of protein.

Socioeconomical analysis indicates satisfactory net earning of 12000 to 14000 pesos per hectare in only 70 days with a benefit/cost ratio of 6:1. Kochia has positive effects in the recovery of rangelands, of eroded soils, in aquifer regeneration due to its low water consumption, and in watershed protection. Water, basic grains, and forage availability are, and will be, basic factors for sustainable development in rural areas.

REFERENCES

- Anaya, G.M. 1992. Socioeconomic and ecological potential of Kochia as a fodder crop to complement rangeland management in arid and semi-arid regions of Mexico. p. 356-359. *In*: IVth Int. Rangeland Cong., Montpellier, France.
- Anaya, G.M. 1993. Kochia: A new alternative for forage under high salinity conditions of Mexico. p. 459-464. *In* H. Lieth and A. Al. Masoom (Ed.): Towards the rational use of high salinity tolerant plants. Kluwer Academic Publishers, Netherlands. Vol. 1.
- Anaya, G.M. 1996. *La Kochia scoparia* L. Schrad (Coquía). Una opción forrajera para zonas áridas y semiaridas de México en: Estudios de Caso de Especies Vegetales Para las Zonas Áridas y Semiáridas de Chile y México. Serie: Zonas Áridas y Semiáridas No 10 FAO. Santiago de Chile. Chile. p. 47-110
- Anaya, G.M. 1999. Potencial forrajero, ecológico y económico de la Coquía (*Kochia scoparia* L-Schrad var Esmeralda). *Guía Técnica*. Colegio de Postgraduados, IRENAT, Montecillo, Méx.
- Coxworth, E. et al. 1988. Effect of stage of maturity on yield, feed value and constituents of Kochia forage grown on a saline soil. p. 127-148. *In*: E. Coxworth, D. Green, and J.A. Hernan (Ed.). Improving the agronomics and feed value of Kochia. Saskatchewan Research Council. Saskatoon, Saskatchewan, Canada, S.R.C. Tech. Rep. No. 221.
- Carmona, B.S. and G.V. De las Fuentes. 1993. Production of halophyte forage plants and their use in semi-desert-like conditions. p. 147-155. *In*: IVth International Conference on Desert Development "Sustainable Development for our Common Future". México, D.F.
- Contreras, G.P.E. 1987. Evaluación de 12 fechas de siembra en Kochia (*Kochia scoparia*) bajo condiciones de riego en el norte de Coahuila. Avances de investigación agrícola en zonas de riego y temporal. INIFAP-SARH. p. 304-305
- Díaz, E.L.F. 1995. Potencial productivo de la Kochia scoparia en suelos salinos del Valle de México. Tesis Doctoral. Colegio de Postgraduados. Montecillo, Méx. México. 260 pp.
- Finley, L.G., and L.B. Sherrod. 1971. Nutritive value of Kochia scoparia. *J. Dairy Sci.* 54: 231-233.
- Foster, Ch. 1980. Kochia: Poor man's alfalfa shows potential as feed. *Rangelands* 2: 22-23.
- Fuehring, H.D. 1984 Cultural practices for Kochia forage production (*Kochia scoparia*, forage crops). Res. Rep. N.M. Agr. Exp. Stn. Las Cruces Issue 538, 5 p.
- Farias, J.M. 1985. Adaptación del cultivo: Kochia scoparia a las condiciones de la Comarca Lagunera. SARH. Centro de Inv. Agr. Del Norte. Avances de Investigación Agrícola. CIAN 85:031:48. Torreón, Coah.
- Flores, N.M.S. 1992. Eficiencia en la producción de leche en cabras criollas con la utilización de Kochia scoparia como sustituto de alfalfa en la Región Lagunera. Tesis de Licenciatura. Instituto Tecnológico Agropecuario No. 10. Ejido Ana. Torreón, Coah.
- García, C.R., et al. 1989. Digestibilidad Aparente de Kochia scoparia (L) Roth en Borregos. XXI Reunión de la Asociación Mexicana de Producción Animal (AMPA). Octubre 11-14, 1939. Centro de Ganadería. Colegio de Postgraduados. Montecillo, Mex. México.
- Griffin, Sh. 1990. (Ed.) Saline agriculture, salt-tolerant plants for developing countries. National Academy Press, Washington D.C. p. 90-91.
- Gobierno del Estado de Hidalgo. 1995. Expediente Técnico sobre Coquía (*Kochia scoparia* L. Schrad) var. Esmeralda. Octubre, 1997. Pachuca, Hgo.
- INIFAP. 1986. Proyecto para incrementar el potencial forrajero con Kochia en regiones áridas y semiáridas de la República Mexicana.
- Osuna, O.M. 1984. El cultivo de Kochia scoparia. Resúmenes de 70 día del forrajero. Campo Agrícola Experimental "Zaragoza" SARH-INIA. Zaragoza, Coah. México.
- Osuna, O.M. 1985. Evaluación de 16 fechas de siembra en Kochia scoparia bajo condiciones de temporal. Secretaría de Agricultura y Recursos Hidráulicos. Instituto Nacional de Investigaciones Agrícolas. (CIAN) Torreón, Coah. México.
- Ramírez, V.H. Y. V.J.L. Méndez. 1998. Ganancia de peso de conejos destetados alimentados con tres niveles de Coquía-Alfalfa (*Kochia scoparia* L-Schrad var Esmeralda-*Medicago sativa* L.). Tesis de Licenciatura. Universidad Autónoma Chapingo. Chapingo, México. 42 p.
- Reyna, I.D.M. 1994. Competitividad económica de un cultivo de introducción Kochia scoparia (L.) Schrad en alimentación de ovinos. Colegio de Postgraduados. Montecillo, Edo. de México. 109 p.
- Rodríguez, F.J.C. 1988. Sustitución de diferentes niveles de alfalfa por Kochia scoparia (L.) Schrad en raciones para corderos criollos en crecimiento. Tesis

- de Licenciatura. Universidad Autónoma Agraria "Antonio Narro". Saltillo, Coahuila. México 41 p.
- Santana, A.G. 1991. Alimentación de Conejos Criollos en Desarrollo y Engorda, con Raciones que Contienen Diferentes Niveles de Heno de *Kochia scoparia* (L) Schrad en Sustitución de Alfalfa. Tesis de Licenciatura. Universidad Autónoma Agraria "Antonio Narro". Saltillo, Coahuila. México. 58 pp.
- Sherrod, L.B. 1973. Nutritive value of *Kochia scoparia* III. Digestibility of *Kochia* hay compared with alfalfa hay. *J. Dairy Sci.* 56(7): 923-926.
- Trejo, M.J. 1997. Engorda de borregos con una dieta a base de tamo de Coquía al 70%. Universidad Autónoma Chapingo. Difusión Cultural. Chapingo, México. 67 p.
- Trejo, M.J. 1998. Potencial ecológico, económico y forrajero de la Coquía en las zonas áridas y semi-áridas de México. En: Memoria de la V Reunión Nacional Sobre Sistemas de Captación de Agua de Lluvia. Oaxaca, Oaxaca, México. 163-166.
- Zahran, M.A. 1986. Forage potentialities of *Kochia indica* and *Kochia scoparia* in arid lands with particular reference to Saudi Arabia. *Arab Gulf J. Sci. Res.* 4 (1): 53-68.

IV. Biodiversity Conservation

Genetic Diversity of Lebanese Wild Wheat Populations: RAPD and AFLP Fingerprinting

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ABSTRACT

A study of the genetic diversity of wild wheats (*Triticum urartu* and *T. dicoccoides*) collected from 14 natural populations in Lebanon was performed using the RAPD and AFLP techniques. For the RAPD analysis, four primers have been chosen for the reactions of amplification. We identified 44 polymorphic bands for *T. urartu* and 31 for *T. dicoccoides*. The dendograms generated from the "Jaccard similarity index matrix" using the UPGMA method have shown the genetic diversity among and within populations, and indicated the geographical and evolutionary patterns of the wild wheat genetic diversity. Amplified Fragment Length Polymorphism (AFLP) analyses for the same populations have also been studied to compare the results with those obtained with RAPD; such fingerprinting combined with appropriate statistical tools offers several advantages over other available DNA marker techniques in evaluating genetic diversity. Differences between similarity matrices generated from the RAPD and AFLP analyses were significant. The present study has brought new information on the genetic diversity of wild wheat populations in Lebanon, which will be used for optimizing the collection and conservation strategy. The better knowledge of wild wheat genetic diversity will also enhance their utilization in wheat breeding.

INTRODUCTION

In the past decade, several DNA-based marker systems were introduced for genome mapping, gene tagging and isolation, and biodiversity identification in plant species. The markers can be classified into categories based on the principles involved: 1) restriction-fragment-length-polymorphism (RFLP) used for mapping genomes of many crops including tomato (Tanksley et al., 1992), corn (Ahn and Tanksley, 1993), and soybean (Lark et al., 1993), but RFLP techniques have, however, the disadvantage of requiring a great deal of operator time and effort without producing a large number of polymorphisms. Another technique developed to generate markers, such as random-amplified-polymorphic DNA (RAPD) (Williams et al., 1990) can be rapidly analyzed, and use only small amounts of DNA; however, the reproducibility between laboratories can be a problem.

Recently, a PCR-based technique of generating molecular markers, amplified-fragment-length polymorphism (AFLP) was reported by Vos et al. (1995).

This powerful DNA fingerprinting technique has been used with different plant species (Vos et al., 1995; Lin et al., 1996; Maughan et al., 1996; Zeng-Qiang et al., 1998; Chabane and Valkoun, 1999).

In this article we compare the application of RAPD and AFLP techniques to DNA fingerprinting in wild wheat *Triticum urartu* and *T. dicoccoides* from Lebanon. The data were analyzed for these species and the levels of RAPD and AFLP polymorphism were compared.

MATERIALS AND METHODS

Plant Material

Seven populations of *Triticum urartu* Tumanian ex Gandilian (A, B, C, K, N, O, P) and four populations of *T. turgidum* ssp. *dicoccoides* Koern. ex Asch. & Graebn. (E, F, G, H) were sampled as single plants from a region in the northeast and southeast of Lebanon, while three populations of *T. dicoccoides* were sampled as bulk of randomly selected plants (R, T, U) - see Fig. 1. Single-plant seed and bulk samples were once increased in the field on ICARDA main experimental farm at Tel Hadya, Aleppo, Syria. For the DNA analyses, seed was sown in flats of commercial potting in the plastic house. Five single-plant progenies from each population were used.

DNA Extraction and Analysis

Genomic DNA was extracted from leaf tissue, frozen in liquid nitrogen of three week-old seedlings according to CTAB protocol as described by Chabane et al. (1998).

RAPD

The PCR reactions for RAPD analysis were performed after modified method of Williams et al. (1990), e.g., 25 µl contained 100 mM tris-HCl, pH 8.3, 15 mM MgCl₂, 500 mM KCl, 100 µM dNTPs, 15 pmoles of arbitrary decamers, 50 ng templates DNA for *T. urartu* and 12.5 ng for *T. dicoccoides*, 1 U Taq polymerase. Reactions were performed as described by Chabane et al., (1998). An aliquot (25 µl) of the reaction was loaded into 1.4% agarose gel with a running buffer of 1X TAE. Amplified fragments were visualized using ethidium bromide and photographed with RFLP scan (Stratagene).

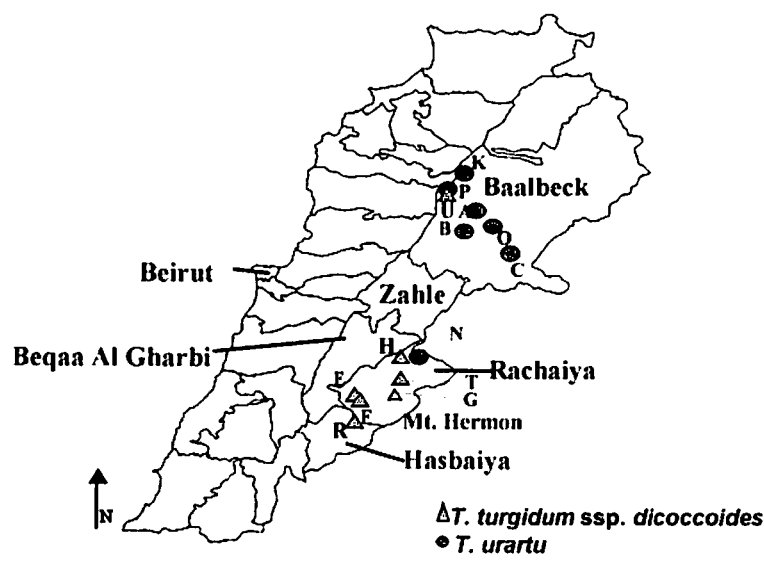


Fig. 1. Map of the study area of Lebanese wild *Triticum* populations.

AFLP

Genomic DNA (500 ng) was digested by *EcoR* I and *Mse* I at 37°C for 2 hr. The DNA fragments were ligated to *EcoR* I and *Mse* I adapter during 4 hr or overnight at 37°C (Table 1). The ligation mixture was diluted 2 × 10 with sterile distilled water and fragments were preamplified non-selectively by 30 cycles PCR (94°C for 30 s, 56°C for 30 s, 72°C for 60 s) using *EcoR* I +00 and *Mse* I +00 primers as described by Vos et al. (1995). Selective amplification was conducted by PCR using aliquots of the preamplified fragments diluted 2 × 10 in TE 0.1, using *EcoR* I +3 and *Mse* I +3 primers (Table 1).

AFLP Electrophoresis

AFLP products were separated by electrophoresis on 6% denaturing polyacrylamide gels containing 7M-urea and 0.5x TBE buffer. One volume of loading buffer (98% formamide, 10 mM EDTA pH 8.0, 0.1% bromophenol blue and xylene cyanol) was added to the

sample. Each gel was run at 65 W for approximately 2h. AFLP products were visualized by silver staining (kit Promega).

Data Interpretation

The presence/absence of RAPD and AFLP markers was scored by hand and coded as 1/0. Monomorphic markers were excluded from subsequent analysis which was carried out using two statistical packages GENSTAT 5 (GENSTAT 5 Committee 1993) and NTSYS-PC, version 2.01 (1997). Data from the four RAPD primers and the three primer combinations for AFLP analysis were combined and the pairwise similarities calculated between samples using the Jaccard coefficient. The resultant similarity matrix was input into both a UPGMA cluster analysis and a principal coordinate analysis. AMOVA (Analysis of Molecular Variance - Version 1.53) was used for variance partitioning into components and for estimating within population diversity.

Table 1. Adapters and primers used in the experiments.

EcoRI adapters	
Adapter R	5'-CTCGTAGACTGCGTACC-3'
Adapter I	3'-CATCTGACGCATGGTTAA-5'
MseI adapters	
Adapter R	5'-GACGATGAGTCCTGAG-3'
Adapter I	3'-TACTCAGGACTCAT-5'
EcoRI + 3 primers	
E 37	5'-GACTGCGTACCAATTCACG-3'
E 42	5'-GACTGCGTACCAATTCAGT-3'
MseI +3 primers	
M 32	5'-GATGAGTCCTGAGTAAAC-3'
M 33	5'-GATGAGTCCTGAGTAAAG-3'
M 40	5'-GATGAGTCCTGAGTAAAGC-3'

RESULTS

RAPD Analysis

Fifty-six primers (Operon kit A, B, C, E, F, G, K, L, N, O and P) were used in the RAPD analysis of the DNA. There were few polymorphic bands revealed by each primer, indicating diversity within and among B, C and K populations of *T. urartu*. There is low diversity within the population B, except for the individual B1, which is different. Fewer bands were present in population C; however, the C5 single plant showed polymorphic bands. Population K displays high diversity, but some bands are missing in K4 compared to the rest of the populations. Some bands are common to many individuals in the three populations.

Four primers (OPB-08, OPC-04, OPC-09, and OPK-16) have been retained for further analysis. We have noticed 44 polymorphic bands for *T. urartu* and 31 for *T. dicoccoides*. The dendrograms generated from the similarity index matrix using UPGMA method (Fig. 2) have shown the genetic diversity among populations.

the total variation observed for *T. dicoccoides* and *T. urartu*, respectively. The use of three primer pairs resulted in a sufficient number of polymorphic bands to give an adequate representation of the genome and a fair assessment of the genetic diversity of the Lebanese populations of wild wheat.

DISCUSSION

AFLP analysis generated an average of 40 to 50 informative bands per primer combination. The proportion of loci that were polymorphic provides a good measure of genetic diversity among and within populations. Each primer combination revealed a high level of polymorphism within the different populations (results not presented) and demonstrated a higher level of polymorphism than did the RAPD analysis. When bands were present with the RAPD analysis, there were typically one to three polymorphic bands obtained per primer. The higher number of DNA markers generated from AFLP analysis makes this method superior to RAPD in the detection of within-population diversity.

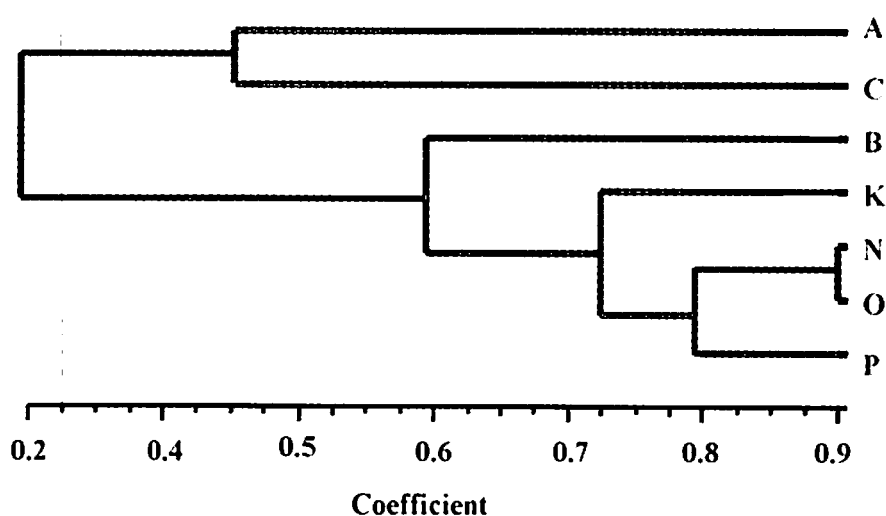


Fig. 2. Dendrogram of *T. urartu* populations derived by cluster analysis obtained with four RAPD markers.

AFLP Analysis

The AFLP primer combinations Eco37-Mse40, Eco42-Mse32 and Eco42-Mse33 were used to analyze 34 single-plant progenies derived from seven populations of *T. dicoccoides* and 32 single-plant progenies of seven populations of *T. urartu*. These yielded 1200 bands for *T. dicoccoides* and 956 bands for *T. urartu*.

Dendrograms of *T. urartu* and *T. dicoccoides* populations were constructed using 150 AFLPs (Law et al., 1998) generated with the three combinations selected. The primer combinations were also used two by two and they gave different results when analyzed in this way (data not shown).

The grouping of populations based on the 150 AFLPs can also be seen in plots resulting from principal coordinate analysis (PCO) (Fig. 3). The first two principal components accounted for 40% and 47% of

This has been demonstrated by seven times and twelve times larger mean-square values for the within-population variance components obtained in AFLP analysis compared to RAPD one in *T. urartu* and *T. dicoccoides*, respectively (Table 2). However, as the among-population components are not too different in AFLP and RAPD analyses, both may be appropriate for the detection of the among-population genetic diversity in wild wheats. A certain similarity of dendrograms for AFLP and RAPD analyses indicate this, even if the original Jaccard similarity matrices were not identical as shown by the Mantel statistics values.

Wild wheats *T. urartu* and *T. dicoccoides* are ancestors and close relatives of both durum and bread wheats and share with them A and AB genomes, respectively. Consequently, the high genome homology with cultivated wheats (Kimber and Feldman, 1987) makes them a valuable source of genes for wheat breeding. These

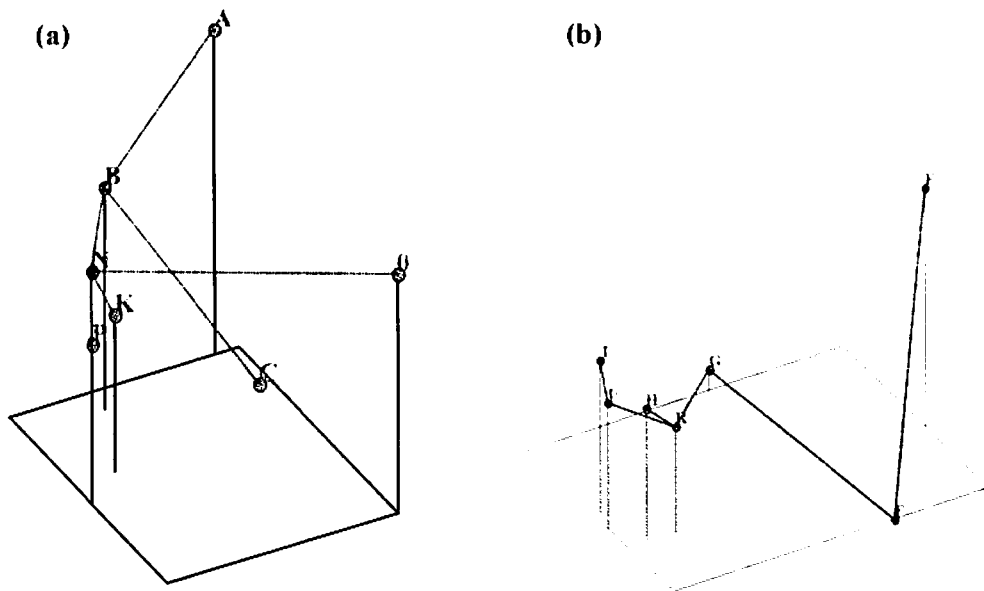


Fig. 3. Principal coordinates for seven populations of *T. urartu* (a) and *T. dicoccoides* (b). Minimum spanning length tree is overimposed.

wild species are endemic to a relatively small dryland region of the Near East arc (Valkoun et al., 1998), and the remaining natural populations are threatened by rapid genetic erosion. Conservation of the extant genetic diversity, both *ex situ* and *in situ*, is not only the responsibility of the national programs in the region, but also a concern of the global community, including CGIAR centers.

Results of the RAPD and/or AFLP analyses in the present study showed that: i) significant amount of genetic diversity is present among populations; ii) geographically close populations may be very different, and iii) an extremely high proportion of genetic variation is within-population, as shown by AFLP data. Therefore, we conclude that the appropriate strategy for *ex situ* conservation of the wild wheats in Lebanon is a sampling of a maximum number of isolated populations, even if they are geographically close. As the very high within-population genetic diversity cannot be adequately sampled and maintained in *ex situ* collections, this method should be complemented with *in situ* conservation of wild wheat populations in their natural habitat. The information presented in this paper may provide guidance for the development of the optimum *in situ* conservation strategy.

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REFERENCES

- Ahn, S., and S.D. Tanksley. 1993. Comparative linkage map of the rice and maize genomes. *Proc. Natl. Acad. Sci. USA*. 90: 7980-7984.
- Chabane, K., and J. Valkoun. 1999. Evaluation of genetic of wild wheat, *Triticum urartu*, using AFLP markers. *Al Awamia*. Dec. 100: 9-18.
- Chabane, K., and J. Valkoun. 1998. Standardization of RAPD marker technique to determine the diversity of diploid wheat: *Triticum urartu*. In *Triticeae* III.A.A. Jaradat (Ed.), p. 155-158. Science Publishers, Inc., Enfield, NH, USA.
- Kimber, G., and M. Feldman. 1987. Wild wheat. College of Agriculture, University of Missouri, Colombia, USA. 141 p.
- Lark, K.G., J.M. Weisemann, B.F. Matthews, R. Palmer, K. Chase, and T. Macalima. 1993. A genetic map of soybean (*Glycine max* L) using an intraspecific cross of two cultivars, Minsoy and Neir 1. *Theor. Appl. Genet* 86, 901-906.
- Law, R.J., P. Donini, M.D.R. Koebner, C.J. Reeves, and J.R. Cooke. 1998. DNA profiling and plant variety registration. III. The statistical assessment of distinctness in wheat using amplified fragment length polymorphism. *Euphytica*. 102: 335-342.
- Lin, J.J., J. Kuo, J. Ma, J.A. Saunders, H.S. Beard, M.H. Mac Donald, W. Kenworthy, G.N. Ude, and B.F. Matthews. 1996. Identification of molecular markers in soybean comparing RFLP, RAPD, and AFLP DNA mapping techniques. *Plant Mol. Bio. Reporter* 14(2): 156-169.
- Maughan, P.J., M.A. Saghai Maroof, and G.R. Buss. 1996. Amplified fragment length polymorphism (AFLP) in soybean: species diversity, inheritance, and near-isogenic line analysis. *Theor. Appl. Genet* 93: 392-401.

- Tanskley, S.D., M.W. Canal, M.C. de Vicente, M.W. Fulton, H. Giovannoni, S. Grandillo, G.B. Martin, R. Messeguer, J.C. Miller, L. Miller, A.H. Patterson, O. Pineda, M. Roder, R.A. Wing, W. Wu, and N.D. Young. 1992. High density molecular linkage maps of the tomato and potato genomes: biological inferences and practical applications. *Genetics* 132: 1141-1160.
- Valkoun, J., J. Giles Wains, and J. Konopka. 1997. Current geographical distribution and habitat of wild wheats and barley. p. 293-299. *In* The Origins of Agriculture and Crop Domestication. A.B. Damania, J. Valkoun, G. Willcox, and C.O. Qualset (Ed.). ICARDA, IPGRI, FAO, UC/GRCP, Aleppo.
- Vos, P., R. Hogerts, M. Bleeker, M. Reijans, T. Vande Lee, M. Hornes, A. Fritjers, J. Pot, J. Peleman, M. Kuiper, and M. Zabeau. 1995. AFLP: A new concept for DNA fingerprinting. *Nucleic Acids Res.* 23: 4407-4414.
- Zheng-Quiang, M.A., and N.L.V. Lapitan. 1998. A comparison of amplified and restriction fragment length polymorphism in wheat. *Cereal Res. Commun.* 26 (2): 7-13.

Phyto-Reclamation for Biodiversity Rehabilitation of Uzbekistan's Desert Rangelands

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ABSTRACT

The Republic of Uzbekistan is situated in Central Asia. One of the traditional kinds of agriculture is Karakul sheep breeding. The Kyzylkum Desert is the main rangeland in the Republic. Diversity of landscapes and climatic desert conditions determine various types of rangelands depending on their botanical composition. The existing biodiversity makes it possible to graze sheep all year round, giving more favorable conditions on rangelands for each season, spring, summer, autumn and winter. As a result of a breakdown of the rational system of using rangelands, desertification processes occur, involving biodiversity reduction and replacement of dominating species by less valuable and less nutritious plants. The reclamation measures on desert rangelands directed at the rehabilitation of biodiversity and regeneration of degraded rangelands have been worked out and are successfully used in Uzbekistan.

INTRODUCTION

According to world classification, rangelands of Uzbekistan are situated in a zone with a high level of desertification. The variability of species composition of desert plants and productivity of desert rangelands depend on the annual climatic conditions. In years of low productivity, the capacity of rangelands is reduced and the loading on them increases, intensifying the desertification process (Nurberdiyev and Reizvikh, 1992). The natural and anthropogenic processes of irreversible changing of soil and plant cover, and decreasing of biological productivity in the external conditions, lead to the complete destruction of biosphere potential and desertification of rangelands. The development of phyto-reclamative work permits restoration of the degraded rangelands and recovery of the variety of plant species and total biomass production in which the balance between reproduction processes in the plant environment and anthropogenic influence is maintained.

MATERIAL AND METHODS

Phyto-reclamation is realized by means of sowing one or several plant species, used for reclamation of degraded rangelands. Phyto-reclamative works are carried out on stage-by-stage basis. Ploughing is considered to be the first stage of this process. It contributes to the soil moisture increase and improvement of physical properties of soils.

The next stage is the establishing of belts of the plant *Haloxylon aphyllum*; a moderate microclimate between the belt areas creates favorable conditions for vegetation growth and plant development (Ephemera). Species composed of highly productive desert plants are then sown; they are semi-shrubs and grasses. Such plants fill up the hollow ecological niches (Reizvikh, 1989).

RESULTS AND DISCUSSION

The main region in Uzbekistan to be reclaimed is the Kyzylkum Desert. *Haloxylon aphyllum*, *Aellenia zuba-phyla*, *Kochia prostrata*, *Salsola orientalis* are used as major species for rangeland reclamation.

Planting of *H. aphyllum* among natural stands of tarragon and ephemerals increases productivity of the latter 2 to 3-fold. Here *H. aphyllum* plays the leading role in the yield production of artificial plant communities, while in natural plant communities' tarragon is of greater effect. The contribution of Ephemera in the total amount of yield is negligible. It varies from 10 to 140 kg/ha for the natural plant communities, and 10 to 320 kg/ha for the artificial ones.

Artificial plantations created in the conditions of the southwest Kyzylkum have high productivity, exceeding the natural desert one several times and producing high feed capacity stability (Table 1).

The rehabilitated biodiversity makes it possible to graze Karakul sheep all year round, giving more favorable rangelands for every season. This ensures the maximum accumulation of forage mass, as observed for shrubs in summer. *Artemisia* has two maxima, in summer and fall; the Ephemera and semi-ephemera have a maximum in spring. Thus, the rangelands can be of spring - summer type, fall - winter type, and year-round ones according to the seasons of intensive use. Some variants of rational species composition used for artificial plantations for different usage have been proposed and are given in Table 2 (Anon., 1972; Shamsutdinov, 1983).

CONCLUSION

Knowing the requirements of natural plants and plants used for reclamation, and which are necessary for survival, we can assess the degree of suitability of agroclimatic conditions of a region for reclamation of rangelands.

Table 1. Productivity of plant communities.

Composition	Dry Matter Production	Coefficient of Variation
	---kg/ha---	---%---
Natural: <i>Artemisia, Turanica, Ephemera</i>	32	80
Artificial: <i>H. aphyllum + A. turanica + Ephemera</i>	182	23
Natural: <i>A. turanica + Ephemera</i>	27	89
Artificial: <i>H. aphyllum + Kochia prostrata + A. turanica + Ephemera</i>	93	43

Table 2. Species composition for creating grazing for seasonal usage.

		Spring - Summer	
<i>Kochia (K) prostrata + camphorosma + Eurotia + Adans + Poa (P) bulbosa</i>		<i>K. prostrata + camphorosma</i>	
		Fall - Winter	
<i>H. aphyllum</i>	<i>H. aphyllum + Aellenia (A) zubaphyla + Salsola (S) orientates + Artemisia (Art) Turanica</i>	<i>H. aphyllum + A. zubaphyla + Art. Turanica</i>	
		All Year	
<i>Haloxylon (H) aphyllum + K. prostrata + Art. turanica+ P. bulbosa</i>	<i>H. aphyllum + K. prostrata + A. zubaphyla+ S. orientatis + Art. turanica + P. bulbosa</i>	<i>H. aphyllum + K. prostrata + A. zubaphyla+ S. orientatis + Art. turanica + Ephemera</i>	<i>H. aphyllum + K. prostrata + A. zubaphyla + S. orientatis +</i>

REFERENCES

Anon. 1972. The instruction of phyto-reclamation of southwestern Kyzylkum rangeland. Tashkent. Uzbekistan. 25 p.

Nurberdyev, N., and O.N. Reizvikh. 1992. The rangeland food capacity of deserts in Central Asia: their valuation and management. Ashgabat, 179 p.

Reizvikh, O.N. 1989. Agroclimatic basis of Uzbekistan pastures phyto-reclamation. *Problems of Desert Development*, 5: 33-38.

Shamsutdinov, Z. Sh., and I.O. Ibragimov. 1983. Long-year rangeland in arid zone of Uzbekistan. Tashkent. Uzbekistan. 180 p.

Rehabilitation of War-Damaged Areas of the National Park of Kuwait

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ABSTRACT

The misuse of natural vegetation through uncontrolled activities such as *overgrazing, uprooting of native vegetation, off-route use of vehicles, and hunting of wild animals* has caused irreversible damage to the native biodiversity and potential recreational facilities in Kuwait. Realizing the need for preserving the native flora and fauna, the Kuwait Institute for Scientific Research (KISR) has conducted a series of investigations to generate baseline information on the native desert ecosystems and recommended protection measures for preserving the native biodiversity. Based on the findings of these studies, Kuwait Municipality established the first National Park for preserving the native biodiversity and improving the wildlife habitat by introducing selected plants and animals.

The National Park suffered severe damage due to Iraqi invasion and the subsequent liberation war ravages during 1990-'91; the external fence was damaged, many bunkers and military observation points were established, and mines were placed at several locations. In the post-liberation period, the Ministry of Defense cleared the area from ammunition and mines and demolished the ordnance in underground pits. All these activities led to severe land degradation and deterioration in natural vegetative cover.

In view of this, KISR recently initiated a study for developing efficient rehabilitation strategy for the restoration of vegetation and wildlife habitats in war-damaged areas of the Park. At the outset, the negative impacts of war on the soil and native vegetation of the park were assessed. Based on the preliminary assessment of damages, rehabilitation strategies have been designed. The ecological and economic feasibility of these rehabilitation strategies in restoring native vegetation and wildlife habitats of the affected areas in the park will be ascertained by undertaking pilot-scale re-vegetation in two 10-ha sites. The selected sites will be re-seeded with a mixture of grasses and forbs, and/or planted with hardy shrubs and trees with consideration on rate of seeding, planting depth, timing, seed distribution, soil type and soil moisture. Additionally, water catchments techniques will be used to improve soil moisture status in the experimental area.

Ecological success of these rehabilitation measures will be ascertained based on recovery of native vegetation, survival, growth, and biomass produc-

tion of introduced species and improvement in wildlife habitats in the study area. The paper describes the negative impacts of war related activities on native vegetation and proposed rehabilitation strategies to restore affected areas in the National Park.

INTRODUCTION

Kuwait, an arid country with a harsh climate, had a unique desert ecosystem, comprising of 374 plant, 28 mammalian, and over 300 bird and 40 reptilian species (Omar, 1982, 1992; Al-Sdirawi, 1986). Out of these 374 plant species, 285 were native to Kuwait (186 forbs, 52 grasses, 44 shrubs, and 3 trees). Uncontrolled activities such as *overgrazing, uprooting of shrubs, off-route use of vehicles, and hunting of wild animals* have caused irreversible damage to native flora, fauna and desert recreational facilities. Realizing the need for conserving the natural flora and fauna for the present and future generation's use, Kuwait Municipality favored the development of an action plan for the preservation of native biodiversity.

Accordingly, the Kuwait Institute for Scientific Research (KISR) was requested to undertake a feasibility study for the establishment of the first National Park. This study identified 330 km² of area in the northeast of Kuwait that combines diverse plant and animal life forms with unique landscape features, good accessibility, and ease of protection (Omar and Taha, 1982). KISR scientists have made concentrated efforts to generate baseline information on Kuwait's native vegetation, required conservation techniques, and to identify possible area sizes and uses within the designated park area in order to accomplish these objectives (Omar and Taha, 1984; Omar and Al-Shuaibi, 1986).

The National Park suffered serious damage during the invasion and liberation war. The external fence was knocked down, trenches and "foxholes" were dug all over the area, and mines were placed from the coastal front of the Park to the *wadis* and gullies in the Jal-Az-Zor escarpment (Sdirawi, 1992; Omar et al., 1998). The Park area also suffered from military activities such as *construction of bunkers, bombing, explosion of munitions and other military debris*, as well as *heavy machinery movement*. Additionally, several large pits were formed due to the EOD program in the area. Collectively, these activities caused severe land degradation, soil compaction and erosion problems. In Bahra, oil pollution also posed a threat to native vegetation and fauna.

Several attempts were made at KISR to assess the impact of Gulf War the on the terrestrial ecosystem and soil (Abdal et al., 1992; Al-Houty et al., 1993). Studies conducted by Zaman and Al-Sdirawi (1993) and Omar and Zaman (1995) highlighted the impact of the Gulf crisis on Kuwait's desert flora. *Negative effects were evident in vegetation structure, species composition, and productivity of native vegetation in polluted areas.* At the time of the environmental disaster, the phenological procession of Kuwait's desert plants was altered due to black clouds that affected the temperature and rainfall pattern. The severity of the damage varied with species, amount of mobile sand, and quantity and quality of pollutants. Similar attempts were also made to ascertain the negative impacts of oil pollution on the fauna (Al-Houty et al., 1993).

Rehabilitation measures in areas subjected to the above-mentioned military activities are essential both for vegetation recovery and restoration of wildlife habitat to pre-war levels. The present study was undertaken to ascertain the nature and magnitude of war-related damages to native vegetation and land, and then develop efficient rehabilitation strategies to restore native vegetation cover and wildlife habitats of the Park. It is hoped that the outcome of this study will serve as a guideline for rehabilitating war-damaged wildlife habitats in other parts of the world.

MATERIALS AND METHODS

Physical and Biological Components of the National Park

The designated park area in the northeast of Kuwait is generally flat with minor undulations. The significant physical feature in the area is the Jal-Az-Zor escarpment, which rises to a height of 150 m and runs parallel to the seashore. Five intersecting landforms have been identified; backslope, scarp, debris, coastal plain, and crest. Drainage patterns are generally northeast in the form of numerous shallow wadis that dissect the debris slope. The pattern to the south is generally described as a series of wadis draining a limited catchment and falling abruptly to sea level. The most poorly drained areas are the coastal plain and some parts of the backslope. Results revealed that the entire surface of the Jal-Az-Zor area is covered with sediments and rocks of sedimentary origin ranging in age from Miocene to Holocene.

During the pre-War period, the coastal region had primarily salt marsh vegetation such as *Zygophyllum qatarense*, whereas the inland desert was occupied primarily by *Rhanterium* and *Haloxylon* steppes. The *Rhanterium* steppe occupied about 85% of the study area, followed by the *Haloxylon* steppe (10%) and the salt marshes (5%). A total of 39 species was recorded in the salt marsh region (coastal habitats), and 87 species were recorded in the inland area. In general, *Halocnemon strobilaceum* dominated near the shore, followed by *Seidlitzia rosmarinus*, *Nitraria retusa*, *Z.*

coccineum, and *Schangania aegyptiaca*. Major plants in the inland ecosystem varied according to the prevailing dominant plant community. At the *Rhanterium* steppe, major associations were *Rhanterium epapposum*, *Stipagrostis plumosa*, *Moltkiopsis ciliata*, *Asthenatherum forsskalii*, *Plantago* sp., and *Cutandia memphitica*. Plants found in the *Haloxylon* steppe are *Haloxylon salicornicum*, *Astragalus* sp., *Medicago* sp., *Schismus barbatus*, and *Cutandia memphitica*.

Since the State of Kuwait is situated at the edge of the Great Arabian Desert, the local fauna has close affinities with those of neighboring countries. The important vertebrate fauna of the Park area were, and still are, reptiles, birds, and mammals. The reptiles are mainly carnivorous (e.g., the desert monitor, wirral), preferring live prey. The dhub (spiny-tailed lizard), however, is the only herbivorous reptile in Kuwait, and both (the dhab and the wirral) are the most visible reptiles. The rest of the lizards and snakes not easily seen. Stone geckos are common in the Park area, while the agamids (lizards) are also common. Snakes are wide-ranging, but appear to be most common between Jal-Zor crest and Umm Ar. Rimmam. Burrowing reptiles are rarely seen, emerging at night when the humidity is high; the skinks and sand boa are found in the sand hummocks adjacent to water runoff. The Arabian worm lizard (a legless lizard, but not a snake) is probably the most common subterranean reptile and may be found buried to a depth of several centimeters in the sand throughout the Park.

Of the 280 bird species recorded in Kuwait, crested larks, shrikes, bee-eaters, wagtails, little owls, kestrels and steppe eagles are among the common ones seen in the Park area. Among the commonly seen coastal and mud-flat birds are flamingos, herons, egrets, cormorants, shank, gulls, shelduck, crab plovers, and numerous waders.

Mammalian fauna are relatively numerous and predominantly nocturnal. The rodents generally prefer the sandy desert region with shrub cover under which they usually burrow. The jerboas are found on the more open flat areas of stony desert. Foxes were been seen in Umm Ar. Rimmam and Jal-Az-Zor, and burrows were found in the deep gully of Jal-Az-Zor and Umm Ar. Rimmam. Feral dog packs range along the coastal stretches and are becoming common; solitary dogs, however, may be mistaken for foxes.

Assessment of War-Related Damages in the Park

Based on biophysical features, the 330-km² area of the Park was initially divided into five sections: coastal area, coastal sand dune area, escarpment, back-slope, and depressions. A preliminary survey was undertaken within each area to assess the current soil and vegetation status. Special consideration was given to areas that were extensively used for military activities. Based on this preliminary survey, two sites showing typical war-related damage (Talha and Umm Ar. Rimam) were

identified for conducting detailed damage assessment. At the outset, a reconnaissance survey of the selected area was conducted to ascertain current status of the site, nature and extent of military activities, and water and soil flow patterns. A 10-ha area (500 × 200 m) showing typical military and human impacts was demarcated in each site for detailed site characterization and re-vegetation study.

Site Characterization

In the Talha site, four transects were prepared on four corners of a 250 × 200 m rectangular area. Holes were prepared on three sides of each transect by hand-auguring to examine the nature of the soil at various depths; soil samples were collected from these holes for laboratory analyses. In addition to the usual soil description and analyses, data on the impacts created by the military activities (compaction, distribution, explosion of ammunition, and abundance of metal fragments) were recorded. Surface flow of water and soil was inferred from topographic survey. Infiltration tests were also undertaken to determine the extent of disturbance to the soil profile.

At Umm Ar-Rimam site, 13 depressions were selected for damage assessment. Soil samples have been collected from each of these depressions for physical and chemical characterization of the site.

Vegetation Assessment

The technique developed by Stohlgren et al. (1998) was used for vegetation assessment in the study area. This technique is based on modified Whittaker multi-scale vegetation plot which measures species richness in a 20 × 50 m plot (K), one 5 × 20 m subplot (C), two 2 × 5 m subplots (A&B), and ten - (0.5 × 2 m) subplots. Percent ground cover was measured in the 10-m subplots. Each plot was replicated four times. Plant species in each plot/ subplot were identified and recorded separately. Percent ground cover was determined by visual estimate for four parameters: gravel, litter, bare ground, and total vegetation. The average percent ground cover for each plot was calculated.

Proposed Rehabilitation Strategies

Pilot-scale rehabilitation studies were conducted in two 10-ha sites that were used for damage assessment. Low (providing protective fencing in the area) or high input rehabilitation strategies were designed and their ecological- and cost-effectiveness was ascertained in pilot rehabilitation studies. In the high-input strategy, mixtures of grasses, forbs, and shrubs were directly seeded, with consideration of rate of seeding, planting depth, timing, seed distribution, soil type and soil moisture. Additionally, seedlings of hardy naturalized tree species were introduced, and water catchment techniques established to improve moisture availability in soil. Survival rate, vegetative growth, and biomass production were recorded on a regular basis. Recovery of native vegetation and improvement in the wildlife habitats in

various treatments were compared with those in the control to ascertain the ecological success of various rehabilitation measures. Rehabilitation cost was assessed based on actual expenditure of seeding and transplanting techniques.

RESULTS

Preliminary data have been gathered. Additional data will be collected during course of the investigation for updating the GIS for the National Park and generating soil and vegetation maps for damaged areas. Talha and Umm Ar-Rimam are the most suitable areas for the Pilot study. While the Jal-Az-Zor area is too difficult ecologically (exposed, rocky), the coastal site suffered less damage of an environmental kind.

After demarcating the study areas, efforts were made to characterize them by conducting detailed soil, topography and vegetation (and fauna) surveys. A brief description of the current soil and vegetation status in the study area sites is presented below.

Talha

This site was heavily used during and after the invasion. Several bunkers were established through out the site, which were later refilled with excavated soil. The loose, refilled soil was subjected to wind and water erosion, resulting in frequent waterlogging problems, particularly in the northern portion of this site. A few old *Prosopis juliflora* and *Acacia* sp. trees still survive and serve as habitat for birds. Besides these, the site also has a lonely specimen of the native *Acacia pachyceras*, which needs to be preserved. The site continues to be overused for hunting.

Preliminary results on the number of species identified in each plot/subplot show that Plots 1 and 2 have higher diversity than Plots 3 and 4. This is due to differences in soil characteristics in the plots, as indicated above. Species richness will be estimated in the near future and compared with adjacent areas not subjected to military activities.

Umm Ar-Rimam

At this site, several pits were prepared for exploding ammunitions and mines collected from other areas in the Park. These pits have been refilled with transported soil. A large number of metal fragments and other remains from the ammunition were found scattered all over the area. Based on the reconnaissance survey, two 5-ha sites have been selected for soil and vegetation assessment. In general, the soils in the first site are deep (200 cm plus), loose, and uniform, indicating that the native soil has been replaced with transported soil. Further physical and chemical characterization is in progress.

Potential Rehabilitation Approaches

Based on the nature and extent of damage, either low- or high-input rehabilitation strategy has been developed for each experimental site. The low-input strategy will

involve fencing of the experimental site to protect it from grazing and off-road vehicles. The high-input scenario consists of environmental modifications and re-vegetation. The environmental modification treatments would include water-harvesting techniques and creation of obstructions to trap the soil and, thus, create better conditions for plants to establish and grow. Re-vegetation will be accomplished through direct seeding (for grasses, forbs and low shrubs), and transplanting of tree seedlings.

Talha

The vision for this site is to re-introduce the indigenous plant community to the vicinity and to expand the plantation of trees and shrubs to increase the native wildlife (including bird) populations. The strategy should involve:

1. Protecting the area from hunters, off-road traffic, and grazing by fencing and patrolling.
2. Retaining existing area with trees as a reference control to demonstrate the effectiveness of various interventions.
3. Using treatments such as:
 - Various forms of water-harvesting (e.g., basins, contour bunds or V-shaped water catchments).
 - Natural rehabilitation under protection from existing seedbank (low input).
 - Tree species - native/ naturalized species: *Prosopis juliflora*, *Zizyphus spina-christi*, *Acacia burketii*, *Azadirachta indica*, *Tamarix aphylla*, *Albizia lebbuck*, and *Acacia faseriana*.
 - Shrubs: *Atriplex sp.*, *Cassia artemisoides*, *Cassia surtii*, *Sena artemisoides*, *Dodonea viscosa*, *Maireana triptera*, and *Maireana pyramidata*.
 - Grass species: *Cenchrus ciliaris*.
 - Protective irrigation and mulching.
 - Open grazing by herds (to demonstrate the importance of protection).

Umm Ar-Rimam

The vision for this site is to re-establish the native shrub community (including annuals) and establish a tree layer to increase habitat diversity and to increase the native fauna populations. The strategy will be similar to Talha. The water-harvesting treatment will include the construction of artificial lakes or ponds to take advantage of the depressions to create favorable environments for birds and other animals. The treatments will include:

- Various forms of water-harvesting (e.g., basins, contour bunds, artificial ponds).
- Natural rehabilitation under protection from existing seedbank.
- Tree species - native/naturalized species: *Prosopis juliflora*, *P. spicigera*, *Zizyphus spina-christi*,

Acacia burketii, *A. coricea*, *A. auriculiformis*, *A. ligulata*, *Azadirachta indica*, *Tamarix aphylla*, *Albizia lebbuck*, and *A. faseriana*.

- Potential Shrubs - *Atriplex sp.*, *Cassia artemisoides*, *Cassia surtii*, *Sena artemisoides*, *Dodonea viscosa*, *Maireana triptera*, *Maireana pyramidata*, *Haloxylon salicornicum*, and *Forsettia aegyptica*.
- Grasses - *Cenchrus ciliaris*, *Stipa barbata*, *Panicum turgidum*, *Pennisetum divissum*.
- Protective irrigation.
- Open grazing by herds (to demonstrate the importance of protection).

Suitable agricultural machinery will be used for making water catchments as well as soil-bed preparation. Thus, a diversity of approaches will be used, according to the needs of that study area. Where possible, interventions will be applied so as to provide replicated treatments to gain as much information as possible from this study. This could include reseeding in successive years to take rainfall variability into account. Techniques like land imprinting and/or hydro-seeding will be considered for direct seeding. The area will be divided into three plots for two treatments (low or high input) and an undisturbed control.

Survival rate, vegetative growth, biomass production, recovery of native vegetation, and improvement in the habitat quality will be monitored for ascertaining the ecological success of these rehabilitation measures.

DISCUSSION

Degraded arid lands, in general, are difficult to restore owing to the harsh climate, although many types of rehabilitation techniques have been tested in different parts of the world. A significant improvement in vegetation cover and the quality of habitat is possible by a simple deferring of grazing. Several researchers have concluded that protection from grazing results in a substantial improvement in vegetation condition in protected areas. According to Zaman and Taha (1995), under Kuwait's conditions Remth and Arfaj plant communities show an improvement in herbage production when protected from grazing.

However, Omar (1992) concluded that very long-term protection might not necessarily lead to an improvement in the habitat, particularly if drought persisted for a longer period. Therefore, re-vegetation with drought and heat-tolerant native or naturalized trees, shrubs and grasses is considered the most efficient tool for bringing rapid improvement in the wildlife habitat. Artificial seeding or transplanting of trees is considered effective in increasing the vegetation cover.

The success of the re-vegetation efforts in arid lands is generally low due to uncertain, erratic, and scanty rains, coupled with meager irrigation resources. To overcome this problem, scientists have used various *in situ* water harvesting and moisture conservation techniques such as contour systems (stone bunds, living

barriers, trash lines, contour furrows), freestanding systems (planting pits, closed microcatchments, semi-circular bunds), measures for improving infiltration and water storage (cover crops, mulching, tillage, minimum tillage and zero-tillage) and reduction of evaporation losses. These modifications create favorable conditions for germination and growth of native vegetation also.

CONCLUSIONS

War-related activities such as construction of bunkers, foxholes, trenches, and military observation points, placement of mines and off-road movement of vehicles during invasion, and explosion of ordnance in underground pits during the post-War period resulted in serious land degradation and deterioration of the native vegetation cover. Proper rehabilitation strategy is needed to restore the vegetation and improve the wild habitats of the Park to pre-invasion levels. It is hoped that the rehabilitation strategy suggested in this paper will contribute significantly towards improvement in the vegetation cover and habitats of the National Park.

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REFERENCES

- Abdal, M., W. Al-Houty, and S. Zaman. 1992. Gulf War Impact on the Desert Ecosystem of Kuwait. In *Third World Academy of Science: Fourth General Conference*. 23-26 November, 1992.
- Al-Houty, W., M. Abdal, and S. Zaman. 1993. Preliminary assessment of Gulf War on Kuwait desert ecosystem. *J. Environ. Sci., Health*, A28: 1705-1726.
- Al-Sdirawi, F. 1986. Conservation and Protection of wildlife in Kuwait. Kuwait Institute for Scientific Research. KISR Report 1927. Kuwait.
- Al-Sdirawi, F. 1992. The impact of the Gulf War on the desert ecosystem. *Paper presented at the workshop on "Environmental Dimensions of the Gulf: Policy and Institutional Perspectives"*. Al-Ain, UAE.
- Omar, S.A.S. 1982. Baseline information on native plants. *Technical Report 1790*, Kuwait Institute for Scientific Research. Kuwait.
- Omar, S.A.S. 1992. Dynamics of range plants following 10 years of protection in arid rangelands of Kuwait. *J. Arid Environ.* 21: 99-111.
- Omar, S.A.S., and F.K. Taha. 1984. Selection of and criteria for the National Park/ Nature Reserve in Kuwait Desert. Phase II Proposal. Kuwait Institute for Scientific Research, *KISR Report 1318*, Kuwait.
- Omar, S.A.S., and S. Zaman. 1995. Post-war rangeland status of Kuwait. *Proceedings of 5th Int. Rangeland Congr.* 414-415
- Omar, S.A.S., E.J. Briskey, R. Misak, and A. Asem. 1998. The Gulf War impact on the terrestrial environment of Kuwait. *Paper presented at the international conference addressing "Environmental Consequences of War: Legal, Economic and Scientific Perspectives"*. Washington D.C. USA.
- Stohlgren, T.J., K.A. Abull, and Y. Otsuki. 1998. Comparison of rangeland vegetation sampling techniques in the central grasslands. *J. Range Manage.* 51: 164-172.
- Zaman, S., and F.K. Taha. 1995. Quantitative evaluation of vegetation in two main steppes of Kuwait's rangelands. In S. Omar, M.A. Razzaque, and F. Al-Sdirawi (Ed.), *Range Management in Arid Zones*. Kegan Paul International. UK.
- Zaman, S., and F. Al-Sdirawi. 1993. Assessment of the Gulf environmental crisis impacts on Kuwait's desert renewable natural resources. Food-7. Kuwait Institute for Scientific Research.
- Zaman, S. 1998. Impact of the Gulf War on Kuwait's desert flora and soil. *Proceedings of "International Conference on Desert Development: Sustainable Development of Arid Zones"*, Assessment and Monitoring of Desert Ecosystems. Balkema, The Netherlands.

V. Combating Desertification

Sandstorms in Xinjiang, China

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ABSTRACT

Xinjiang, situated in northwest China, is characterized by a windy and dry climate, and has the largest area of desert in China, which provides dynamic conditions and material sources for sandstorms. According to the meteorological data, Xinjiang is the region where sandstorms happen frequently. There are about five to eight sandstorm days in north Xinjiang and over 20 sandstorm days in southern Xinjiang every year. In the center of the Gurbantonggut Desert, the largest fixed and semi-fixed desert in China, sandstorm days reach 20, whereas they reached 70 days in the Taklamakan Desert. In Xinjiang, 70% of the sandstorms appear in April, May, and June. Xinjiang is a source of sandstorm in China, too. When the cold air current forming in the Ural'skije Gory or Siberia enters Xinjiang from the western mountain passes, generally speaking, it accelerates and meets with the local warm air mass, then blows sands and dust into the air and moves eastward.

As a result, it produces a great impact on people's lives and productivity in north China. Sandstorms are considered a serious problem for humans, causing injury and death to local people and heavy economic losses. They also cause significant agricultural losses when they occur during the sowing and growing seasons. This paper discusses the effect of a sandstorm, which occurred in April 1998, as a case study, and the counter measures taken to reduce its effects. The forecast of sandstorms, at present, is the most important measure to reduce its impact. Meanwhile, the protection and construction of an eco-environment must be placed on a high priority.

GENERAL SITUATION: SANDSTORMS IN XINJIANG

Sandstorms, generally speaking, occur when strong wind blows the sands and dusts into the air and makes the air visibility less than 1 km. It is evident that the formation of sandstorm includes three indispensable conditions: *strong winds, unstable air currents heated by the ground, and material sources*. Its intensity is determined by the scale of wind and the air visibility. The stronger the wind and the lower the visibility, the more severe the sandstorm.

Xinjiang, situated in northwest China, is characterized by windy and dry climate, and has the largest area of desert in China, which provides dynamic conditions and material sources for sandstorms. In history, Xinjiang has had severe sandstorms frequently. It has

been described as "Black Storm" or "Yellow Wind" in Chinese, which made some farmlands near deserts abandoned, houses buried, and causes death of many people. In the last 50 years, sandstorms have occurred more frequently with the development of land and water resources in Xinjiang on a large scale.

According to the meteorological data, Xinjiang is the region where sandstorms happen frequently. There are about five to eight sandstorm days in north Xinjiang and over 20 sandstorm days in southern Xinjiang every year. In the center of the Gurbantonggut Desert, the largest fixed and semi-fixed desert in China, the sandstorm days reach 20 days, and in the center of the Taklamakan Desert, the most famous sand sea in the world, they are over 70 days with high evaporation (2,100-3,400 mm) and low rainfall (20-70 mm/year). In Jungar Basin, where rainfall is higher (100-200 mm) and evaporation lower (< 2000 mm), sandstorm days are lower also, i.e., 5-8. The sandstorms in Xinjiang appear mainly in April, May, and June, accounting for 70% of the whole year.

Xinjiang is a source of sandstorms in China, too. When the cold air current forming in the Ural'skije Gory or Siberia enters Xinjiang from the western mountain passes, generally speaking, it accelerates and meets with the local warm air mass, then blows sands and dust into the air and moves eastward. As a result, it produces a great impact on people's life and productivity in North China.

Sandstorms are obviously a serious disaster, particularly when they harm humans, causing local people injury and death and heavy economic lost. In Xinjiang, for example, dozens of people died from sandstorms in the last 50 years. When sandstorms happen in the sowing and growing season, the harm to agriculture is more serious. It erodes surface soil severely and causes soil nutrient loss: it deposits dusts on the crops affecting their photosynthesis and respiration, or it can bury the crops. It is clear that sandstorms are one of the most serious environmental problems in Xinjiang.

THE XINJIANG SANDSTORM OF APRIL 1998

On April 18, 1998, a severe sandstorm occurred in Xinjiang, China, caused by the strong cold air current from Siberia. The sandstorm impacted on large area of Xinjiang, and then moved eastward and affected North China. It was reported that the dust from the sandstorm flowed to Japan and North America. The general wind velocity of the sandstorm in Xinjiang was over 15 m/s, and in some area it reached 40 m/s. The visibility was less than 30 meters. This sandstorm was characterized

by a large affected area, lasting a long time, with serious damage in Xinjiang.

The Sandstorm Weather

The sandstorm that occurred on April 18, 1998 was one of the severest sandstorms in Xinjiang. The formation of this sandstorm was related to the previous conditions. During January to October 1997, Xinjiang had less rainfall and higher temperature in general, and in winter the temperature was lower than normal. In spring of 1998, especially in April, the cold air masses invaded Xinjiang frequently. This cold air, mixing with the local warm air, provided the requisite unstable dynamic conditions for sandstorms.

Before the sandstorm of April 18, 1998, happened in Xinjiang, the air and ground temperature rose rapidly. Between April 14 and 18, according to the observing data, the air temperature increased at a speed of 2-6°C/d in general, so did the ground temperature (Table 1), which provided the conducive conditions for a sandstorm. Meanwhile, a strong high-pressure ridge had formed in north Europe and expanded. When the high-pressure ridge developed, it pushed the low eddy in the Ural'skiye Gory to move eastward and the cold air in the front of the ridge filled in the eddy.

pressure ridge or the cold air current) formed in the north Europe and in the Ural'skiye Gory and the Siberia. As the high pressure developed, the cold air current expanded and entered Xinjiang. When this cold air mixed with local warm air and uplifted sands and dusts into air in Xinjiang, the sandstorm had been formed. After that, it moved eastward and affected North China. Almost all of Xinjiang, occupying one sixth of total area of China, and other regions in North China, had been affected by the sandstorm.

Long Duration

The process of the sandstorm on April 18, 1998 behaved as a strong wind. The visibility was about 1,000 m. As it moved eastward, the visibility became less and less. At 14:34 p.m., the visibility was about 300 m in Changji. At 15:30 p.m., the visibility of <30 m was observed; this situation lasted 6 hours in Xinjiang. In general, the sandstorm of <30-m visibility in each station (Tacheng, Changji, Qitai, Mulei, and Balikun) lasted about half an hour.

Weather Factors

During the sandstorm, the weather factors, such as air pressure, air temperature, and air humidity had a great

Table 1. Maximum air and ground temperature changes during April 14-19, 1998.

Station	14		15		16		17		18		19	
	Air	Gnd ¹	Air	Gnd	Air	Gnd	Air	Gnd	Air	Gnd	Air	Gnd
-----°C-----												
Tacheng	13.9	24.5	22.4	28.8	26.2	36.0	25.7	24.8	14.5	17.5	12.0	26.2
Changji	18.0	30.7	25.2	41.6	28.2	45.3	33.0	50.5	22.3	38.0	18.2	32.0
Mulei	9.7	30.6	13.0	42.4	18.1	43.5	20.2	47.0	17.4	50.3	11.6	32.5
Balikun	15.6	32.6	17.9	37.4	23.2	42.0	24.6	43.8	25.7	40.9	16.6	37.0

¹Gnd = ground.

At 08:00 am (Beijing Time) of April 17, the north part of Xinjiang was still controlled by low pressure. At 11:00 am, April 18, the front of high pressure arrived at the northwest mountain area of Xinjiang. After accelerating in the mountain passes, the cold air mass entered north Xinjiang at a speed of 130 to 150 km/h. In some meteorological stations, the wind velocity of over 30 m/s had been recorded. When the frontal surface reached Changji at 14:34 p.m., the sandstorm appeared and then continued to move eastward.

The visibility of <30 m and the wind velocity of >35 m/s were recorded in Qitai Meteorological Station (16:02 p.m.) and other stations in eastern Xinjiang. As described by local people, nothing could be seen and it was too hard to breathe and walk outdoors during the sandstorm. After the sandstorm passed, it rained and the temperature decreased markedly.

The Sandstorm's Characteristics

Large Affected Area

The sandstorm on April 18, 1998, in Xinjiang was a typical one in China. Its dynamic condition (high-

change, which shows the process of the sandstorm was strong. In the west part of Xinjiang, where the sandstorm had not formed, the weather factors changed less than that in east part. In Tacheng, in west part of Xinjiang, for example, the air pressure increased 5.5 hPa, air temperature decreased 1 °C, humidity was and air humidity reduced from 87% to 49% in one hour during the sandstorm, while in Qitai in east part of Xinjiang, the air pressure increased 10 hPa, air temperature decreased 12.5 °C, and air humidity rose up from 10 to 53%.

Serious Damage

The severe sandstorm on April 18, 1998, had heavy damage to the agriculture production, transportation, communication, construction in Xinjiang, as well as local people. According to the investigating data, in part of the area in Xinjiang, about 40,000 ha cropland was damaged by the storm. In some areas, the eroding depth of farmland reached 7 cm. The sandstorm made three people lose their lives and caused a forest fire. The estimated direct economic lost in Xinjiang was about 40 million US dollars.

The Material Sources for the Sandstorm

When the cold front of the high-pressure entered Xinjiang, it was characterized by strong wind at first, and the visibility was about 1,000 m. That means there were less sand or dust in the air. While the strong wind moved at a high speed in north Xinjiang, it blew lots of sand and dust into the air and the visibility became less and less, and the severe sandstorm formed in the east part of Xinjiang. It is clear that the materials of the sandstorm were from the surface soils in Xinjiang. In north Xinjiang, the surface of land there is covered by sandy deserts, Gobi deserts and oases, which were the main material sources for the sandstorm.

For example, the Gurbantonggut Desert occupies an area of 48,800 km² in the center of the Jungar Basin. Although the Gurbantonggut Desert is a fixed and semi-fixed desert, the crests of the dunes there are mainly covered by shifting sands. When the wind velocity reaches 7 m/s in the Gurbantonggut Desert, according to the results of the experiment in the wind tunnel, the sands start to jump up. Similarly, when the wind velocity is over 20 m/s in the Gobi deserts that are distributed around the Gurbantonggut Desert, the sands are blown into the air.

That indicates that the sandy desert and Gobi deserts in north Xinjiang were the main material sources for the sandstorm on April 18, 1998, while the wind speed was higher than 30 m/s. In the oases, it was the time to sow seed; therefore, the surface soils of the farmlands were bare and loose. Before the sandstorm happened, the ground temperature was over 50°C and surface soils were drier than normal, which provided the conditions for wind erosion. In this case, the oases were the important dust sources for the sandstorm, too.

minerals are resembled (Fig. 1). The contents of the unstable, the stable, the more stable and the very stable minerals in the sands and the dusts show less difference. In other words, the materials of the sandstorm are mainly from the deserts in north Xinjiang, although the dusts have other minerals that one does not find in the sands, such as coal dusts, soil humus, etc.

COUNTER-MEASURES TO REDUCE SANDSTORM EFFECTS

Sandstorms are a kind of weather disaster and a serious environmental problem in arid area. It is necessary to reduce their effects in arid areas through forecasting and by eco-environment construction. According to the sandstorm characteristics and the physical conditions in Xinjiang, some counter-measures to reduce the effects of sandstorms have been put forward as follows.

Monitoring and Forecasting

Although sandstorms break out abruptly, they have previous weather processes and general moving patterns. Sandstorms can be forecasted through long-term monitoring. In Xinjiang, China, however, little research work on sandstorm formation and transportation has been done in last 50 years. As a result, the shortage of monitoring data limits precise forecasting. Therefore, it is important to monitor the weather processes and the moving pathways of sandstorms in Xinjiang, which is the basic step to forecast sandstorms and the efficient way to reduce their adverse effects.

Reducing Sandstorm Sources

Xinjiang has an area of deserts of 1,020,000 km², which are the main material sources of sandstorms, but so are oases of 70,700 km², which are surrounded by

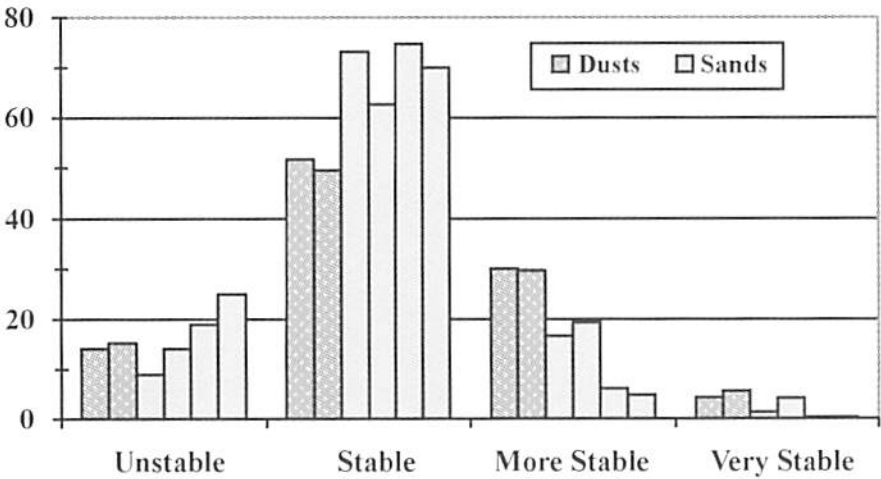


Fig. 1. The mineral contrast between sands and dusts

The mineral components of the sandstorm show that the materials are mainly from sandy desert. According to the analyzed results of the sand samples collected from desert and dust samples from the sandstorm, the

deserts. Meanwhile, desertification has developed rapidly because of misuse of water and land resources. That shows that there are rich material sources of

sandstorms. So, rehabilitating vegetation in deserts and building the protecting belts of oases are key ways to cut off material sources and decrease wind speeds of sandstorms and then to reduce their effects on oases.

Improving Awareness

The sandstorms in Xinjiang break out mainly in spring and summer. It is just the same time for crops to be sown and grow. Therefore, strengthening management of farmland, on the one hand, is an approach to protect crops from damage of sandstorms. On the other hand, people should pay more attention to sandstorms

through publicizing the damage of sandstorms and prevention knowledge of sandstorms.

REFERENCES

- Zhengan, Q. 1997. The classification standard and statistics characteristics of sandstorms in northwest China (*in Chinese*) *Study on Sandstorms in China*, Meteorological Publ. House.
- Qiyun, X. 1997. The distributing characteristics of sandstorms in space and time in northwest China (*in Chinese*), *Study on Sandstorms in China*, Meteorological Publ. House.

Assessment and Monitoring of Desertification in Northern Jordan

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ABSTRACT

This study applied remote sensing techniques to extract and evaluate the natural resources parameters related to land degradation and desertification such as water, vegetation, geomorphology, drainage system, soil, etc. Also, the study used multi-temporal analysis of Landsat TM data to analyze the status of vegetation as well as the irrigated area during the period of 1983-1995. The analysis clearly shows the decreasing vegetation cover. The phenomena of disappearance of palatable plants was seen and confirmed during the field survey. We noted also the presence of unpalatable species that replaced the palatable ones. Then GIS was used to analyze and combine these parameters which resulted in thematic map layers, including land use, geomorphology, drainage system, soil moisture, soil erosion susceptibility, vegetation degradation, and salinization based on assessment of irrigated areas. A final stage of this research was the creation of desertification maps describing the different types of land degradation in the study area.

INTRODUCTION

The use of satellite data, remote sensing techniques, and geographic information systems (GIS) is becoming an important means to provide environmental information on earth's surface, which leads to a better understanding of environmental conditions and problems, including desert conditions, land degradation, and natural resources assessment and monitoring. However, due to the complexity of the desertification process, analysis and monitoring of this phenomenon require the simultaneous use and integration of data collected from conventional sources and satellites of various types through GIS. Natural resources in arid and semi-arid lands, which are declining in productivity, require special attention. Therefore, we should look for the optimum solution regarding the land use plan in order to minimize environmental degradation.

So the analysis and assessment of these environmental problems require the study of major environmental factors, such as rainfall, geomorphology, soil, and vegetation cover. Also, socio-economic factors, such as population and agriculture production, should be taken into consideration. The on-going study aims to evaluate and demonstrate the ability of remote sensing and GIS techniques to analyze and solve environmental problems. The result includes erosion susceptibility map and others. Based on remote sensing and field data analyzing the vegetation, soil, and land conditions and status, a desertification map was prepared as a basic element in order to combat desertification.

DATA AND MATERIALS

Two sources of data were used to achieve and complete this study. Satellite images include Landsat TM January 1983, Landsat TM May 1985, Landsat TM July 1989, Landsat TM March 1995 and NOAA AVHRR 1km April 1992 through March 1993, and thematic maps including geological (scale 1:250,000), soil (scale 1:250,000) and rainfall (scale 1:750,000) and topographic (scale 1:50,000).

ENVIRONMENTAL FEATURES

General Description

The study area, approximately 1300 km² in extent, lies on the eastern plateau of Jordan. Some 40 km northeast of Amman, with altitude ranging between 500 and 950 m. Geological formations occurring within the area consist of marl limestone, chalky limestone, cherts, alluvial of *cretaceous origin* and thick flows of basaltic lava.

Climatic Factors

The climate of study area can be classified as a semi-arid to arid. Only the highlands in western part of study area have a Mediterranean climate; cold and mild in winter to hot and dry in summer. Temperatures in the study area can rise in summer to 33°C with an annual average varying between 12°C in western part and 15°C in eastern part. The relative humidity is low. In winter, it is generally around 40-56%, and in summer it drops to 26%. The low relative humidity throughout most of the year makes the hot summer days more tolerable and the cold winter days more severe. Winds of northwest-southeast direction are common during summer time and change to southeast during winter. The annual average of wind speed equal to 197.9 km/day (2.3 m/s), rising to 3.2 m/s during April; in the southeast part of the study area the wind speed may arise 5.7 s/m.

The rainy season extends from October to April, with peak precipitation taking place during January and February. The highest rates of rainfall occur over the highlands in the western part of the study area, which receives a long-term annual average of 250 mm. To the east of these highlands, rainfall decreases to 100 mm/year in the eastern part of the study area. Worth mentioning is that 250 mm/year is the least amount needed for dryland agriculture; this amount covers less than 10% of the study area, which means that only 14% of precipitation can be used in dryland farming. The rest (86%) requires certain technologies to be made available for different uses. The rainfall in the study

area also is characterized by variability in time and location, which reaches a value of 32% in western part and 48% in eastern part (Khalaf, 1987). The potential evaporation rates range from about 1277 mm/year in the west part to 3832 mm/year in the eastern area

Soil

Soil represents the meeting point between the physical and the biological worlds. Soil is a fundamental land resource because it allows plant conditions the presence of vegetation and the utilization of land for agriculture. The color composite of vegetation index, color index and brightness index was used to recognize the different types of soil.

According to the soil map of Jordan developed by Moorman (1959) and the interpretation of enhanced images, we could distinguish the following types of soils:

- **Red Mediterranean Soil and Lithosols:** Dark reddish brown and reddish brown, deep, calcareous, containing significant percentage of calcium carbonate (17%). This unit is located in the xeric moisture regime, and is intensively cultivated to cereals and tree crops.
- **Yellow Mediterranean Soil and Regosols:** This unit is derived from aeolian deposits, shallow, fine and dissected texture.
- **Yellow Mediterranean Soil and Basalt:** Derived mainly from basalt, this unit is characterized by a fine texture, with a high percentage of calcium carbonate; with a rainfall above 200 mm, cultivation of barely is possible. Irrigated agriculture is widespread in this unit, which leads to soil salinity.
- **Yellow Soil:** This unit is rich in calcium carbonate, has a medium texture, and medium depth.
- **Yellow Soils and Regosols:** This unit is characterized by a high permeability and coarse texture; it is facing problems of overgrazing and the disappearance of many vegetation species.
- **Yellow Soils and Basalt:** Parent materials derived from weathering products of basalt and tuff consist of brown silt loam to clay loam with varying amount of basalt fragments and calcium carbonate concretions; an important part is derived from aeolian deposits. Its high depth allows for irrigation agricultural activity.
- **Basalt Lands:** Covered mainly by basaltic flows with a stony surface, it has a fine-loamy texture and weak soil structure in upper layers.
- **Solonchaks:** This unit occurs in the south part and contains a high amount of salts, reaching up to 10%. (Rihani et al., 1987) and Khalaf, (1987) investigated the soil characteristics of the study area; part of their results is summarized in Table 1.

As for moisture, a soil moisture map was produced using satellite data and classified according to soil

moisture regime adopted by MOA (1993). The study area has the following soil moisture regimes:

- **Xeric:** The moisture control section is moist in some part more than half the time, the soil temperature is higher than 5°C, or is moist in some part for at least 90 consecutive days in 6 out of 10 years when soil temperature is higher than 8°C. The mean annual temperature is less than 22°C.
- **Xeric-Aridic Transitional:** Moisture regime is intermediating between xeric and aridic regimes in which the control section is too moist for the aridic regime and too dry for the xeric regime.

Geomorphology

The principal components of Landsat TM and other remote sensing techniques were used to determine the following geomorphologic units:

- **Sloping area:** This unit is characterized by the existence of rill erosion and overgrazing problems.
- **Gently sloping area:** This unit is characterized by rill and sheet erosion, and formation of eroded rocky area. The overgrazing and plowing of range-land in this unit are the main desertification features.
- **Level-nearly level area:** Colluvial material is the predominant formation in this unit. Sheet erosion, wind erosion, marginal agriculture, and soil salinity are the principal problems of this unit.
- **Basaltic land:** This unit occurs in the eastern part of the study area, generally a flat area. The unit presents problems of salinity in the irrigated areas, wind erosion and the presence of boulders and stones.
- **In-filled valley (floodplain):** This unit contains a deep homogeneous and fertile soil, which is very useful for dryland agricultural activities. Valley terraces have been included in this unit.

Land Use and Vegetation Cover

Land use change detection and natural vegetation monitoring are very important elements to assess land degradation and to provide a basis for scientific decision-making. Natural vegetation groups are generally related to physical conditions, particularly the prevailing climate, soil types and topographic characteristics. According to the study reported by MOA (1993), the vegetative communities in the study area belong to the following zones:

Mediterranean Region: This area encompasses those areas of dissected limestone plateau with rainfall in excess of 200 mm; the most easterly extension of transitional Mediterranean species is about 5 km to the west of Mafraq. It includes degraded Mediterranean scrub vegetation and planted woodlands, mainly of *Pinus spp.* occurring on shallow soils associated with rock outcrops.

Steppe Region: Steppe vegetation occurs mainly in the rainfall range 100-200 mm. Steppe species may occur in association with Mediterranean transitional species. Two major types of steppe vegetation occur, *Artemisia* brush steppe and grassland steppe. The cover of browse species range from 2-50%, with *Sharan* dominant and including *Mileh*, *Sirr*, *Shnan*, *Hamd*, *Shih*, *Gaisum* and *Ajram*. The steppe lands are especially prone to erosion by wind once the protection afforded by the vegetation is removed, which can be seen after ploughing.

Remotely sensed satellite imagery (Landsat TM 1989) has been used to produce a land use map for the study area, which reflects topography, climate, soil type and moisture availability. The following classes were recognized:

Rainfed and Marginal Agriculture: Rainfed agriculture occurs on land lying within the xeric moisture regime and generally in areas where rainfall exceeds 200 mm. There are two main sub-divisions within the rainfed sector: Tree crops are a major component within the hilly and steeply sloping lands of the western part of the study area. There has been significant expansion of this area, especially of olives; this is a trend which has been encouraged by the government under various projects. The area of this category within the study area is about 7000 ha.

On the undulating lands of the plains, wheat is the major annual crop, especially within the plains of Rihab and Bala'ma, with lesser areas of tobacco. In the marginal zone of low rainfall (100-200 mm), deep soils of the valley bottoms and alluvial plain areas have been used for barely and occasionally wheat, using runoff from surrounding hillsides. Marginal agriculture is estimated at about 33K ha.

Irrigated Agriculture: The major areas of irrigated agriculture that use fossil groundwater are located on the basalt plateau soils of east of Mafraq and in the southeast of the study area (Hallabat). In these areas, the limited water availability and use of drip irrigation leads to rapid build-up of salinity and abandonment of the irrigated areas after 7-9 years. Vegetables are the main crops. The total land used for irrigation is about 6,440 ha.

Forest (woodlands) and Scrub: Scattered planted woodlands are located on the hills in the west part of study area where the rainfall exceeds 210 mm; degraded Mediterranean scrub vegetation occurs on the steeper, rocky slopes. The total mixed area of woodlands and scrub is estimated at 3,100 ha.

Reserved Rangeland: The study area includes some reserved rangelands which are controlled and managed by the Ministry of Agriculture. These reserves are protected from degradation from overgrazing, ploughing, and woodcutting, thus allowing natural plants to be grown. The estimated area is about 1,960 ha.

Dense Grassland: This category belongs to the grassland steppe region in Jordan, which is prevalent in the 150-250 mm rainfall zone in the western part of the

study area. The major constituent species are *Poa sinaica* and *Carex pachystylis*. Over large areas of the steppe, ploughing has destroyed the turf, leaving the silty soils susceptible to both wind and water erosion. This area in this category equals about 39,333 ha.

Sparse Grassland: This category occurs on the gently undulating alluvial plains and the basalt plateau. Much of this steppe has been destroyed by inappropriate cultivation and overgrazing. The present practice of bulldozing stones and boulders to clear fields in the basalt areas leads to total destruction of the turf. About 29% (28,860 ha) of the study area is considered as sparse grassland; sometimes it is called desert rangeland.

Urban Area: Mafraq is the only city in the study area, and in addition there are more than 30 small towns and villages. We noted that the expansion of these settlements generally onto the agricultural lands, especially in the west part of the study area. The urban area covers about 2,200 ha.

Rocky Area: Mafraq area is very well known for its stones for building construction, especially the southwest of Mafraq city; in this part, there are quarries, which destroyed an important part of the dense grassland area. The total rocky area is estimated at 513 ha.

SOCIOECONOMIC FACTORS

The human activity in the study area is considered to be a continuity of what people have been used to do in the past. Several archeological studies have mentioned the agricultural activities in this region, which date back to 4000 years ago in Jawa and Umm Al Jimal (east of Mafraq City), where people have used the harvested water behind small dams and *romaine* basins "Beraks" to irrigate cereal crops (Betts, 1977). According to Moorman, (1959), the western part of the study area have been used extensively in agriculture for 1000 years ago.

Population

It is clear that rapid population growth, accompanied by food and resource shortages, as well as environmental degradation, is threatening social and economic development. The population of Mafraq governorate is estimated to be 198,700 people in 1997, with a rate of population growth equal to 3.4%. It was about 11,255 people in 1953. This high rate of increasing population reflects the important development of different sectors: agriculture, services (transportation, tourism), industry and others. It is estimated that the population in the study area equals 80% of the total population of Mafraq governorate. The population density increased from 8.7 person/km² in 1953 to 130.7 person/km² in 1997. This situation increases the demand on land resources and, considering the ecosystem occurring on the study area as fragile and limited in its resources, makes the conditions of land and its general environment in a critical situation, facing serious problems of desertification.

Agriculture Activities

Cultivation

The main agriculture activity is the rainfed cultivation in the west part of the study area, where the rainfall exceeds 210 mm, followed by marginal rainfed cultivation in the areas where the rainfall is less than 200 mm. The main cultivation types are wheat, barley and olives trees. We noted the increasing human pressure on the marginal lands, which caused the rangeland and soil degradation. The third form of cultivation is irrigation agriculture. The main part of this activity occurs in the north and the east-south part of the study area, where it began at the end of 1960. In 1970 the irrigated area was estimated at 400 ha (Khalaf, 1987). Satellite images were used to assess the expansion of irrigated areas from 1983 through 1989.

Livestock

Livestock production is an important sub-sector of agriculture; many farmers depend largely on livestock for food and additional income. Livestock is the major source of livelihood for the nomadic population. The livestock population in the Jordan was estimated in 1997 at 3.15 million head, whereas in 1961 it was estimated at 0.62 million heads. The total livestock in Mafrq governorate is estimated at 25% of total livestock in Jordan.

These statistics show clearly the heavy impact of livestock on rangeland, which actually support 40% of total feed requirements. The marked reduction in forage productivity also makes the vegetation degradation apparent. Forage productivity, estimated to 100 kg DM/ha in steppe grassland, is about 450 kg DM/ha in the reserve rangeland (Nesheewat, 1996). Production of forage depends highly on precipitation, and the livestock impact on rangeland of study area is very high in the western part of study area where forage productivity is high.

DESERTIFICATION ASSESSMENT

The International Convention to Combat Desertification (CCD), adopted in 1994, defines desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variations and human activities". We describe here the causes and indicators of desertification persisting in the study area.

Desertification Causes

Simultaneously with drought conditions, the misuse of natural resources is regarded as the cause of desertification. This is attributed to several factors:

- **Cultivation of Marginal Lands:** This practice is expanding into areas which display only a low capability and which, in view of the available precipitation, do not actually permit sustained cultivation. In years with good precipitation, large grazing areas are converted into arable land (mostly barley). However, as these favorable periods occur only once every 10 years under the natural climatic conditions, in normal years after the shrubs and permanent grasses have been cleared, ploughing has destroyed the stability of soil and the field lies fallow, soil particles are then exposed to wind erosion. Then soil particles are carried away by dust storms.
- **Expansion of Orchard Areas:** Particularly occurs in the uplands in the western part of the study area where farmers often use bulldozers to build terraces, which leads to soil erosion.
- **Urbanization:** The growth of settlements is regarded as a desertification problem, as resources are lost due to the construction of buildings on valuable arable land.
- **Over-exploitation of Fertile Soil:** The analysis of soil samples showed clearly the diminution of organic matter in the deep fertile soil in the west part of study area, which is explained by the old and intensive use of land.
- **Traffic of Heavy Machines:** This action, which occurs with intensive use, affects and destroys the structure of soil, especially with high amount of silt, so soil particles are removed by wind and water.
- **Cleaning of Stones:** The basaltic stones on the Jordanian desert rangelands have the advantage to keep the soil moisture, which permit the growing of some bushes for grazing. Removing these stones generally for ploughing and irrigation agriculture leads to vegetation degradation and the disappearance of palatable species.
- **Irrigation Returns Flows and Over-Exploitation of Groundwater:** The aridity characteristic of the study area promotes to use the groundwater to irrigate lands. The studies of Jordanian Water Authority show an important over-exploitation of groundwater wells in Mafrq governorate, increased from 23 wells in 1970 to 427 in 1997. This practice has led to high salt concentration accumulating in the soils. Continual irrigation allows the salts to seep down below the capillary fringe and to reach the groundwater or to seep again to the earth's surface and reach the surface water. In Dhuleil area, in the southeast part of the study area, the salinity of the water increased twice or three times its original value. As a result of irrigation flows and over-exploitation of groundwater, salt concentration lowers crop productivity, which could no longer be used for irrigating normal crops, and consequently land was laid fallow (Salameh and Bannayan, 1994).

Desertification Indicators

The following may be considered as indicators of desertification caused by the processes described above:

- **Loss of Yield and Forage:** The marked reduction in productivity also makes the loss of soil apparent; in 1966, wheat harvests amounted to 980 kg/ha, but in 1984 only about 180 kg/ha were harvested. Forage productivity is estimated to be 100 kg DM/ha in steppe grassland, while it is about 450 kg DM/ha in the reserve rangeland (Nesheiwat, 1996).
- **Appearance of Unpalatable Plants:** The disappearance of palatable species and their replacement by unpalatable species is a form and indication of moderate or severe vegetation deterioration. The extent to which the various plants are browsed differs quite considerably depending on their palatability. This favors appearance of plants, which are less palatable or unpalatable, i.e., *Anabasis Aphylla* and *Anchusa Strigosa*.
- **Increase in Abandoned Farmlands:** In some areas, productivity has dropped so severely that farms have had to be abandoned. This is seen in the arid east part where the farmers used to shift their cultivation to the neighboring land after several years of use. This phenomena leads to the extension of salinization.
- **Dust Storms:** The statistics of weather department mentioned that there is a continued increase of dust storms from few days/year in the 1950s to more than 30/year days in the 1980s.
- **Bare Lands:** The pronounced soil wash result is seen in almost vegetation-free and eroded areas. Such areas are found most frequently in highlands and on former arable land where the original vegetation has been cleared.
- **Changes in Soil Characteristics:** Land degradation affects soil characteristics in its organic matter content, salinity and texture. Studies of soil analysis (Rihani et al., 1987; Khalaf, 1986; 1993) showed a decrease of organic matter from 2.98% to 1.0% in the northeast part. The content of organic matter in ploughed areas of marginal lands is very low 0.15-0.70%. In the western part of the study area, it is possible to consider three situations which reflects the human pressure on the land.

In the control rangeland, organic matter may reach 2%. In the reserved rangeland, which shows an important recovery, the OM is about 2.65%, while just outside this reserved land the content of OM decreases to below 0.30%; here we note the intensive overgrazing. The third situation occurs in the rainfed agricultural land where its organic matter decreases to 0.45% in some places; this area has been under cultivation for 1000 years ago.

As for soil salinity, Rihani et al. (1987) mentioned that in the eastern part of the study soil salinity

exceeded 200 mmhos/cm in the field under irrigation, and just 800 m from this field where there is no irrigation activity the salinity is around 5.1 mmhos/cm. This is not a general result because other fields show an acceptable values of salinity. The analysis of soil texture shows a decrease in clay and silt content and an increase of sand content, which leads to coarse texture of soil. It is evident that this is a result of wind erosion which blows out the fine material after a period of dry weather and soil compacting.

- **Groundwater Deterioration:** The salinity measurements of wells used for irrigation shows that the salinity at the beginning of pumping in the seventies was about 250-300 ppm. The measurements of 1985 and 1987 show salinity generally more than 1500 ppm and sometimes exceeding 4000 ppm. The same studies indicate a decrease of 12 m in the watertable level from 1977 through 1985 for wells in north of Mafraq City.

Risk of Desertification

Soil erosion is a dynamic problem which has to be continuously monitored, as it results not only in loss of fertile soil but also it is the primary factor for landslides. Soil erosion is caused by removal of vegetation, deforestation, overgrazing, rainfall intensity, etc. An erosion-susceptibility map was produced using a model of geographic information system developed by the Tunisian national remote sensing center (CNT, 1992). This model is based on the integration of relief, soil, drainage system, and vegetation. A cross-comparison system has been proposed to finally classify the erosion susceptibility in four classes ranging from stable areas to areas with highly susceptibility to erosion. As for wind erosion, the desert soils generally have high susceptibility for wind erosion and the eastern area, which is covered by stones, is also highly susceptible to wind erosion, once the cover stones are removed. The fragile arid and semi-arid ecosystems do not allow a high exploitation and use of natural resource, especially natural vegetation. The study area should be kept under controlled of grazing and agricultural practices.

Desertification Status Mapping

Criteria Assessment

Criteria for desertification assessment must take in consideration, the local conditions of the study area. These conditions should be investigated through field observations with the help of remote sensing tools. The results of such investigation can be interpreted according to the type and degree of desertification. The types of desertification considered in this study are: *degradation of natural vegetation*, *wind erosion*, *water erosion*, and *soil salinization*. Criteria for the assessment and mapping of desertification were developed for each land-use type. The following categories of land use were identified: *forest/scrub*, *rangeland*, *dryland*

agriculture, and irrigation agriculture. Criteria could be taken in consideration are: *plant community, decrease of total plant cover, percentage loss of forage on rangeland, type of erosion, percentage removal of top horizon, percentage loss of yield of main crop, soil salinization, salinity of irrigation water, and seasonal salt accumulation, ton/ha* (Kharin et al., 1991).

Map Compilation

Satellite images of 1983, 1985, 1989, and 1995 were used to compile the desertification map. The fieldwork was achieved using the satellite data of 1989 and 1995. The desertification-mapping units (DMU) were generated after a series of image-processing of the Landsat TM image. The first step was the performing of the radiometric and geometric corrections followed by principal-component analysis and normalization of single bands. The normalization of the first band, the first principal component, and the second principal component, were used to perform unsupervised classification, which constituted the basic layer for desertification mapping. Then, this layer was multiplied by the land-use map generated previously. These processes produced 12 classes of DMU which were identified in terms of their land types and land-unit types. The information relative to the vegetation status per DMU was obtained using the monthly NOAA AVHRR NDVI (Normalized Difference Vegetation Index) composite data set from April 1992 through March 1993.

From these data we calculated also the Vegetation Condition Index (VCI), which is defined by the following formula (Vogt et al., 1998):

$$VCI = (NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min})$$

The VCI is an indicator of the vegetation cover as a function of the NDVI minima and maxima encountered for a given ecosystem over many years. The study area belongs to the steppe ecosystem, and the available data for this calculation (April 1992 through March 1993) represents a normal climatic year. The VCI is dimensionless and varies between zero and one, with zero indicating the worst condition and one indicates the best condition during the same period of time. If the period includes wet and dry years, VCI could have a high potential for monitoring water stress. It is very difficult to make direct measurement for desertification criteria, which need an intensive and accurate field survey, but using available information, we could make estimation of desertification degrees and types. To explain the land degradation types occurring in the study area, a legend of the desertification map was made, which is composed of land-use types, dominant land degradation types, and the degree of the land degradation from slight to very severe degradation.

CONCLUSIONS

The study of land characteristics identified some serious problems such as soil salinity, which is due to the poor irrigation practices and shifting cultivation. The

erosion analysis pointed out environmental problems, such as the large distribution of quarries in regions with good suitability for agricultural activities. A good and accurate desertification assessment requires a field survey to assess and measure the criteria for desertification mapping; soil analysis is also required. Next step of this study will be the calculation of desertification rate and desertification hazards.

Remotely sensed data can be considered an effective tool for assessing and monitoring land resources parameters. Geographic information systems played a valuable role to analyze and evaluate erosion and desertification. It is evident that an "integrated approach" in solving environmental problems such as erosion and desertification is absolutely necessary. Based on a set of scenarios embodying present and future populations, food and agriculture demands and socioeconomic development needs, a range of policy issues for development planning could be addressed

REFERENCES

- Arnaldo M., and S. Tonelli. 1990. Soil moisture detection and mapping, remote sensing application to land resources, *RSC Series* 54, FAO, Rome.
- Betts, A. AM. 1977. Evidence of the stone age studies of prehistoric settlement in eastern Jordan, Dept. Public Archeology of Jordan, Amman.
- CNT (Centre National de Teledetection, Tunis). 1992. Project of hill dam sites location. *Report*.
- Khalaf. 1987. Desertification in the Mafraq Governorate. *MA Thesis*, The University of Jordan, 153 p.
- Kharin N., N.S. Orlovesky, T.A. Babaeva, P. Esenov, A. Kiriltseva, G. Alfereov, M. Dmitriev, and E.N. Kharina. 1991. Methodologie pour l'evaluation at cartographie de la desertification au Sahel. Desert Institute: Academy of Sciences of Turkmenistan, Ashkhabad.
- MOA (Ministry of Agriculture/ Jordan). 1993. The soils of Jordan, Level 1, Vol. 2, *Main Report*.
- Moorman, F. 1959. Soil of the east of Jordan, *Report No. 1132*, FAO, Rome.
- Nesheiwat, K. 1996. Facts and figures on the rangelands in Jordan, p. 49-74, Workshop on rangeland research and development in Jordan, 7-9 May 1996.
- Salameh, E., and H. Bannayan. 1993. Water resources of Jordan, present status and future potentials. Friedrich Ebert Stiftung, Amman.
- Vogt, J.V., A.A. Viau, I. Beaudin, S. Niemeyer, and F. Somma. 1998. Drought monitoring from space using empirical indices and physical indicators. *Proc. International Symposium "Satellite-Based Observation: A Tool for the Study of the Mediterranean Basin"*, Tunis, 23-27 Nov. 1998.

Sustainable Management of Deserts: Environmental Concerns in Combating Desertification

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ABSTRACT

The increase in desertified and degraded lands can often be linked to anthropogenic activities. Several activities, including inappropriate land use, overgrazing, incorrect farming practices, overuse of limited water resources, and deforestation can be held accountable (Mainguet *et al.*, 1996). Additionally, the so-called man-induced climatic changes, particularly global warming, are also thought to exacerbate the situation. Increasing desertified and degraded landmasses means less resources to feed and sustain an ever-growing global population. An indirect consequence of reduced rangelands is the diminished capacity to produce food and sustain livestock. It is no coincidence that the regions facing the worst desertification problems are also the least developed (Middleton and Thomas, 1992). Desertification, thus, becomes a part of the vicious cycle where a poor economic situation worsens land degradation, which in turn damages the economy further.

With this backdrop of a somewhat bleak picture, there is an increasing knowledge of traditional and advanced technologies developed for combating the problem of desertification (El Beltagy, 1999). In a broader sense, the common approaches used in these technologies lead either to stopping and retarding the advance of deserts and sand dunes, or to re-claim the already desertified areas for beneficial purposes (Mainguet, 1994). Sustainable and long-term management of water resources, directly or indirectly, is a cornerstone of the success of these technologies. Equally important is to evaluate the long-term impacts of these technologies on the environment.

INTRODUCTION

It is now well understood that the efforts to combat desertification must be implemented over longer term, i.e., at least within 10-20 years. This long-term perspective allows the programs to be flexible enough to self-correct based on feedback from implementation results. These programs must be closely linked to economic and social policies, while keeping in view the dynamics of traditional systems in place (El-Shorbagy, 1998). The UN Convention to Combat Desertification (CCD) already provides a mechanism for achieving this in the form of *National Action Plans*. In addition, the environmental impact of these programs should be carefully reviewed *a priori* in a standardized manner.

The primary purpose of this paper is to highlight the importance of environmental issues in the development and implementation of technologies to combat desertification. The thesis is put forward that in many efforts to overcome desertification problems the impacts on biodiversity and environment in general are not fully appreciated or considered. Additionally, the realization that sufficient (with a positive recharge-withdrawal ratio) and sustainable (over the long term) water resources are essential to manage desertification remains in the back seat. A preliminary quantitative analysis of groundwater resources provides focus on six North African countries: Algeria, Chad, Egypt, Libya, Sudan, and Tunisia.

WATER IN DESERTIFICATION CONTEXT

In the context of desertification, the appropriate minimal time scales are of the order of 10-20 years. Therefore, evaluation of water availability for use in technologies for combating, or perhaps managing, desertification should also follow a similar long-term perspective. Such an evaluation should have two major components: (a) a hydrologic evaluation of long-term availability of water at desired rates (volume/year), and (b) an explicit quantification of the costs for using water.

Hydrologic Evaluation

The scope of this evaluation should be based on the scale of the program to combat desertification, i.e., it can be on a *national*, *regional*, or *local* level. However, it is best to include local-level information in all evaluations because essential details, such as climatic variability within the country, may be lost on the national scale. This evaluation can be performed based on information obtained from meteorological services: *annual average rainfall (P)*, *loss by evaporation (E)*, *recharge to groundwater (G)*, *influx (I) from transboundary water resource (river or canal)*, and *minimum outflux (O)* required.

It may be difficult to determine the minimum outflux (*O*), because it has to be based on the requirements of downstream users as well as other socio-political factors. Even greater difficulty may be faced in obtaining data for 'reasonable' capacity (*C*) of groundwater withdrawal. Ideally speaking, the *C* value should be similar to *G*, but this is rarely the case in practice (Gupta, 1996). Existing water usage (*WU*) information should include *agricultural (A)*, *industrial (T)* and *urban (U)* per capita usage figures; this should also

include data on population statistics (*N*) in the region under consideration. The available water at a given point in time to combat desertification can thus be calculated using a modified hydrological balance equation:

$$P + I + C - E - G - O - WU.....(1)$$

Where: the water usage is calculated as:

$$WU = [A + T + U] \times Total\ Population.....(2)$$

The long-term projections of the figures used in Equations (1) and (2) should be used to estimate the availability of water over the duration of the program.

Cost Evaluation

The process of placing a cost on water resources may be more difficult than would appear on the surface. The cost evaluation for water should comprise three main components: (a) direct costs for usage of and access to water; (b) direct costs for water treatment; and (c) indirect costs in terms of environmental degradation as well as benefits.

First, the direct usage costs can be calculated relatively easily based on local costs for manpower and energy resources as well as on capital costs for water usage infrastructure (e.g., reservoirs and canals for surface water, pumps and piping for groundwater). Second, it cannot be assumed that the quality of water will be such that it is directly useable for efforts to combat desertification, particularly in some cases when the desalination costs can be quite significant. For example, nine North African countries (Algeria, Djibouti, Egypt, Libya, Morocco, Mauritania, Somalia, Sudan, and Tunisia) have a combined water desalination capacity of over 1 million m³/day (Abdulrazzak, 1997), indicating the magnitude of water quality problems in these countries. Third, it is a much more complex process to fully evaluate the environmental costs, in part, due to uncertainties in impact and inherent difficulty in assigning costs to a natural resource. This issue is discussed in somewhat greater detail in the following section.

It is equally important to give due consideration to climatic fluctuations and their impacts on water resources. In other words, the Programs to combat desertification should have reasonable contingency plans for years during which extremes of climate and hydrological patterns occur, e.g., droughts or floods. Dixon *et al.* (1989) argue that a generally conservative approach in designing such Programs would yield the highest returns over the long term.

The final decision to use a certain technology should, in part, rests on a positive outcome of both hydrologic and cost evaluation. If the overall hydrologic budget is negative, a desertification technology that appears viable on the short term may cause environmental and economic damage in the long run. This is quite true for groundwater resources, where over-

withdrawal over longer periods can result in land subsidence, water-quality degradation, saltwater intrusion and a general decrease in the aquifer capacity (Gupta, 1996). Similarly, if the cost evaluation demonstrates a net negative benefit, then the technology should not be pursued further.

ENVIRONMENTAL COSTS IN COMBATING DESERTIFICATION

In general, the current practice of evaluating costs for combating desertification does not include quantification of environmental benefits or costs. In other words, the available technologies and techniques to combat desertification are thought of as benevolent in all circumstance. Typically, the net fiscal gain through corrective measures is computed using the following formula applied to one unit of land area (derived from Mainguet, 1994):

$$Net\ gain = (Value\ of\ salvaged\ land - Value\ if\ not\ salvaged) - Cost\ of\ salvage.....(3)$$

The 'value' of land is related to its market value and degree of productivity. These values are closely linked to its traditional use as irrigated cropland, rainfed cropland, or as a rangeland.

However, it is important to point out what is missing in this process, i.e., the costs and benefits for environmental impacts of the corrective measure. Most importantly, the costs of adverse environmental impacts should be explicitly included in efforts to combat desertification. Like the case of water cost evaluation, this environmental evaluation should be performed over a longer-term (ca. 20 years) to truly capture the full range of impacts. As an example, Chou and Dregne (1993) argue that rangeland rehabilitation requires between 10 and 30 years, depending on the methodology applied.

To emphasize the importance of environmental impacts, a number of cases can be easily found in the history of efforts to combat desertification. For example, El-Shorbagy (1998) has recorded an excellent overview of adverse impacts of Programs to combat desertification. The case studies described by him include unsuccessful placement of foreign plant and sheep species in Ras El-Hakma (Egypt), failure of shrub plantation schemes in Libyan rangelands, and mechanized farming schemes for sorghum and sesame in the Sudan resulting in encroachment and degradation of otherwise productive rangelands.

Similarly, Mainguet *et al.* (1996) have reported the case of replacement of traditional nomadic practices in the Algerian steppe by a truck-based transportation of fodder, water, and livestock. This policy helped maintain the livestock flocks in the short-term but resulted in such massive overgrazing that the area was unable to recover under natural processes. In part, this land degradation and increasing population has resulted in Algerian dependence on imported food for 50% of its needs (which is projected to grow up to as much as 80% over the next 50 years).

These case studies, just a few among numerous similar cases, show that evaluation of strategies to combat desertification has to go beyond the somewhat over-simplistic procedure used in Equation (3). The most significant common factor in failure of the programs cited here is the absence of long-term evaluation, both cost-wise and in terms of environmental impacts (El-Shorbagy, 1998). Additionally, the importance of understanding and incorporating the traditional and cultural customs in effective implementation plans is underlined. Involvement of the local population in design and implementation of such programs cannot be over-emphasized.

It is proposed here that all schemes for combating desertification should include an environmental impact assessment, such as that typically applied to industrial development projects. Such a process that includes placing explicit costs on ecological damage will help quantify the environmental costs and benefits of such schemes. The responsibility for implementing the environmental impact assessment can be shared by national governments and external agencies that contribute financially to these programs.

It is particularly important to evaluate the impact on existing ecosystems. Typically, the ecosystems on the fringes on deserts are 'fragile' and more vulnerable to relatively small changes. The impact of some traditional technologies, such as surface petroleum mulching, on these fragile ecosystems should be carefully evaluated. Similarly, the impact on biodiversity should also be closely evaluated. If the planned scheme includes plantation of introduced species, a long-term failure of the scheme may result in permanently wiping out indigenous plant diversity. A more complete list of potential environmental problems is listed in Table 1.

groundwater resources (e.g., Ahmad, 1988). However, such studies fall short of a long-term evaluation of costs, impacts on water resources, and environmental impacts as discussed earlier in this paper. To emphasize the importance of such studies, data for six African countries in the Maghreb and Sahel have been evaluated to demonstrate the precarious situation. As shown in Table 2, the annual groundwater withdrawal is compared against the annual recharge to the aquifers.

The data provided in Table 2 represent cumulative figures on a countrywide basis and may lose some finer detail about local groundwater utilization patterns. Nonetheless, these estimates of annual groundwater recharge and withdrawal are useful in evaluating the overall picture. The annual groundwater withdrawals are also compared to the total annual withdrawal to provide a general overview of the importance of groundwater on a national basis.

It is quite interesting to observe that for three countries, Algeria, Egypt and Libya, the *groundwater withdrawal far exceeds the aquifer recharge capacity*. Additionally, groundwater comprises about 40% of the total water requirements for Algeria and Libya. This provides an indication of the fact that total renewable groundwater resources in these three countries must be declining on the whole. This could possibly result in the adverse environmental impacts, as discussed earlier, in addition to higher withdrawal costs due to lowering of the water-table. Conversely, Chad and the Sudan do not utilize groundwater resources to a substantial extent. Notwithstanding other limitations to groundwater use, and climatic variability within the country, one may argue that groundwater may be utilized as a resource for combating desertification in those countries. Lastly, *Tunisia appears to be the only country*

Table 1. List of potential environmental impacts and their likely causes.

Potential Environmental Damage	Likely Causes
Biodiversity loss	<i>Mono-cropping</i> of introduced plant species; <i>Overgrazing</i> in rangelands; Various surface <i>mulching technologies</i> for sand dune control
Ecosystem damage	Loss of soil productivity due to a variety of reasons; Soil erosion by wind or water
Loss of vegetative cover and carbon sequestration capacity	<i>Overgrazing</i> ; High <i>soil-salinity</i> levels; <i>Deforestation</i>
Salinization	Poor water management strategies, particularly in irrigated agriculture; Inappropriate introduced plant species
Water quality degradation	Over-withdrawal from aquifers; Excessive use of fertilizers to maintain introduced plant population
Human health impacts	Dust storms; Malnutrition caused by lack of land productivity, e.g., during a drought

GROUNDWATER RESOURCE EVALUATION

Several researchers have argued that the efforts to combat desertification in North Africa and Sahel cannot be based on rainfed agriculture and must utilize

where groundwater utilization is at par with the recharge capacity.

On the surface, it appears that, by and large, groundwater resources in this region cannot be relied

Table 2. Evaluation of groundwater resources in six African countries.

Country	Annual Recharge	Annual Withdrawal	Net Increment in Resources	Total Annual Withdrawals	Withdrawal ¹
	-----km ³ -----			-----km ³ ----	%
Algeria	1.7	2.0	Deficit	4.5	44
Chad	11.5	0.0	-	0.2	0
Egypt	1.3	3.0	Deficit	55.1	5
Libya	0.5	2.0	Deficit	4.6	43
Sudan	7.0	0.0	-	17.8	0
Tunisia	1.2	1.0	Positive	3.1	33

Source: WRI, 1998. ¹Groundwater as a fraction of total withdrawal

upon as a long-term source for substantially large projects for combating desertification. However, the same may be utilized in a more sustainable manner if artificial aquifer recharge approaches are made an integral element of the overall program. Although success of such groundwater recharge approaches greatly depends on local soil and aquifer conditions, there are a few success stories. For example, floodwater-spreading programs in Iran have been reported as generally successful (Kowsar, 1991). Similarly, the artificial recharge through the Ophthalmia Dam in the arid zone of Australia has been useful in replenishing an alluvial aquifer (Commander, 1998). These examples re-emphasize the need for taking a holistic approach in design of programs that utilize groundwater.

SUMMARY

The following recommendations can be made based on the information provided in this paper:

1. A holistic approach for evaluation of programs to combat desertification is required. This should include a comprehensive evaluation of water resources, availability and costs, and an environmental impact analysis. In addition, special attention should be paid to understanding the local conditions and engaging the local population through training and publicity programs.
2. The design duration of such programs, not including pilot-phase studies, should at least be in the range of 20 to 30 years. Shorter evaluations may not be able to give a full view of the sustainability of such efforts.
3. Use of groundwater in efforts to combat desertification should additionally include artificial recharge if expected annual withdrawal exceeds the 'natural' recharge processes.
4. Technologies to combat desertification should be evaluated on a 'local' basis, and when they do not qualify the recommendations 1-3, their use should be discontinued to avoid environmental disasters in the long term.

REFERENCES

Abdulrazzak, M. 1997. The future of freshwater resources in the Arabian peninsula. p. 17-43. In: J.I. Uitto and J. Schneider, (Ed.). *Freshwater Resources*

in Arid Lands, United Nations University Press, Tokyo, Japan.

Ahmed, M.U. 1988. Ground water resources: The key to combating drought in Africa. *Desertification Control Bull.*, United Nations Environment Program, Nairobi, Kenya, Vol. 16: 2-6.

Chou, N-T., and H.E. Dregne. 1993. Desertification control: costs and benefits. *Desertification Control Bull.*, United Nations Environment Program, Nairobi, Kenya, Vol. 22: 20-26.

Commander, P. 1998. Groundwater from Australian deserts. *J. Arid Land Studies*, Vol. 7S: 77-80.

Dixon, J.A., D.E. James, and P.B. Sherman. 1989. *The Economics of Dryland Management*. Earthscan Publ. Ltd., London, UK.

El-Beltagy, A. 1999. Can desertification trends be reversed in West Asia and North Africa. *UNU Desertification Series No. 1: New Technologies to Combat Desertification. Proc. Inter. Symp. Tehran, Iran, 12-5 October, 1998*. United Nations Univ., Tokyo, Japan

El-Shorbagy, M.A. 1998. Impact of development Programs on deterioration of rangeland resources in some African and Middle Eastern countries, In: V.R. Squires and A.E. Sidahmed (Ed.). *Drylands - Sustainable Use of Rangelands into the Twenty-First Century*, Inter. Fund Agric. Devel. Rome, Italy.

Gupta, A.D. 1996. Groundwater and the environment, In: A.K. Biswas (Ed.). *Water Resources: Environmental Planning, Management, and Development*, McGraw-Hill, New York, USA.

Kowsar, A. 1991. Floodwater spreading for desertification control: An integrated approach, *Desertification Control Bull.*, United Nations Environment Program, Nairobi, Kenya, Vol. 19: 3-18.

Mainguet, M. 1994. *Desertification - natural background and human mismanagement*. 2nd Ed., Springer-Verlag.

Mainguet, M., K. Mersmann, and M. Visser. 1996. Man-induced desertification. *The United Nations University Lectures-12*. United Nations Univ. Press, Tokyo: 24 p.

World Resources Institute. 1998. *1998-99 World resources: a guide to the global environment*, Oxford Univ. Press, New York, USA.

Assessing Techniques for Cartographical Estimation of Desertification

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ABSTRACT

Comparative estimation was made of existing techniques of desertification mapping, including an optimum choice of landscape parameters and their updating for soil-forming conditions of the Volgograd region. Peculiarities of a soil cover, its agricultural use, conditions of soil formation (climate, relief, geology) and changes of soil properties were investigated on the basis of literary facts and published maps.

For comparison, the following techniques of a cartographic estimation of desertification were taken: 1) Harin and others (1987), 2) Kust, (1995), 3 and GLASOD, (1988). In the technique of Harin, types of processes describing desertification, are allocated. Several aspects submit each of types: modern desertification, rate of desertification, internal danger, influence of domestic animals on natural environment, and degree of human impact. The qualitative and quantitative criteria for each of types are developed. Ecosystems are used as a unit of mapping. In the technique of Kust, besides by a set of types of desertification, a circuit of cause-effect relations is offered that allows deeper understanding of desertification processes. Degradation of a soil cover is examined.

Three positions of the desertification reasons are distinguished: 1) anthropogenic and natural; 2) global, regional and local; 3) man-initiated. On attributes of anthropogenic effects, five types are allocated: irrigation, non-irrigated agriculture, distant animal industries, and destruction of tree-shrub vegetation, and technogenic effect. For each type of antropogenic effects, the cause-effect relation and directions of degradation of soils and soil cover are found. The technique of GLASOD is not designed for the forecast of desertification; it reflects only current conditions of a soil cover and rates of recent desertification. Except a determined set of desertification types, some reasons of desertification are shown: deforestation, overgrazing and others.

INTRODUCTION

The problem of soil desertification is one of the main ecological problems in arid zones. According to determinations offered by the United Nations Environmental Program, UNEP (1990), desertification is a degradation of soils in arid, semi-arid and droughty sub-humid regions as a result of unfavorable anthropogenic

impacts. There are a number of approaches to desertification evaluation: manual of UNEP, principles of a mapping of the degraded soils of GLASOD, and a number of regional developments.

The main purpose of our work is the drawing up of soil desertification/degradation maps of Volgograd region scale of 1:2500000 by different methods, their comparison and valuation of soil degradation of the region.

RESEARCH AREA

Volgograd region is located within two soil zones - *chernozemic* and *chestnut*. The chernozemic zone is characterized by a sub-zone of ordinary and southern chernozems. The chestnut zone is divided into three sub-zones: dark-chestnut, common chestnut, and light-chestnut soils. In the territory of the region, there are inter-zonal soils which form independent areas or which occur as complexes with zonal soils in the region.

From northwest to southeast of the region the precipitation amount decreases from 515 to 165 mm in a year, and the total evaporation increases from 700 to 1000 mm. The number of days with dry winds is 30-90. Agricultural production is the main activity. In Volgograd region, arable lands make up 84.1%, forest and afforestation 4.7%, industrial, transport and other non-agricultural lands 6.7%, and other lands 3.4% (Vorob'ev, 1992). The area of solonetzic complexes in a soil cover of region makes up 3.3 million ha; the area of eroded lands is 2.5 million ha.

RESEARCH METHODS

Three methods of drawing up of desertification maps were used. In *Harin's technique*, the following types of desertification are allocated: degradation of a vegetative cover; deflation and water erosion; soil salinity; technogenic degradation. For each type of desertification, a separate map was made. The following aspects are shown on the map: current condition (CC), desertification rate (DR), internal danger of desertification (IDD), and impact of animals (quantity per hectare) and people (population density) on the natural environment.

For the soil salinity map, the following categories of desertification aspects are taken into account: CC - quantity of toxic salts in soil, area of salinity, DR - annual increase of the saline soils area; IDD - annual depth and mineralization of groundwaters, relief of district, and lithology. Each aspect and category are

divided into four classes of desertification: weak, moderate, strong and very strong are evaluated. On the basis of series of maps, a uniform map is created on which four degrees of desertification danger are shown by different color found as the sum of separate aspects and their classes.

On GLASOD classification, types of degradation processes (physical, chemical, biological deterioration of soils, wind and water erosion) are divided on two categories. The first category deals with displacement of a soil material. The second category describes types of degradation as a result of internal deterioration of soil properties (Table 1). The parameters for evaluation of a various degree of water erosion of soils are indicated. The soil degradation rates are evaluated depending on change of a climate, degree of mechanization for 5-10 years, change of population quality and livestock numbers.

Table 1. Evaluation of water erosion of soils.

Degradation Degree	Removal of Soil Profile	Soils with, Optimum Efficiency
		--%--
Weak	The top part	> 70
Moderate	Humus layer	30 - 70
Strong	Completely	< 30
Extreme	Soils and subsoils	0

Kust (1995) developed a typology of desertification causes that allowed connecting diverse natural and anthropogenic effects and their consequences in a circuit of cause-effect relations. Three positions of the desertification reasons are distinguished: 1) *anthropogenic and natural*; 2) *global, regional and local*; 3) *man initiated*. On an attribute of anthropogenic effect, five types are allocated: *irrigation, non-irrigated agriculture, distant animal industries, and destruction of tree-shrub vegetation, and technogenic effects*. For each type of antropogenic effects, the cause-effect relation and directions of degradation of soils and soil cover are found. On the basis of it, desertification risk is determined, which is divided on four gradations: weak, moderate, strong and very strong. The general map of desertification risk/degree is made from separate maps of different desertification types.

For Volgograd region, separate maps of desertification were made based on the salinity using Kust's and Harin's techniques, and on alkalization and water erosion using Kust's and GLASOD methods.

Soil map of Russia on a scale of 1:2,500,000 made under the edition of V.M. Fridland (1988) was the basis for six of our maps. For preparation of maps, many materials were gathered. These are as follows: *relief, climate, soil-forming rocks, depth and mineralization of groundwaters, granulometric composition, modern humus condition of soils and its change for last twenty years*. Degree of soil erosion in solonetzic and saline soils, soil chemistry, and degree of their salinity, and

the information about character of soil use, livestock numbers, and population density were included in the database.

RESULTS

Soil Salinity

Harin's technique considers salinization only in irrigated areas, whereas the Kust's technique reflects the danger of soil salinity in all Volgograd region, while on the soil salinity map based on Harin's technique, 55 soil contours subjected to desertification are allocated. The degree of soil desertification on two maps for 25 contours coincides, but for 20 contours it does not coincide. As the whole, the map on Kust's technique is characterized by a higher degree of soil desertification in comparison with the map prepared on Harin's method. It is explained by that in addition to criteria of desertification by Harin, such information as thickness of humus horizons, humus content, climatic parameters were taken into account.

The weak degree of soil desertification, according to Harin, is marked for sandy profiles on the left-bank of Tsimljansk reservoir. The strong salinization of soils is dated for solonetzic, saline-chestnut, and light-chestnut soils in a complex with meadow semi-hydromorphic solonetztes and meadow-chestnut soils in the interfluvium of the Volga and Don Rivers. The very strong degree of soil desertification is characteristic of light-chestnut soils and automorphic solonetztes.

The greatest degree of soil desertification, with salinization and alkalization, is characteristic of the southeast part of the chestnut soil zone. The center of a strong degree of soil desertification is observed as a result of salinization on the right bank of the Don River. Here, soil cover is the southern shallow, low-humus, chernozems in a complex with solonetzic chernozems and solonetztes. Weak desertification is marked on sandy soils of the right bank of the Volga, Don, and Hoper Rivers.

Alkalization and Water Erosion

The maps of desertification based on alkalization and water erosion based on GLASOD and Kust's techniques supplement one another. The first evaluates current conditions of soil cover and its change for the last 20 years, and the second map characterizes desertification risk/degree for the future. The map of a soil conditions is necessary for evaluation of desertification dynamics. For example, southern shallow low-humus chernozems for the last 20 years were subjected to weak desertification in the direction of alkalization. But the risk of forecasting desertification of this soil is evaluated by Kust's method as moderate.

According to a GLASOD technique, a change of quantity of solonetzic soils in the last 20 years is displayed on the map; for this time, 28% of Volgograd region area is subjected to alkalization. On a map based on Kust's technique, the chestnut and light-

chestnut soils are subjected to the greatest risk of desertification in a direction of alkalization, and chernozems have normal or least risk.

On the map of soil desertification caused by water erosion, prepared with Kust's technique, 18% of the region is subjected to a strong risk of erosion. The greatest part of region (78%) is characterized by moderate risk/degree of desertification on water erosion. Soils of the right bank of the rivers Volga and Ilovja are subjected to strong water erosion and make up 5.5% of Volgograd region. The contours with weak water erosion are located on territories with light wavy relief, i.e., plain of the Pre-Caspian lowland.

Thus, in the Volgograd region, a complex of soil processes initiated or increased by antropogenic activity such as non-irrigated agriculture, irrigation, cattle breeding, are reasons for soil and soil cover degradation.

The non-irrigated agriculture is the main reason for soil cover degradation of Volgograd region, and results in expansion in soil erosion or of sodicity. The main share of soil contours, on which these types of desertification are distributed, is located on dark-chestnut soils and chernozems of the right bank of Volga. On the left bank of the Volga, soil salinization and alkalization - the effect of poor irrigation management and overgrazing - have the greatest distribution.

CONCLUSIONS

Comparison of different methods of soil desertification valuation permitted the following conclusions. The technique offered by GLASOD is designed for survey maps at a scale of 1:10,000,000 and considers current conditions of soil cover and its change in the past 20 years. Other methods give forecasts of desertification. The recommendations offered by Kust and GLASOD deal with soils and soil cover degradation. The Harin's technique is based on analysis of ecosystem degradation, thus lithogenic and geomorphological conditions are indirectly taken into account. Therefore, many researchers (Rafikov, 1988; Ptichnikov, 1991) consider that use of ecosystem as a mapping unit is not absolutely correct. Besides drawing up desertification maps on Harin's method, large financing is required since investigations on key plots for 20 and more years and large volumes of other materials are necessary. For valuation of desertification/degradation processes of soils and soil cover in Volgograd region, the Kust's technique is most acceptable. In this method, desertification types and cause-effect relations depending on a kind of antropogenic effect are taken into account.

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REFERENCES

- Desertification/land degradation (a working concept for the propose of it's assessment). 1990. Ad-Hoc Consultative Meeting "Assessment of Global Desertification: Status and Methodologies". UNEP. Nairobi, Kenya.
- Filin, V.I., and O.N Gubina. 1992. Agrochemical map. (scale of 1:2,500,000). (Soil-ecological problems in steppe agriculture). Proceedings, *Pushchino. (in Russian)*.
- Gubina, O.N. 1992. Map of productivity of agricultural cultures (scale of 1:2,500,000). Soil-ecological problems in steppe agriculture. Proceedings, *Pushchino (in Russian)*.
- Guidelines for general assessment of the status of human-induced soil degradation. 1988. Global Assessment of Soil Degradation (GLASOD). Edited by L.R. Oldemen. ISRIC. Wageningen.
- Harin, N.G., N.S. Orlovskij, T.A. Babaeva, A.A. Kiril'tseva, and K. Redgephaev. 1987. Explanatory slip to "Map of antropogenic desertification of arid territories of USSR" (scale of 1:2,500,000). Ashkhabad (*in Russian*).
- Harin, N.G., N.S. Orlovskij, N.A. Kogaij, and G.B. Manuijlov. 1986. A modern condition and forecast of desertification in an arid zone of USSR (Problem of development of deserts). No. 5: 58-68. (*in Russian*).
- Kust, G.S. 1995. Desertification and evolution of soils of droughty territories (on an example Priaralie). Dissertation on competition of a scientific degree of the Doctor of Biological Sciences. MSU. Faculty of Soil Science. Moscow. (*in Russian*).
- Ptichnikov, A.V. 1991. Dynamics of Priaralie landscape desertification for the last 15 years. Dissertation on competition of a scientific degree of the Candidate of Geographical Sciences. Moscow (*in Russian*).
- Rafikov, A.A. 1982. Features of a salinization of soils of southern Priaralie in connection with decrease of a level of the Aral Sea (Soil Science). No. 10 (*in Russian*).
- Vorob'ev, A.V. 1992. Ground resources (Soil-ecological problems in steppe agriculture). *Pushchino*, 16-231 (*in Russian*).

Land Use and Sandy Desertification in the North China

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ABSTRACT

Land desertification is one of the most serious environmental and social-economic problems in North China. The processes of desertification have been mainly caused by the interaction of human activities and fragile eco-environment; the pattern and intensity of land-use are major factors for development or reverse of desertification. Since the increase of human impact on the land-use which had been forced by the increasing pressure of population, the zone of mixed agro-pasture in North China has been pushed northwards, which changed land-use from grazing to cropping in a large area and destroyed the natural vegetation cover. The resulting wind erosion desertification has developed very quickly as farms of land were subject to degradation.

According to the statistics of desertified land areas with different land-use purposes, the human impact contributing to the sand desertification were 25% for over-cultivation, 28% for over-grazing, 32% for over-gathering firewood, and 8% for misuse of water resources. During the last five decades, sandy desertified land has expanded continually in North China, whose total area has reached over 350,000 km² by mid 1990's. Based on remote sensing monitoring, we found that the growth rate of desertified land has increased decade by decade; the annual average area has increased from 1,560 km² in 1950s to mid 1970s, to 2,100 km² of between mid 1970s and late 1980s, to 2,460 km² in the last decade.

But some successful models of combating desertification have improved; where the reasonable land-use has been adopted over some years, the sandy desertified land has been reversed and can be used again for more effective farming or grazing.

INTRODUCTION

Desertification is one of the most serious environment and socioeconomic problems in the world today, and China is one of the countries suffering from serious desertification, especially in North China where sandy desertification is developing rapidly over large areas and receiving widespread attention. According to human activity and socioeconomic characteristics and their interactions through nearly 20 years of theoretical research and practices, we can give a view of sandy desertification.

Sandy desertification is the process with sand drift activity occurred in arid, semi-arid and partial sub-

humid areas resulting from irrational human economic activities and disharmony between natural resources and environment (Zhu and Wang, 1993). Development of sandy deserts in North China has occurred throughout civilization's history, and especially in the recent hundred years such deserts have quickened. Sandy desertification processes aggravate soil wind erosion, cause deterioration of soil physical and chemical properties, reduce land productivity, cause great economic loss, and seriously affect livelihoods and living environments of the mixed agropastoral region in North China.

Accordingly, an in-depth study of anthropogenic effects, in particular the effect of land use on the sandy desertification development, has important practical significance to elucidate the mechanism of sandy desert occurrence, enrich the theory of desertification, and formulate policies and measures to combat desertification.

DEVELOPMENT OF SANDY DESERTS

Based on the genetic characteristics, sandy desertification in North China can be divided into three types, namely, *sandy desertification of grassland*, *reactivation of fixed sand dune* (sandy land), and *sand dune encroachment*. Sandy desertification in the historic period mainly appeared in the steppe, desert steppe and other arid zones such as riverbanks in desert marginal belts and lower reaches of rivers in the hinterland of the deserts. Modern sandy deserts developed at a rate of 1,560 km² per year from the late 1950s to the mid-1970s. According to large area of field investigation and remote sensing data analysis, sandy deserts developed at a rate of 2,100 km² per year from the mid-1970s to 1980s.

As a result, the total area of desertified land in North China reached nearly 350,000 km². This is mainly distributed in three regions (Zhu and Wang, 1990):

1. In the semi-arid, mixed agro-pastoral region, desertified land occupies 40.5% of the total desertified land area of North China, especially in the reclaimed grassland. For example, desertified land area in the reclaimed grasslands of the Bashang region in Hebei province and the Houshang region in Inner Mongolia increased from 3% of farmland area in the late 1950s to 13% in the mid-1970s and to 25% in the late 1980s.
2. In the semi-arid undulating sandy grassland, desertified land occupies 36.5%; for example, desertified land area in the Horqin sandy land increased from

20% of grassland area in the late 1950s to 53% in the mid-1970s and to 77.6% in the late 1980.

3. In arid oasis margins and lower reaches of inland rivers, desertified land occupies 23%, mainly manifested in the reactivation of fixed sand dunes: for example, desertified land area in the lower section of the Ruoshui River increased from 5% in late 1950s to 22% in the mid-1970s and 36% in the late 1980s.

In the same period, in local places where effective measures have been adopted to combat desertification, desertified land area was reduced. According to the analytical results of remote sensing data, about 10% of desertified land was reversed. In addition, another time interval of remote sensing data (1987 and 1993 TM data) was used in the study of the dynamic changes of sandy land. The study showed that during 7 years from 1987 to 1993 desertified land area decreased from 32,586 km² (67.5% of total monitored area) to 30,497 km² (63.5% of total monitored area), or a decrease of 2,089 km². As a whole, it is in a reversing process, and about 276.6 km² of desertified land were improved per year. However, when entering the 1990s, the sandy desertification in the entire northern region of China shows an accelerated development tendency and has reached an expansion rate of 2,460 km² per year (CCI-CCD, 1996).

LAND USE AND SANDY DESERT DEVELOPMENT

Human activity and natural environment interact and form a man-land system, which, to a great extent, reflects human land-use systems and intensity. Natural resources and environment decide human land-use patterns in most of civilization's history. Nevertheless, until modern time, man's increasing demand for natural resources became evident due to population growth and the progress in science and technology. This also allows us to enhance the subjective initiatives and regulating ability of human activities in the man-land system.

In many cases, this reflects human progress in the effective use of resources. However, some irrational land-use of resource and environmental changes, even promote the gradual or sudden harmful changes of the resources and environment, such as an increase in greenhouse gases, rivers ceasing to flow, natural fire, earthquake in water reservoir region, and soil erosion. Among those events, sandy desertification of land is an obvious example.

In the history of China, nomadic peoples in the North often advanced south at a time and retreated north at another time for political and economic benefits or during warm-cold and dry-wet climate changes. Land-use methods often changed from farming-dominated use to grazing-dominated use following the change of rulers; sandy desertification was also shown as an alternating development or reversing processes

due to the difference in land-use. In the processes human activities often play an inductive role depending on the natural conditions; this is mainly manifested in the interrelations between desertification development and major historic events.

For instance, during the civil war and political unrest periods, such as in the last years of East Han Dynasty and Tang Dynasty, Five Dynasties, Song-Liao war period, after middle periods of Ming Dynasty and Qing Dynasty, sandy desertification developed rapidly. Dry and cold climates in these periods also exacerbated sandy desert expansion and weakened the land's self-restoration ability, and thus led to further degradation of the natural environment. The interaction between anthropogenic factors and natural factors facilitated the occurrence and expansion of sandy desertification in the steppe region of North China. With an increase in population and strengthening of economic activity, sandy desertification as a whole is in an aggravation process, both in extent and severity.

In China's history, the north has always been an economically backward region due to dry climate and meager natural resources and their exploitation difficulty. People in this region used to adopt traditional land-use ways to adapt to climatic fluctuations and precipitation changes. For example, herdsmen migrated to where water and grass were available, whereas farmers practised a rotation cropping system. In most of the historic period nomadic herdsmen made full use of the diversity of natural grasslands and seasonal water sources to raise livestock, thus avoiding overgrazing of grasslands.

On the other hand, the rotation cropping system or shifting cultivation system also coordinated the relation between land-use and natural restoration of ecological environment and restorative ability of soil physio-chemical properties and thus reached a primary sustainable development. The main reason for this is that human activities did not exceed the load capacity of natural resources; by means of self-restorative ability of natural vegetation, the ecosystem maintained a dynamic balance and the environment remained relatively stable.

However, since the middle of 18th Century, and especially after entering the 20th century, the population in North China increased greatly, with several large-scale migrations for reclaiming virgin land. Since the 1950s, the region has experienced several high tides of land reclamation, mainly in the "Agricultural Cooperation", "Great Leap Forward", and "Cultural Revolution" periods, when the annual population growth rate reached 2.5-3.0%. For example, the annual population growth rate in the mixed agro-pastoral region increased to 3.08% from 1950s to 1980s, mean population density increased from 10-15 persons/km² to 40-60/km², and even reached 80/km².

In seven desertification-affected counties (Banners) in the Houshan region of Inner Mongolia, rural population increased from 515,000 in 1949 to 1.258 million in 1985. Although only a few people entered the

desertified region of North China after 1980s, the region's population growth is rather rapid due to its considerable population base. One reason for this is that the central Government formulated a preferential policy for the population growth of minority nationalities.

Population growth and increasing social requirements exert great pressure on land resources and destroy the rationality of traditional land-use patterns. Reclaiming grasslands also decreased pastureland area and in many places land use has turned from being grazing-dominated to farming-dominated. Land-use intensity is also heightening, and land fallow interval has been shortened from more than 10 years to a few years, even to every two years or every year. Doubled the number of livestock is often concentrated on the degraded grasslands, thus greatly exceeding carrying capacity. Increasing demand for fuelwood leads to over-collecting. All these constitute the major anthropogenic factors responsible for the occurrence and development of sandy desertification.

Based on the study of sandy desertification in North China, Zhu and Shu (1989) put forward a causal classification and identified the area of desertified land associated with human activities; in 1989, desertified grassland area resulting from over-cultivation was 44,700 km², occupying 25.4% of the total desertified area; the area resulting from overgrazing 49,900 km², or 28.3%; the area resulting from road and other project construction was 1300 km² or 0.7%; and the area resulting from water conservation construction was 14,700 km² or 8.3%.

It is the above land-use processes that trigger sandy desertification they disturb the ecosystem balance, lead to vegetation degradation or disappearance, and facilitates surface soil deflation, transportation and deposition. Wind-blown sand movement processes mainly include: (1) sandy surface morphology changes under wind force, (2) fixed sand dune reactivation, and (3) sand dune encroachment at the margin of the desert under wind force. It is the disturbance by human activities and above-mentioned windblown sand movement that cause the occurrence and development of sandy desertification in the North China.

LAND USE AND DESERTIFICATION CONTROL

Irrational land-use causes the development of sandy deserts. For sustainable development to be achieved and desertification to be stopped, the fundamental solution lies in rational and highly effective land-use. According to the characteristics of natural resources and environment, socioeconomic features, problems in land development and use, as well as desertification control experiences in the desertified region of the North China, sandy desertification control should have a unified objective in economic benefit, ecological benefit and social benefit, and should be able to halt the development of sandy deserts and promote the

development of production to form a resource-saving, fairly large-scale and environment-protecting type of economic system.

As for the concrete measures to combat sandy desertification in the mixed agropastoral region, in the light of scattered features of settlements, cultivated land, and pasture land, measures should be adopted such as closure to livestock grazing, readjusting of dry farming-dominated, land-use structure, increasing forest and grassland area, practising intensive management of land with better water-use conditions, establishing wind-breaks and sand-break forests, planting sand-fixing plants on sand dunes, and planting patchy forests in inter-dune depressions. In the grazing grassland region, we should define a rational stocking rate, practice rotational grazing, establish artificial grassland and forage base, rationally allocate wells, designate grazing points, and build pasture roads. In arid zones, we should work out an overall plan with an inland river basin as the ecological unit, formulate a water-use plan with the oasis as the center, establish a protective forest network inside the oasis, and a tree-shrub, sand-break forest belt around the oasis, and stabilize sand dunes at the outer fringes of the oasis to form an overall protective system.

Many practices have proved that rational land-use can effectively halt land sandy desertification and reach the objective of sustainable utilization. Taking Yulin region in Shaanxi Province as an example (Zhao, 1992), according to historic literature records, until 1500 years ago the region was still covered with dense trees and grasses and was suitable for farming and grazing. Afterwards, owing to frequent wars and uncontrolled felling, the vegetation cover was reduced to only 1.8% and sand dunes moved over the Great Wall and approached the Yulin City. According to investigations, during the 100 years before the founding of new China, some 134,000 km² of cultivated land and grazing land were abandoned due to sandy desertification, 113,000 km² of farmland and 267,000 km² grassland were seriously threatened by sandy deserts, and crop yields and carrying capacity decreased greatly.

Since 1950s, through formulating unified planning, readjusting and optimizing land-use structure, establishing forest belts and stabilizing sand dunes to protect the production of agriculture and animal husbandry, great ecological, economic and social benefits have been achieved. From 1950 to 1990, the reserved sand-break forest area in the Yulin region reached 740,000 km² and the improved rangeland area reached 667,000 km², total grain output in 1990 was six times higher than that in 1950, the large livestock increased from 76,000 to 360,000, sheep increased from 360,000 to 1.5 million, standing timber volume reached 3.4 million m³ or valued at 700 million Yuan, and about 50,000 peasant household have been shaken out of poverty and become prosperous.

Horqin region is a typical sandy desertification area in the zone of mixed agro-pasture in North China. It

was a traditional nomadic region for thousands of years. But cropping agriculture has become the dominant economic activity in the region since the rangeland had been gradually cultivated with increasing population for last 100 years. The occurrence and development of sandy desertification are related to the influences of natural factors such as dry windy climate and highly eroded sandy ground surface, etc. However, the main cause is irrational human landuse.

On the other hand, it should be pointed out that the degree of sandy desertification in the region seemed to be aggravated. Compared to before, the area of severe degree of desertified land increased from 5,384 km² in 1987 to 17,142 km² in 1997, representing a net increase of 11,758 km² or 218.39%; the area of moderate degree one increased from 5,637 km² in 1987 to 16,155 km² in 1997, representing a net increase of 10,518 km² or 186%. The main reason for this was that local

Table 1. Changes in sandy desertified land in Horqin region, Inner Mongolia.

Year	Degree of Desertification				Total	± %
	Very Severe	Severe	Moderate	Slight		
	-----km ² -----					
1975	2908	7969	24997	22114	57978	
1987	5384	5637	24480	36182	71683	+ 23.64
1997	17142	16155	11533	18513	63343	- 11.63

Under the background of rapid population growth and low productivity level, plundering use of land resources such as over-cultivation, over-grazing and over-collection of fuel wood were inevitable, and hence leads to significant reduction of vegetation cover, destruction of soil structure, shifting sand encroachment, serious soil wind erosion, and rapid spread of desertified land. For example, the total area of sandy desertified land in the region increased from 57,978 km² in 1975 to 71,683 km² in 1987, representing a net increase of 13,705 km² or 23.6%. In the same period, some 5,470 km² of desertified land had been rehabilitated through establishing artificial forests, protecting rangeland, and readjusting land-use structure.

In the recent 10 years, the reversing trend of sandy desertification has gradually become obvious due to human interference. Owing to increasing investment, readjusting land-use and intensity, reducing cultivated land area, strengthening intensive management, planting trees and excluding livestock from desertified land as well as forbidding over-grazing, considerable area of sandy desertified land in some places has been rehabilitated and restored to a certain productivity. The total area of desertified land in the region decreased from 71,683 km² in 1987 to 63,343 km² in 1997, representing a net decrease of 8,340 km² or 11.63%.

government put much capital and manpower in the rehabilitation of slight and potential sandy desertified land, and thus reduced the total area of sandy desertified land, while in the localities where no anti-desertification measure was adopted, the degree of desertification severity has been further aggravated.

Another successful example is the Xinglongzhao region in Naiman Banner of Inner Mongolia. According to remote sensing monitoring (1974 and 1994) and field investigation (Wang and Wu, 1998), land-use structure and other changes before and after sandy-desert rehabilitation is presented in Table 2. It can be seen that desert rehabilitation has brought about quite significant environmental and economic benefits.

CONCLUSION

Land use is directly related to the occurrence and development of sandy desertification. People's land-use methods and use-intensity are the leading factors responsible for the spread of sandy desertified land in North China, which not only leads to the environmental deterioration and land degradation but also causes great economic loss. Rational land use has proved to be an effective way to halt sandy desertification. Further study and summing up experiences will lay a theoretical basis and provide a practical example for the sandy desertification control in other regions of China.

Table 2. Effectiveness of combating desertification in Xinglongzhan, Naiman Banner, Inner Mongolia.

Land	1974 ¹		1994 ¹		Increase/ Decrease
Desertified land, km ²	15700	(29.6)	2100	(3.9)	- 86.6%
Forest land, km ²	777	(1.5)	15,840	(30.1)	+19 fold
Cultivated land, km ²	4960	(9.4)	6900	(13.0)	+39.1
Total grain output, t	2790		13,110		+3.7
Grain yield kg, km ²	562.5		1,900		+2.4 fold
Grassland carrying capacity (sheep unit)	124.2		152,200		+22.5
Per capita income/Yuan	80		1,120	(+1040)	+ 13 fold

¹Percentage of total land area in parenthesis.

REFERENCES

- CCICCD, 1996. China country paper to combat desertification. China Forestry Publish House, Beijing. 18-32.
- Wang, T., W. Wei, W. Xizang. 1998. Remote sensing monitoring and assessment of sand desertification. *Quaternary Research*, 2: 108-118.
- Zhu, Z., and L. Shu. 1989. Desertification and its control in China. Sinica Press, Beijing. p. 27-42.
- Zhu, Z., and W. Tao, 1993. Potentiality, status, development trend and countermeasures of desertified land in North China. p. 198-202. Chinese Academy of Sciences. Collected papers on the potentiality, trends, and countermeasures of resources in China (Earth Science Div.). Beijing Publ. House, Beijing.
- Zhu, Z., and W. Tao. 1990. Analysis on evolution trend of land desertification in recent ten years in several typical regions of China. *Acta Geographic Sinica*, 45(4): 430-440.
- Zhao, B. 1992. Carrying forward the Yanan spirit, adhering to comprehensive rehabilitation to speed up economic development steps in desert areas. p. 80-86. Desert Control Office. *Collected papers of national desert control conference "Mobilize the Whole Nation and March Towards the Desert"*. China Forestry Publ. House, Beijing.

Taklimakan Desert and its Prospects

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ABSTRACT

It is well known that the Taklimakan Desert is the second largest shifting-sand desert on the world and the biggest desert in China. It situated in the northwest of China in Xinjiang Uygur Autonomous Region. The topography of Xinjiang appears to be the characteristic of two basins (the Tarim Basin and the Junggar Basin) sandwiched by three mountains (Altay, Tianshan, and the Kunlun). The Tianshan Mountains cross the center, separating this region into two parts, the southern Xinjiang and the northern Xinjiang. Topographically, the highest and lowest differ greatly. Xinjiang is situated in the inner Asia far away from the ocean; it has the characteristic of typical continental climate. The differences of temperature vary greatly between seasons, districts, and between day and night; spring and autumn are short, while winter and summer are long. Xinjiang is multi-national. Up to 1990, the total population was 15.16 million. Among them, the Uygur accounts for 47%, while the Han is 38%. The other nationalities, such as the Kazak, Hui, Kirgiz, Mongolia, Xibo, Tajik, Manchu, Uzbek, Daur, Tartar, Russian, etc., have been living in this region for generations.

TAKLIMAKAN DESERT

Lying in the central Tarim Basin, south of the Tianshan Mountains in China's northwest Xinjiang Uygur Autonomous Region, the Taklimakan Desert is 1,000 km long from east to west and 400 km wide. It covers an area of 337,600 square kilometers, accounting for one half of the country's total desert area. It is the second largest shifting-sand desert in the world.

The name Taklimakan means the "place you can enter but cannot leave" in the language of the local Uygurs. However, scientific investigation and many years of prospecting and development prove that the vast desert is not a "sea of death."

Four years of observation have shown that the annual precipitation in the center of the Taklimakan Desert measures 20-80 mm. Satellite pictures also show 10,000 km² of rain areas. In the extremely dry Taklimakan Desert, the annual number of frost days average 140-230 and the annual foggy days average 3.5, mainly occurring in summer and autumn. When winter comes, snowfall in the desert can reach a maximum depth of 5 cm. Hail and dew also occur in the desert.

Under the co-effects of unique geographical location, topography and multi-direction winds, and also the water action, the Taklimakan Desert shows compli-

cated, changeable and well rounded dunes. In general, the height of sand dunes is 20-70 m, but some are higher than 100 m, and the area of higher than 50 m accounts for 50% of total area.

Sea of Oil Beneath the Desert Hinterland

China began to search the desert for oil in the 1950s. Up to the 1980s, a petroleum prospecting team entered the Taklimakan Desert and discovered rich oil and gas deposits. In 1983, the Ministry of Petroleum Industry and American Geophysical Technology Service Company together prospected for oil. They have verified six oil and natural gas fields and many oil-bearing tectonic zones.

About 600 million years ago, the Tarim Basin was a vast old land. Under the influence of crustal movements, it was transformed into a sea linked with the Tethys Sea. At that time, a large number of fauna, flora and microbes grew in the luxuriant forest along the coast. By the late Tertiary period during the Cenozoic Era, the further uplift of Tianshan, and Kunlun Mountains and the Qinghai-Tibetan Plateau broke the connection to the Tethys Sea, thus helping to create the formation of geomorphological patterns of the Tarim Basin. Both the arid climate and river sediments provided conditions for the formation of the Taklimakan Desert, under which the organic-matter sediments affected by high-temperature and high pressure, were turned into oil deposits.

A Giant Underground Reservoir

It is difficult for oil prospecting teams to work in the desert without water. As the team penetrates deeper into the desert, the water supply line is continuously extended and becomes more difficult to maintain.

In 1987, on the basis of the unified planning of the State Science and Technology Commission, the Chinese Academy of Sciences and China Oil and Gas Exploration and Development Corporation, jointly organized a comprehensive scientific investigation of the Taklimakan Desert involving meteorology, geomorphology, Quaternary geology, geochemistry, biology, soil, hydrology and archaeology. A 200-300 m thick water-bearing stratum was found under the desert with total underground water reserves of up to 8,000 billion tons. Except for the northeastern corner, most of the Taklimakan Desert has a groundwater level less than 10 m below the surface of the earth. Many fresh-water strata were also found along the banks of the Hotan and Keriya Rivers. Chinese and foreign experts considered the discovery of water as important as that of oil.

Animals and Plants

The Taklimakan Desert has been regarded as a "restricted zone of life". However, scientific investigation discovered that the "sea of death" is also a habitat of unique animal life. Many kinds of rats and the largest population of birds are found in the desert. Rare birds, such as the red-billed wild duck, are distributed along the margin of the desert and the banks of interior rivers. The Taklimakan Desert was once an animal paradise.

One hundred years ago, red deer, wild boar and Mongolian gazelle appeared along the lower reaches of the Keriya River. Since the mid- 20th century, Xinjiang tiger and wild boar have disappeared entirely due to the eco-environment changes. Wild bactrian camels and red deer are now under State protection.

According to statistics, there are 32 animal species, 183 birds, 13 reptiles, 4 amphibians and 40 fishes in the Taklimakan Desert and adjacent areas. Of these, 90% were discovered during this investigation. There is vegetation in the Taklimakan region. About 70 plant species come from the family: *Tamaricaceae*, *Salicaceae*, *Compositae*, *Liliaceae*, *Chenopodiaceae*, *Polygonaceae*, *Cruciferae* and *Leguminosae*, etc.

Rich Cultural Relics

In the Xinjiang Uygur Autonomous Region, the Uygur people call the desert "a place where treasures are buried, a place of grand castles, beautiful buildings and treasures". The Taklimakan Desert was once a cultural meeting place between the East and West. The southern and northern fringes of the desert were the central and southern routes of the ancient Silk Road. The area has many historical sites and cultural relics. At least 20 ancient cities were buried under the desert in the West Region. Archaeologists have a basic knowledge of the overall distribution of relic sites in the Taklimakan Desert. They have also discovered many new ruins and unearthed a great amount of pottery, wooden articles, stoneware, metal works, and ancient coins.

Transportation in the Desert

In the wake of increasing tourism, science and technology, oil exploration, and development activities, transportation in the desert has developed. At present, there are air bases at oases on the south and north fringes of the desert. Helicopters and small passenger planes continuously take off and transport workers from the geological prospecting team and oil-drilling crew in the desert and supply them with vegetables, meat and articles for daily use.

The Tarim Desert Road, China's first desert road and longest desert road in the world, opened on October of 1995, total 522 km long and 446 km in the desert, extends southward from the Lunnan County, crosses the Tarim River and the hinterland of the Taklimakan Desert, and reaches the Desert's southern tip. By that time, the vast desert will be turned into a busy thoroughfare.

The Desert Road and its sand-controlling system was regarded as "Desert Great Wall"; it reduced the distance between Urumqi and Hotan from 2000 km to 1500 km, and will promote the local economy, tourism, science and technology, oil exploration and other development activities.

Tourism in the Desert

Along with these increasing activities, taxicabs and simply furnished guesthouses have appeared in the desert. More and more foreign project collaborators from England, Sweden, France, Japan and the United States are coming to the desert. It has also attracted many tourists and scientific researchers trekking and studying in the desert.

Scientific Research on the Desert

Movement of sand dunes caused local people face the crisis on environment, agriculture, and health. Meanwhile, the demand of local people for fuel let the vegetation outside the oasis be subject to greater damage.

So many research studies were carried out in these regions and put into practice. In 1995, two projects of our institute got the UNEP Awards "Outstanding Contribution on Combating Desertification and Controlling Land Degradation in Dryland Environments".

Another exploration has proved that oil and natural gas deposits in the Tarim Basin make up one seventh and one fourth of China's total, respectively. The Taklimakan Desert has estimated oil reserves of about 10 billion tons. Thus, the Tarim Basin will be the center of China's future oil development base. In the light of this, we also carried out the "greening" project for the oil base and desert road.

Potential for Agricultural Development

From the map of China we can know that there is the unbalanced distribution on the land resources, and also we can say the future agricultural development in Xinjiang will be accelerated and fruitful. On a line from Heihe to Tengchong (NE-SW), the distribution in the east half is 45% land and 93.8% population; the west half has 55% land, 6.2% population; the east half has 85.8% farmland and 66.2% forest; and west half has 98.3% desert and 79.9 rangeland.

FUTURE

The unique conditions and rich natural resources will make the prospect of Taklimakan Desert bright. It has the following favorable aspects:

1. A stable social environment.
2. Development of the oil industry adheres to the national principle of "stabilizing the east while developing the west".

3. The second Eurasian Continental Bridge creates favorable conditions for the opening of Xinjiang.
4. Strategy of Xinjiang's Development is: "Black (Oil) and White (Cotton)".
5. The national policy of developing agriculture, energy, transportation and raw material industries and supporting economic development in minority regions promotes the realization of Xinjiang's economic potentials.

6. National Project on Eco-environmental Construction: "Rebuild a beautiful Northwest of China" will be carried out in this region next year.

Therefore, the Taklimakan Desert makes many people aware of Xinjiang's true conditions, and especially of its development in the past decades; in another words, deserts in Xinjiang are also part of its treasures. Their rich natural resources will play an important role on the region and local economic development.

VI. Stress Physiology

Response of Tomato to Mycorrhizal Fungi and Salt Stress

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ABSTRACT

High salt levels in soil and water can cause limitations to agricultural production and land development in arid and semi-arid regions. Arbuscular mycorrhizal fungi (AMF) are known to increase plant growth in saline soils. The objective of this study was to examine the growth and mineral acquisition responses of greenhouse-grown tomato to infection by AMF under varying levels of salinity. The NaCl was added to soil through irrigation water to give EC_e of 1.4 (non-saline), 4.7 (medium) and 7.4 dS m⁻¹ (high salt stress). Plants were grown in sterilized, low-P, silty clay (Typic Xerochrept) soil-sand mix. Mycorrhizal infection was higher under non-saline than under saline soil conditions. Shoot and root dry matter (DM) yields and leaf area were higher in mycorrhizal than in non-mycorrhizal plants. The enhancement in shoot DM due to AMF inoculation was 44, 50, and 36% for plants grown under non-saline, medium, and high salt stress conditions, respectively. The total accumulations of P, Zn, Cu, and Fe were higher in mycorrhizal than in non-mycorrhizal plants, and higher under non-saline than under saline soil conditions. Shoot Na concentrations, but not total accumulations, were lowering in mycorrhizal than in non-mycorrhizal plants. The improved growth and nutrient acquisition in mycorrhizal tomato demonstrate the potential of AMF colonization for the protection from salt stress of plants grown in arid and semi-arid regions.

INTRODUCTION

Jordan is considered as one of the most water-stressed countries in the world. Rain is the main water resource. However, about 90% of Jordan's area receives less than 200 mm rain annually. Water scarcity in Jordan represents a critical constraint to further expanding, or even maintaining, the present irrigated areas. There is increasing demand for agricultural water use to be restricted in favor of other water consumers, such as local communities and industry. Irrigation water accounts for about 75% of total water use (Min. Water Irrig., 1999). The irrigated area in Jordan is about 95,000 hectares (Min. Agric., 1997), where 50% of this area is planted to vegetables.

As fresh water resources in Jordan are very limited and already fully exploited, future potential can only been seen in irrigation water with lower quality (e.g., saline water, treated wastewater). Moreover, presently used irrigation water is of different quality, with EC_w values of 0.7-7.0 dS m⁻¹ which are considered as slightly or moderately saline (Kuck, 1999). Irrigation with

saline water is often associated with enhanced salinization of the soil. Salt is continually accumulated as water evaporates and builds up in the soil over time. Salinity problems exist when salt accumulates in the crop root zone to a concentration that causes crop damage and reduces the yield due to soil/plant osmotic imbalances (Wyn Jones and Gorham, 1983). There is also a direct effect of salinity due to high concentrations of Na⁺, Cl⁻, and B⁻ ions and nutrient imbalance of soil solution (Ayers and Westcot, 1985; Hasegawa et al., 1986). Therefore, incorporating or using factors which enable plants to withstand salt stress would be helpful to improve crop production under saline conditions.

Arbuscular mycorrhizal fungi (AMF) has been shown to decrease yield losses of plants in saline soils (Hirrel and Gerdemann, 1980; Pond et al., 1984; Poss et al., 1985). This may be due to increased uptake of low mobile nutrients such as P, Zn and Cu (Al-Karaki and Al-Raddad, 1997; Al-Karaki and Clark, 1998; George et al., 1994; Marschner and Dell, 1994; Ruiz-Lozano et al., 1996), and improved water relations (Al-Karaki and Clark, 1998; Bethlenfalvay et al., 1988; Ruiz-Lozano and Azcon, 1995; Sylvia et al., 1993), leading to increased growth and subsequent dilution of toxic ion effects (Juniper and Abbott, 1993).

Tomato is the most widely grown vegetable in Jordan, and is grown under open field and greenhouse conditions. As continued tomato production in Jordan is now threatened by decreasing supply of fresh water, implementing saline water into the irrigation water becomes inevitable. The symbiotic interactions between AMF and host plants under saline conditions need to be studied in order to optimize beneficial effects of AMF. The objective of this study was to determine the effects of mycorrhizal infection on growth parameters and nutrient acquisition by tomato under different levels of soil salinity.

MATERIALS AND METHODS

Seeds of tomato (*Lycopersicon esculentum* Mill. cv. Pello) were germinated in a moist mixture of peat and sand in polystyrene trays. Three 21-day-old seedlings, uniform in size, were transplanted into 5-liter plastic pots filled with a silty clay soil (fine, mixed, thermic, Typic Xerochrept) mixed with sand (soil: sand, 1:1, v:v), fertilized with 0.35 g NH₄NO₃ kg⁻¹ soil. The soil mix was fumigated with methyl bromide under airtight plastic sheets for 3 days, and the fumigant was allowed to dissipate for 10 days.

The soil properties, before mixture with sand and fertilizer, were 6.5% sand, 45.0% silt, and 48.5% clay; 1.1% organic matter; pH 8.0; electrical conductivity

(EC_e) 1.4 dS m⁻¹; 0.26 P (NaHCO₃-extractable), 23.1 K, 6.2 Na, 0.2 Fe, 0.02 Zn and 0.03 Cu (5 mM DTPA-extractable) in mmol kg⁻¹ soil. No additional P was added to the soil mixes in order to stimulate mycorrhizae formation. The plants were grown in a greenhouse (27 ± 5°C) under natural illumination during the spring of 1998.

Half of the pots received *Glomus mosseae* (Nicol. and Gerd.) Gerd. and Trappe, by inoculum placed in soil below tomato seedlings. Inoculum was placed directly adjacent to tomato seedling transplants to facilitate fungal colonization of plant roots. *Glomus mosseae* was initially isolated from a wheat (*Triticum durum* desf.) field in northern Jordan (Al-Raddad, 1993) and multiplied in pot cultures using chickpea (*Cicer arietinum* L.) as a host. Control treatments received no AMF inoculum.

Plants were established for 2 weeks before they were subjected to three salt levels by adding NaCl to soil through irrigation water at rates of 0, 3.0, and 6.0 g NaCl kg⁻¹ soil. This resulted in saturation extract (EC_e) values of 1.4, 4.7, and 7.4 dS m⁻¹, respectively. The soil was salinized stepwise to avoid osmotic shock. Plants were watered with tap water (EC = 0.4 dS m⁻¹) in such a way to avoid leaching. However, when leaching occurred, the leachate was collected and added back to soil to maintain salinity treatments at target levels. The plants were harvested after they had been grown under salt-stress conditions for 6 weeks. Plants were separated into shoots and roots. Leaf area was determined using LI-300 (Li-Cor, inc., NE). Shoots were then oven-dried at 70°C for 48 hr, weighed, and saved for mineral analysis.

Roots were rinsed free from soil, cut into 1-cm fragments, thoroughly mixed, and representative fresh samples (1 g) were removed for determination of root AMF colonization. Root samples for determination of root colonization with AMF were cleared with 10% (w/v) KOH and stained with 0.05% (v/v) trypan blue in

lactophenol as described by Phillips and Hayman (1970), and microscopically examined for colonization by determining percentage root segments containing arbuscules + vesicles using a grid-line intercept method (Bierman and Linderman, 1981).

Dried shoots were ground to pass through a 0.5-mm sieve in a cyclone laboratory mill, and saved for determination of mineral nutrients. Shoot P concentration was determined colormetricazlly (Watanabe and Olsen, 1965) and Zn, Fe, and Cu concentrations were determined by atomic absorption spectroscopy. Potassium and Na concentrations in plant shoots were determined using a flame photometer.

A factorial arrangement of treatments in a randomized complete block design was used with four replications. Data was statistically analyzed using analyses of variance in the MSTAT (Michigan State Univ., East Lansing, MI). Probabilities of significant among treatments and interactions and LSDs (P< 0.05) were used to compare means within and among treatments.

RESULTS

Nearly all salinity and AMF treatment effects were significant for the growth and nutrient acquisition traits, but the only significant salinity × AMF interaction was for P concentration and total accumulation of P, Fe, and Zn.

Root colonization did not occur for plants provided no AMF inoculum. Substantial AMF root colonization occurred for plants inoculated with AMF, and the plants grown in non-saline soil had higher AMF colonization than plants grown under saline soil conditions (Table 1). Shoot and DM yields and leaf area were higher for mycorrhizal than for non-mycorrhizal plants regardless of salinity level. However, no significant differences between mycorrhizal and non-mycorrhizal plants for shoot and root DM at the high salinity (7.4 dS m⁻¹) treatment, and for leaf area at non-saline treatment. Shoot and root DM and leaf area decreased as soil salinity increased.

Table 1. Root mycorrhizal colonization, shoot and root dry matter yield, and leaf area by non-mycorrhizal and mycorrhizal tomato grown with different salinity levels.

Salinity Level	AMF1 Status	AMF Colonization	Dry Matter Yield		Leaf Area
			Shoot	Root	
dS m ⁻¹		--%--	--g plant ⁻¹ --		-cm ² plant ⁻¹ -
1.4	Non-AMF	0	1.62	0.20	256
	AMF	57	2.33	0.28	277
4.7	Non-AMF	0	1.05	0.10	119
	AMF	45	1.57	0.18	186
7.4	Non-AMF	0	0.44	0.08	43
	AMF	35	0.60	0.09	87
LSD (0.05)		7	0.48	0.08	37

1Arbuscular mycorrhizal fungi.

Shoot P concentrations (Table 2) and total accumulation were higher in mycorrhizal than non-mycorrhizal plants at both non-saline and medium soil salinity, but not at high salinity level. However, shoot P concentrations and total accumulation in both mycorrhizal and non-mycorrhizal plants were decreased with increasing soil salinity.

Shoot K concentrations and total accumulations were similar for mycorrhizal and non-mycorrhizal plants grown at all salinity levels, but these variables were decreased as soil salinity increased. Sodium concentrations and total accumulation were increased as soil salinity increased in both mycorrhizal and non-mycorrhizal plants. Sodium concentrations were lower in mycorrhizal than in non-mycorrhizal plants at moderate and high salinity levels, but not at non-saline treatment. Shoot total accumulation of Na was similar for mycorrhizal and non-mycorrhizal plants grown at all salinity levels.

Shoot concentrations of Fe, Cu and Zn were generally higher for mycorrhizal than for non-mycorrhizal plants grown at all salinity levels. Total accumulation for Fe, Cu, and Zn were generally higher for mycorrhizal than for non-mycorrhizal plants, but these differences were not significant for plants grown at high salinity level. Shoot concentrations and total accumulation of Fe, Cu, and Zn were decreased as soil salinity increased.

concentrations and total accumulation than non-mycorrhizal plants. Plant growth (dry matter and leaf area) increase due to inoculation with mycorrhiza under saline conditions may also be attributed to improved water relations (Poss et al., 1985; Rosendahl and Rosendahl, 1991). Plant growth enhancements attributed to AMF root colonization decreased at high salinity (7.4 dS m⁻¹) treatment. This might have occurred because of reduced AMF colonization under these conditions. Similar results were reported by other workers (Hirrel and Gerdemann, 1980; Pond et al., 1984; Poss et al., 1985). However, enhanced plant growth (dry matter) may not be related to the degree of AMF root colonization in some plants (Ahiar and Hirata, 1994; Al-Karaki and Clark, 1998).

Many studies have indicated that AMF contributes to plant growth via enhancement of mineral nutrient uptake, especially immobile soil nutrients (P, Cu, Zn) (Bethlenfalvay et al., 1988; Al-Karaki and Al-Raddad, 1997; Al-Karaki and Clark, 1998; Marshner and Dell, 1994). In this study, the mycorrhizal tomato plants had higher shoot P concentrations and total accumulation than the non-mycorrhizal plants regardless of salinity level. Higher Fe, Cu, and Zn concentrations and total accumulation in mycorrhizal compared to non-mycorrhizal plants were also noted. The higher mineral nutrient acquisition in mycorrhizal compared to non-mycorrhizal plants most likely occurred because of increased

Table 2. Shoot concentration of nutrients by non-mycorrhizal and mycorrhizal tomato grown with different salinity levels.

Salinity Level dS m ⁻¹	AMF ¹ Status	Shoot Concentration					
		P	Na	K	Fe	Cu	Zn
		----- mmol kg ⁻¹ -----				-----µmol kg ⁻¹ -----	
1.4	Non-AMF	44	169	1080	2529	164	622
	AMF	63	123	1137	3416	230	713
4.7	Non-AMF	40	1155	710	2534	137	407
	AMF	60	773	909	2860	222	431
7.4	Non-AMF	39	1739	624	1930	114	394
	AMF	43	1229	654	2747	163	428
LSD (0.05)	5	352	343	666	41	51	

¹Arbuscular mycorrhizal fungi.

DISCUSSION

Plants inoculated with mycorrhiza had higher shoot and root DM yields and leaf area than non-mycorrhizal plants at all salinities, but the responses were more pronounced under medium salinity (4.7 dS m⁻¹) treatment. Enhanced growth of mycorrhizal plants when grown in saline environments have been related to mycorrhizal-mediated enhancements of host plant P nutrition (Hirrel and Gerdemann, 1980; Pond et al., 1984; Poss et al., 1985). In our study, mycorrhizal plants had higher P

availabilities or transport (absorption and/or translocation) by AMF hyphae. Enhanced acquisition of P, Zn, Cu, and Fe by mycorrhizal plants has been reported (Al-Karaki and Al-Raddad, 1997; Al-Karaki and Clark, 1998; Marshner and Dell, 1994; Trimble and Knowles, 1995).

However, AMF root colonization did not significantly affect shoot K concentrations and total accumulation in plants grown at all salinity levels. Nevertheless, K uptake was affected little by AMF root colonization in tomato grown under salinity conditions

(Poss et al., 1985). Root colonization with AMF reduced shoot Na concentrations, but did not influence total accumulation of Na regardless of salinity level. This probably occurred because of dilution from enhanced growth (Jarrell and Beverly, 1981).

In summary, the results of our study indicated that plant tolerance to salt stress was improved by AMF colonization. Mycorrhizal tomato plants had greater nutrient acquisition (especially P) compared to non-mycorrhizal plants grown at all salinities. Greater nutrient acquisition in response to AMF colonization was suggested to be a plant strategy for salt stress tolerance (Hirrel and Gerdemann, 1980; Pond et al., 1984; Poss et al., 1985). The improved growth and nutrient acquisition in mycorrhizal tomato demonstrates the potential of AMF colonization for the protection from salt stress of plants grown in arid and semi-arid regions. However, several AMF isolates should be investigated in order to maximize efficiencies of AMF symbiosis under saline conditions.

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REFERENCES

- Ahiabor, B.D., and H. Hirata. 1994. Characteristics responses of three tropical legumes to the inoculation of two species of VAM fungi in Andosol soils with different fertilities. *Mycorrhiza* 5: 63-70.
- Al-Karaki, G.N., and A. Al-Raddad. 1997. Effects of arbuscular mycorrhizal fungi and drought stress on growth and nutrient uptake of two wheat genotypes differing in drought resistance. *Mycorrhiza* 7: 83-88.
- Al-Karaki, G.N., and R.B. Clark. 1998. Growth, mineral acquisition, and water use by mycorrhizal wheat grown under water stress. *J. Plant Nutr.* 21: 263-276.
- Al-Raddad, A. 1993. Distribution of different *Glomus* species in rainfed areas in Jordan. *Dirasat* 20: 165-182.
- Ayers, R.S., and D.W. Westcot. 1985. Water quality for agriculture. *FAO Irrig. Drainage Paper No. 29*, Rome, Italy.
- Bethlenfalvay, G.J., M.S. Brown, R.N. Ames, and R.S. Thomas. 1988. Effects of drought on host and endophyte development in mycorrhizal soybeans in relation to water use and phosphate uptake. *Physiol. Plant.* 72: 565-571.
- Bierman, B., and R. Linderman. 1981. Quantifying vesicular-arbuscular mycorrhizae: proposed method towards standardization. *New Phytol.* 87: 63-67.
- George, E., V. Romheld, and H. Marschner. 1994. Contribution of mycorrhizal fungi to micronutrient uptake by plants. p. 93-109. In: J.A. Manthey, D.E. Crowley, and D.G. Luster (Ed.) *Biochemistry of Metal Micronutrients in the Rhizosphere*. Lewis Publ., Boca Raton, FL.
- Hasegawa, P.M., R.A. Bressan, and A.K. Hanada. 1986. Cellular mechanisms of salinity tolerance. *Hort. Sci.*, 21: 1317-1324.
- Hirrel, M.C., and J.W. Gerdemann. 1980. Improved growth of onion and bell pepper in saline soils by two vesicular-arbuscular mycorrhizal fungi. *Soil Sci. Soc. Am. J.* 44: 654-655.
- Juniper, S., and L. Abbott. 1993. Vesicular-arbuscular mycorrhizas and soil salinity. *Mycorrhiza* 4: 45-57.
- Kuck, A.J. 1999. Integration of marginal water resources into a strategy for irrigation water supply in the Jordan Valley. p. 331-344. In: *Proc. Regional Symposium on Irrigation Management, and Saline Conditions*, 21-23 June 1999, Jordan Univ. Sci. Technol., Irbid, Jordan.
- Marschner, H., and B. Dell. 1994. Nutrient uptake in mycorrhizal symbiosis. *Plant Soil* 159: 89-102.
- Ministry of Agriculture. 1997. Department of Statistics-*Annual Report 1997*. Amman, Jordan.
- Ministry of Water and Irrigation. 1999. Sources and uses of water in Jordan. National Water Master Plan Project 1999. Amman, Jordan.
- Phillips, J., and D. Hayman. 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. *Trans. Brit. Mycol. Soc.* 55: 158-161.
- Pond, E.C., J.A. Merge, and W.M. Jarrell. 1984. Improved growth of tomato in salinized soil by vesicular-arbuscular mycorrhizal fungi collected from saline soils. *Mycologia* 76: 74-84.
- Poss, J.A., E. Pond, J.A. Meng, and W.M. Harrell. 1985. Effect of salinity on mycorrhizal onion and tomato in soil with and without additional phosphate. *Plant Soil* 88: 307-319.
- Rosendahl, C.N., and S. Rosendahl. 1991. Influence of vesicular-arbuscular mycorrhizal fungi (*Glomus* spp.) on the response of cucumber (*Cucumis sativus* L.) to salt stress. *Environ. Exp. Bot.* 31: 313-318.
- Ruiz-Lozano, J.M., and R. Azcon. 1995. Hyphal contribution to water uptake in mycorrhizal plants as affected by the fungal species and water status. *Physiol. Plant.* 95: 472-478.
- Ruiz-Lozano, J.M., R. Azcon, and M. Gomez. 1996. Alleviation of salt stress by arbuscular mycorrhizal *Glomus* species in *Lactuca sativa* plants. *Physiol. Plant.* 98: 767-772.
- Sylvia, D.M., L.C. Hammond, J.M. Bennett, J.H. Haas, and S.B. Linda. 1993. Field response of maize to a VAM fungus and water management. *Agron. J.* 85: 193-198.
- Trimble, M.R., and N.R. Knowles. 1995. Influence of vesicular-arbuscular mycorrhizal fungi and phosphorus on growth, carbohydrate partitioning and mineral nutrition of greenhouse cucumber (*Cucumis sativus* L.) plants during establishment. *Can. J. Plant Sci.* 75: 239-250.

Watanabe, F.S., and S. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and NaHCO_3 extract for soil. *Soil Sci.* 21: 677-678.

Wyn Jones, R.G., and J. Gorham. 1983.

Osmoregulation. p. 35-38. *In*: O.L. Lange et al. (Ed.) *Physiological plant ecology. III. Responses to chemical and biological environment. New Series 12C.* Springer-Verlag, New York, N Y.

Wheat and Barley Response to Saline Conditions in South Sinai

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ABSTRACT

Two field experiments on wheat and barley were conducted at Beer Abou-Kalam Experimental Farm, South Sinai Governorate, where seven wheat cultivars and six barley cultivars were sown in saline soil (5.6 mmhos/cm) and irrigated with underground saline water (about 2800 ppm). Some growth attributes and the final yield were determined. The results showed that the growth and yield of Sakha 8, Giza 163 and Giza 164 wheat cultivars seemed to surpass other cultivars under saline conditions. The results also showed that barley hybrid 89 surpassed other cultivars in grain yield. It was concluded that relative salt tolerance of wheat and barley cultivars should be taken into consideration if successful yields have to be produced under saline conditions in south Sinai.

INTRODUCTION

Salinity is considered to be the main threat to sustainability of agricultural production in new reclaimed land in Egypt. High salt concentration in soil solutions generates a high osmotic pressure and, correspondingly, a low water potential and some nutritive imbalance (N.A.S., Washington, 1974). With respect to high salt concentration, there are highly sensitive crops like maize, onion and beans and more or less tolerant crops like cereals and sugar beets (Amberger, 1997).

Crop production under South Sinai conditions depends mainly upon the underground brackish water, which contains varying amounts of dissolved salts, ranging between 1500-6000 ppm. In addition, the cultivated soil is saline and contains a relatively high percentage of CaCO_3 .

Increasing salinity level in the root media induced a significant decrease in plant growth and retarded dry matter accumulation, as well as decreased final yield (Gupta and Baijal, 1984; Haqqani et al., 1984; Hammad et al., 1988; El-Sharawy et al., 1997).

Genotype performance $\times$ environment interaction is considered to be one of the most important strategies to improve final yield for several crops (El-Sayed et al., 1990; Noaman et al., 1990). Under South Sinai conditions crop production can be developed if the proper genotypes are selected (Ashour et al., 1992). In this connection, Bassyouni (1985) reported that there were great differences in the response of various cultivars of several crops to the agro-ecological conditions. In addition, Cox (1990) and Hindi (1990) reported significant genotypic interactions with different environmental attributes.

This work was carried out to study the response of growth and grain yield as well as chemical composition of some wheat and barley cultivars grown under saline conditions in the South Sinai region.

MATERIALS AND METHODS

Two field experiments were carried out at Beer Abou-Kalam Experimental Station, Tour-Sinai, South Sinai Governorate, during two successive seasons. The aim of the work was to study the effect of varietal differences on growth and yield of seven wheat cultivars, i.e., Sakha 69; Sakha 8, Giza 155, 157, 160, 163 and 164 as well as six barley cultivars, i.e., Hybrid 89, Giza 117, 119, 121, 123 and 124 grown under saline conditions and irrigated with saline water.

The experimental design was a complete randomized complete block design with four replications. The experimental unit area was 5 m² (2 m $\times$ 2.5 m). Each plot consisted of 12 rows 16 cm apart and 2.5 m in length. The seeds of each cultivar were sown at a rate of 60 kg/feddan in November 2nd and 10th in the first and second seasons, respectively. The normal cultural practices of growing wheat and barley were followed.

Organic manure and calcium superphosphate (15.5% P_2O_5) were added during soil preparation at the rate of 25 m² and 150 kg superphosphate/feddan, respectively. Nitrogen fertilizer was added after 35 days from sowing at the rate of 60 units of N/feddan in the form of ammonium nitrate (33.5% N). Mechanical and chemical analysis of the soil of the experimental site as well as chemical analysis of the underground water used for irrigation were performed according to Jackson (1958) and Chapman and Pratt (1961). Chemical properties were: EC, 5.6 dS/m; pH, 8.4; O.M., 0.9%; CaCO_3 , 14%; 0.37 meq/kg K; and 1.7 ppm Fe. The water salinity was 3.60 dS/m or 2842 ppm, with an adj. SAR of 9.4. The soil was sand, with 50% coarse sand, 33% fine sand, 32% silt, and 9% clay.

Plant samples were taken randomly from each cultivar of each crop at heading stage. The following characters were studied: plant height, number of tillers, fresh weight, and dry weight per square meter. Harvest took place after 155 days from sowing in both seasons. At harvest, a sample was randomly collected from the inner rows from each plot (sample size was plants per m²). The following characters were studied, number of spikes/m², number of grains per spike, and 1000-grain weight. Grain and straw yield per feddan were also calculated.

Data were statistically analyzed using analysis of variance according to Gomez and Gomez (1984). Means were compared by the Least Significant

Difference Test (LSD), which was modified by Waller and Duncan (1969).

RESULTS AND DISCUSSION

One average rainfall is very low (8.5 mm), mainly from December to March; temperature ranges from 20°C in January to 31°C in May with a constant relative humidity of about 56%.

Growth Characters

Data presented in Table 1 indicate that growth characters of both crops grown under saline conditions were affected by varietal differences at heading stage. Sakha 8 and Giza 155 surpassed other cultivars in plant height, number of tillers as well as fresh and dry weight per m². In this respect, others (Nour El-Din et al., 1984; Sharan et al., 1986; Roshdy, 1988; Abd El-Gawad et al., 1990) reported that the differences in plant height among wheat cultivars might be attributed to the differences in number and/or length of internodes reflecting the genetic makeup. In addition, the superiority of some cultivars may be due to their relative salt tolerance.

Yield and Yield Components

Data presented (Table 2) show yield and yield components of wheat and barley cultivars grown under saline conditions. It seems that the yield of Sakha 8, Giza 163 and Giza 164 of wheat cultivars surpassed other cultivars. The superiority of these cultivars may be due to the number of grains per spike and weight of 1000-grains. With regard to barley, it seems that the yield of Hybrid 89 surpassed other cultivars which may be due to both higher number of grains per spike and weight of 1000 grain. Such effect between cultivars might be due to the differences in their genetically constitution and, in turn, their relative salt tolerance.

Chemical Composition of Grains

Results in Table 3 showed that grain of Sakha 8 and Giza 163 and 164 (wheat) and Hybrid 89 of barley contained the highest percentage of protein as well as proline. Ash percentage in grain seems not to be significantly affected by varietal differences.

From the results obtained, it can be concluded that the yield of Sakha 8, Giza 163 and Ziza 164 of wheat cultivars, as well as Hybrid 89 of barley cultivars, surpassed

Table 1. Mean varietal differences on some growth characters of wheat and barley cultivars grown under saline conditions at heading stage, South Sinai.

Crop	Cultivar	Plant Height --cm--	Tillers -no. /m ² -	Fresh Weight, -g/m ² -	Dry Weight, -g/m ² -
Wheat	Sakha 69	56	475	1243	268
	Sakha 8	68	503	1438	295
	Giza 157	59	468	1168	256
	Giza 155	97	499	1329	282
	Giza 160	62	476	1190	263
	Giza 163	63	481	1230	271
	Giza 164	61	485	1280	268
	<i>LSD (0.05%)</i>	2.7	15.5	57.1	13.3
Barley	Hybrid 89	61	354	1097	236
	Giza 117	51	326	955	201
	Giza 119	54	296	904	196
	Giza 121	62	355	1083	231
	Giza 123	60	309	998	219
	Giza 124	48	287	889	187
	<i>LSD (0.05%)</i>	5.4	12.7	40.6	17.9

The same picture was also observed with regard to barley cultivars. The growth of Hybrid 89 surpassed other cultivars. Those results confirm those obtained by Noaman (1990) who reported that salinity might inhibit plant growth due to the accumulation of ions to a toxic level after the beginning of cell division. The extra energy spent by the plant to realize osmotic adjustment may also negatively affect plant growth.

that of other cultivars and seems to be the most adapted cultivars under saline condition of South Sinai.

Table 2. Mean varietal differences of yield and yield components of wheat and barley cultivars grown under saline conditions, South Sinai.

<u>Crop</u>	<u>Cultivar</u>	<u>Spikes</u>	<u>Grains</u>	<u>1000-Grain Weight</u>	<u>Grain Yield</u>	<u>Straw Yield</u>
		-no./m ² -	-no./spike-	--g--	--ton./feddan ¹ --	
Wheat	Sakha 69	484	35	35	1.6	2.3
	Sakha 8	518	41	36	2.2	2.5
	Giza 157	502	41	35	2.0	2.5
	Giza 155	454	35	35	1.8	2.8
	Giza 160	478	35	34	1.7	2.8
	Giza 163	507	42	35	2.1	2.9
	Giza 164	494	42	36	2.1	2.6
	<i>LSD</i> (0.05%)	12.5	2.8	0.8	0.41	0.21
Barley	Hybrid 89	302.9	48	39	1.7	1.3
	Giza 117	271.7	44	36	1.3	1.1
	Giza 119	267.9	35	31	1.1	1.1
	Giza 121	292.9	41	36	1.5	1.3
	Giza 123	254.3	39	31	1.2	1.3
	Giza 124	226.9	35	32	1.1	1.0
	<i>LSD</i> (0.05%)	21.8	3.2	3.4	0.2	0.12

¹One feddan = 4200 m²**Table 3. Varietal differences in chemical composition of grain of wheat and barley cultivars grown under saline conditions, South Sinai.**

<u>Crop</u>	<u>Cultivar</u>	<u>Protein</u>	<u>Total Carbohydrate</u>	<u>Ash</u>	<u>Proline Content</u>
			-----%-----		--μ mol/gm--
Wheat	Sakha 69	12.3	20.4	1.9	22.8
	Sakha 8	12.8	18.8	2.4	25.3
	Giza 157	12.2	21.6	2.1	23.9
	Giza 155	12.3	20.6	2.2	23.8
	Giza 160	12.2	24.7	1.9	20.2
	Giza 163	12.4	15.1	2.2	25.7
	Giza 164	12.6	18.4	2.2	24.0
	<i>LSD</i> (0.05%)	0.4	3.6	0.1	1.2
Barley	Hybrid 89	9.5	72.7	3.1	19.5
	Giza 117	8.7	72.5	3.2	16.8
	Giza 119	8.4	74.1	3.1	17.0
	Giza 121	8.9	71.5	3.2	14.6
	Giza 123	8.3	64.0	3.2	15.8
	Giza 124	7.7	66.6	3.2	17.5
	<i>LSD</i> (0.05%)	1.0	1.2	N.S.	0.6

REFERENCES

- Abd Elgawad, A.A., A.A. Kishk, M.A. Abou Shetaia, and W.K. Hassan. 1990. Studies on the productivity of wheat plants under salinity of Wadi Sudr. *Proc. 4th Conf. Agron.* 1: 111-166.
- Ashour, N.I. 1992. Final report of the project "Growing varieties of field crops: Tolerating salinity and drought in Sinai". Academy of Scientific Research and Technology, National Research Center, Cairo.
- Amberger, A. 1997. Plant response under saline conditions. p. 249. Abstracts: International Symposium on "Sustainable Management of Salt-Affected Soils in Arid Ecosystems", Cairo, Egypt.
- Bassyouni, A.H. 1985. Studies on yield potentiality in wheat. *Ph.D. Thesis*, Fac. Agric., Zagazig Univ., Egypt.
- Chapman, H.D., and P.F. Pratt. 1961. Methods of analysis for soil plants and water. Univ. Calif., Davis. Ca.
- Cox, M.C., C.O. Qualset, and D.W. Rains. 1985. Genetic variation for nitrogen assimilation and translocation in wheat. I. Dry matter and nitrogen accumulation. *Crop Sci.* 25: 430-435.
- El-Sayed, A.A., M.M. Noaman, S. Ceccarelli, F.A. Assad, and F.M. El-Rayes. 1990. Yield stability characteristics of some barley cultivars grown under different environments I. Under low rainfed conditions. *Proc. 4th Conf. Agron.*, Cairo, 1: 42-50.
- El-Sharawy, M.O., M.A. Mostafa, and F.M. El-Boraci. 1997. Use of sea water for wheat irrigation. I. Effect on plant growth and nutrient uptake. p. 267. Abstracts: International Symposium on "Sustainable Management of Salt-Affected Soils in the Arid Ecosystem", Cairo, Egypt.
- Gomez, K.A., and A. Gomez. 1984. Statistical procedures for agricultural research, 1st ed. John Wiley & Sons, New York.
- Gupta, G., and B.D. Bajjal. 1984. Influence of different levels of sodium chloride on barley seedling growth of certain cultivars (*Hordeum vulgare* L.). *Indian J. Agric. Res.* 18: 18-40.
- Hammad, A.H.A., A.K. Abd El-Halem, T.O.A. Orabi, and M.M. Hussein. 1988. Effect of gamma irradiation and salinity on growth, yield and its components and chemical composition of barley. *Egypt. J. Agron.* 13: 101-108.
- Haqqani, A.M., A. Ranf, and M.A. Zahid. 1984. Salt tolerance studies on wheat in farmers fields. *Pakistan J. Agric. Res.* 5:2: 78-81.
- Hindi, L.H.A., R.A. Mitkees, A.H. El-Attar, and M.K. Moshref. 1990. Effect of genotype, environment and their interaction on bread wheat. *4th Conf. Egyptian Soc. Crop Sci.*, Cairo, 1: 13-27.
- Jackson, M.L. 1958. Soil chemical analysis. Constable Co. Ltd., London.
- National Academy of Sciences, Washington, D.C. 1974. More water for arid lands, promising technologies and research opportunities. *Report of an Ad Hoc Panel, Board of Science and Technology for International Development.* 154 p.
- Nour E-Din, A.N., A.M. Hegazi, M.A. Abd El-Gawad, and M.O.M. Salem, 1984. Growth response of some wheat cultivars to "Cycocel" treatment under Wadi Sudr region conditions. *Egypt. J. Agron.* 9: 75-81.
- Roshdy, A. 1988. Response of some wheat varieties to nitrogen fertilization. *Ann. Agric. Sci., Moshthor.* 26: 739-742.
- Sharaan, A.N., F.M. Ismail, S.M.M. Hassan, and A.M. Mohamed. 1986. Performance of the varietal wheat characters as affected by locations and years. *Ann. Agric. Sci., Moshthor.* 24:2:683-689.
- Waller, R.A., and D.B. Duncan. 1969. Symmetric multiple comparison problem. *Amer. Stat. Assoc. Jour.* 1485-1503.

Ecophysiological Indicators of Water-Use Efficiency in Hot Dry Lands

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ABSTRACT

Water use efficiency (WUE) by crop plants to be cultivated in dry lands is a key determinant tool for the success of amelioration of such areas. The importance of WUE becomes crucial under limited water resources, e.g., using underground water resources. Both high thermal regimes and limited water supply drastically affect WUE.

Considerations of habitat thermal amplitudes and impact of radiant energy (heat and light stresses) on plant productivity is essential. Recognizing and identifying the effects of edaphic and climatic drought on plant metabolism and productivity is also crucial since maintaining normal metabolism is one of the two variables determining WUE. Prospective salinization of surface groundwater resulting from over-discharge and its impact on plant productivity must be considered. Interaction between two or more factors of the arid lands environmental complex in their effects on water use by plants and/or plant metabolism, and hence WUE, should be evaluated. Occurrence of such interactions is the rule rather than being an exception, especially under desert conditions. The research data presented hitherto allows for discussing and clarifying the considerations outlined above.

INTRODUCTION

Water use efficiency (WUE) by plants is the core for success of amelioration of dry lands, which are characterized by deficiency of water resources and severe environmental stresses, mainly edaphic and/or climatic drought, heat and light stresses, as well as soil salinity. In its simplest definition, WUE relates the amount of dry matter buildup to the amount of water consumed by the plant (mainly by transpiration) for a given period of time (Chang, 1968). i.e.:

$$WUE = \frac{\text{Dry matter content Increase in a given time period}}{\text{Amount of water transpired in the same period}}$$

In this respect, Chang (1968) refers to WUE as "Transpiration efficiency". Growth retardation as a result of water deficiency is well recognized. Stocker (1960) related this to the general retardation of enzymatic processes due to water deficits in the plant and particularly to shortage of plant-building material occasioned by reduction of photosynthesis. This reduction can be the result of reduced leaf surface area (impaired growth), decreased pigment content, or impaired pigment function.

Decreased chlorophyll content and impairment of its function can be due to either a low rate of pigment synthesis or, as occasioned in many areas subject to high insolation intensities (such as in upper Egypt, and hot deserts in general), to decreased resistance to heat (chlorophyll heat-stability). It follows therefore that any environmental factor affecting either increased transpirational water loss or decreased drymatter buildup by plants would drastically decrease WUE.

Accordingly, this paper is mainly concerned with clarifying factors affecting and ecophysiological parameters indicating efficient water use by plants. In this respect, it is worth to mention that due to the multiplicity of factors affecting both terms of the WUE equation, plus the differences in genetic adaptability of species and varieties (ecological amplitudes or range of tolerance), WUE variations are high. The data presented here summarize previous research experience of the authors in ecophysiological investigations of parameters affecting WUE by plants, especially under environmental stresses.

MATERIALS AND METHODS

Due to its wide scope, details on methodologies and materials are included in reference material mentioned in the text. For expressing the efficiency of water use by plants, several ratios are applied (Kvet et al., 1971). Of these, "Transpiration efficiency" of Jen-Hu-Chang (1968), is the simplest, especially when direct measurements of CO₂ exchange is not feasible. Proportionality between shoot and root systems are also used in this respect. A high value of "root/ top" ratio is believed to be a property of drought-and heat-hard varieties of wheat (Sandhu and Lande, 1958). Increased "leaf/stalk" ratio under increased moisture tension was recorded.

The Role of Climatic Factors

Changes in WUE in plants, as stated above, could result from changes in the rate of water consumption (*Transpirational loss*), or, changes of material buildup. Since both variables in the WUE are greatly affected by climatic parameters (as single factors or interacting), the data presented here should be quite clarifying. The most effective climatic parameters are mainly light, air temperature, and vapor pressure deficit of air. In this respect, influence of certain climatic factors on transpiration and dry matter buildup, hence its reflection on WUE, will be projected. More important could be the existence of significant interactions in the effects of two or more of such factors on both transpiration and dry matter buildup.

Measurements of transpiration and evaluation of diurnal and seasonal water output in some fruit trees under desert conditions in Egypt were started early in the sixties (El-Rahman and El-Sharkawi, 1968, 1974). Such studies were part of investigations on water relations and aspects of drought resistance in olive and almond plants grown in desert orchards in response to limited supplementary irrigation regimes. One of the important results reached was recognizing the fact that olive trees were able to check their transpiration at noon with conditions for high rates of water loss e.g., high light intensity and vapor pressure deficit (VPD) of air.

In an estimation of stomatal resistance (r) in both plants (El-Sharkawi, 1981), it was realized that this resistance increases in response to temperature at high light intensities. In a study on two grasses, transpiration was found to greatly decrease with increasing air humidity, even at decreasing soil matric water potential (El-Sharkawi and Michel, 1977). The response of net photosynthesis to air humidity was likewise. Accordingly, WUE was much higher at high air humidity and it also increased with decreasing soil water matric potential. This reflected efficient water use in the two grasses investigated.

In some wheat and barley cultivars, super-x wheat showed increased transpiration efficiency, i.e., WUE with decreasing soil ψ_s , particularly at the time of day (7 p.m.) when a high water deficit is expected to be develop in leaves. This indicates an advantage of this cultivar over Giza 155 (El-Sharkawi and Salama, 1977). Likewise, barley Giza 117 was compared to Borg El-Arab.

Temperature gradients between air and soil (T_A/T_S) is the rule in natural habitats. In inland deserts (usually referred to as continental climates), wide soil-to-air temperature gradients (positive or negative) reaching 20-30°C are quite common. In such conditions, semi-dry surface soil may attain extremely high air temperatures during midday and early afternoon and vice versa during late night times. Crop plants, particularly under dry farming practices, are greatly affected by such gradients, especially concerning their water relations governing metabolism. In a recent laboratory investigation of Farghali and El-Sharkawi (1998), WUE in soybean at $T_A - T_S = 0$ was decreased drastically (to about 1/5) with increasing air and soil (root culture) temperatures.

EDAPHIC FACTORS (DROUGHT)

In this respect, we should be looking at the response of both terms of the WUE equation to reduced availability of soil water to plants (reduced soil-water potentials). However, clear distinction should be made between the effects of reduced soil matric "water potential" (ψ_m) resulting from decreased soil water content and that of reduced soil "osmotic" water potential (ψ_s) resulting from increased salinity of the soil solution.

The impact of reduced ψ_m on plants is mainly relative turgidity (R.T.) of plant leaves and on metabolic

processes directly affected by development of internal water deficits. But the impact of reduced ψ_s includes, besides the plant water relations (osmotic effect of salinity), the toxicity effect of certain specific ion, e.g., Na^+ and the disturbances in ion absorption (the *antagonistic effects*) related to the concentrations of ionic composition of saline soils. Therefore, the effect of reducing ψ_s should not be comparable to that of reduced ψ_m ; so should be their impacts on WUE regarding the mechanisms of effects, especially metabolic ones.

BIOLOGICAL INDICATORS

One of the main mechanisms involved in response of WUE, through both transpiration or through metabolism, is the change in relative turgidity (= relative water content, RWC) of leaves, indicative of the existence and magnitudes of water deficits in plants. Since plant metabolism is essentially sensitive to development of water deficits in leaves, R.T. in leaf tissues should be considered in judging WUE, since it refers to the water status in leaves, especially free mobile water involved in both transpiration and metabolism, together with osmotically-bound and colloid-bound water. In this respect, a definite relation exists between the water content of the cell, the distribution of this water in such various fractions and the amount of water the plant spends in transpiration. A dynamic relation, however, exists between the free-and osmotically bound water.

In its simplest form, a simple inverse proportionality exists between R.T. and osmotic pressure of leaves, which is osmotic potential may decrease due to increased RT and vice versa (El-Sharkawi and El-Monayeri, 1976). However, this is not always the case since metabolic additions and/or enzymatic conversions of hydrolysable soluble metabolites may change this inverse proportionality into a direct (positive) one, especially when water is unavailable for plants (reduced soil water potential).

This implies that osmotic potential increases with increasing R.T. and vice versa, as indicated by data of El-Sharkawi and Michel (1977). Also, an increase of R.T. may be accompanied by uptake and translocation of ions by the plant (especially under increased soil salinity) or increased photosynthetic buildup of osmotically active sugars.

Photosynthesis is sensitive to both matric and osmotic stress (El-Sharkawi and Michel, 1975). Salinity (osmotic) stress and, to a limited extent, sodicity represented by sodium adsorption ratio (SAR), significantly affect both chlorophyll content and chlorophyll stability to heat as given by data of El-Sharkawi et al. (1986).

Anatomical modifications accompanying decreased water availability to crop plants apparently favor better WUE, and hence drought resistance in such plants. Increased lignification of the outer cortical cells under salinity stress was observed in stems of super-x wheat, exceptional among other cultivars (El-Sharkawi and Salama, 1977). Relatively high temperatures (35°C)

caused lysis of parenchyma cells in developing roots. Sakha 8 wheat growing under normal water supply and the anatomy of the root is distorted, (El-Sharkawi et al., 1999). Increasing matric stress, however, caused lignification of the vascular tissue, including xylem and increased suberization of the endodermis in such roots. This has been observed also by Valenti et al. (1992), who stated that increased or early lignification of xylem is apparently a general characteristic of plants growing in habitats with a low water potential.

Boron-treated plants, however, did not suffer from such lysis at high temperatures, indicating a role for B in keeping the integrity of the anatomical structure. Another advantage of B-treatment was an increase in seminal roots and root hair density. This may express the need for careful recognition of microelement deficiencies in general and B-deficiency in particular, especially in generally deficient arid lands. Boron is localized in the cell wall and associated with pectin (Hu and Brown, 1994). Thus, species with high pectin content would have a higher tissue-B requirement (Hu et al., 1996). The role of B in enhancement of cell division, tissue differentiation, maturation, and maintaining root integrity is quite clear at high temperatures in Sakha 8 wheat cultivars. This may be attributed to increased uptake of B at high temperature as the formation of B complexes is temperature-, tissue- and organelle-dependent (Brown and Hu, 1993).

In conclusion, the data discussed above refer to the need to take into consideration, when choosing a certain crop for propagation in desert areas, the following precautionary measures:

- Select species having high stomatal control (measurable).
- Check soils for micronutrient deficiencies, especially those elements relevant to plant water relations.
- Test for chlorophyll stability to heat in species prospective for propagation.
- If salinization of water resources is expected, changes in osmotic pressure of plants should be examined, as a maximum osmotic pressure attained with increasing salinity is highly indicative of limit of tolerance to salinity, especially concerning WUE and productivity in plants.

REFERENCES

- Abd El-Rahman, A.A., and H.M. El-Sharkawi. 1968. Effect of salinity and water supply on olive. *Plant Soil*, 28: 280-290.
- Abd El-Rahman, A.A., and H.M. Sharkawi. 1974. Response of olive and almond orchards to partial irrigation under dry-farming practices in semi-arid regions: II: Plant-soil water relations in olive during the growing season. *Plant Soil*, 41: 13-31.
- Brown, P.H., and H. Hu. 1993. Boron uptake in sunflower, squash and cultured tobacco cells: studies with stable isotope and ICP MS. *Plant Soil*, 156: 147-150.
- Chang, J.H. 1968. Climate and agriculture, an ecological survey. Aldine Publ. Co., Chicago.
- El-Sharkawi, H.M. 1981. Transpiration resistance in olive and almond trees under semi-arid conditions. *Egypt. J. Physiol. Sci.*, 8: 31-42.
- El-Sharkawi, H.M., and M. El-Monayeri. 1976. Response of olive and almond orchards to partial irrigation under dry-farming practices in semi-arid regions III: Plant-soil water relations in almond during the growing season. *Plant Soil*, 44: 113-128.
- El-Sharkawi, H.M., K.A. Farghali, and S.A. Sayed. 1999. Growth characteristics of *Triticum aestivum* L. roots under different treatment combinations of boron, matric water potential and temperature. *Seed Sci. & Technol.*, 27: 1-11.
- El-Sharkawi, H.M., and B.E. Michel. 1975. Effects of soil salinity and air humidity on CO₂ exchange and transpiration of two grasses. *Photosynthetica*, 9: 227-282.
- El-Sharkawi, H., and B.E. Michel. 1977. Effects of soil water matric potential and air humidity on CO₂ and water vapor exchange in two grasses. *Photosynthetica*, 11: 176-182.
- El-Sharkawi, H.M., and F.M. Salama. 1977. Effects of drought and salinity on some growth-contributing parameters in wheat and barley. *Plant Soil*, 46: 423-433.
- El-Sharkawi, H.M., F.M. Salama, and A.A. Mazen. 1986. Chlorophyll response to salinity, sodicity and heat stresses in cotton, rama and millet. *Photosynthetica*, 20: 204-211.
- Farghali, K.A., and H.M. El-Sharkawi. 1998. Effect of air-root culture temperature gradients and VPD of air on parameters contributing to water balance in soybean *Glycine max*, L. *Proc. 6th Egypt. Bot. Conf.*, Cairo Univ., Nov. 24-26, 1998, Vol. III: 433-444.
- Hu, H., and P.H. Brown. 1994. Localization of boron in the cell wall and its association with pectin. Evidence of a structural role of boron in the cell wall. *Plant Physiol.*, 105: 681-689.
- Hu, H., P.H. Brown, and J.M. Labavitch. 1996. Species variability in boron requirement is correlated with cell wall pectin. *J. Exp. Bot.* 47: 227-232.
- Kvet, J., J.P. Ondok, J. Necas, and P.G. Jarvis. 1971. Methods of growth analysis. p. 343-391. *In: Plant photosynthetic production, a manual of methods*. Z. Sestakl, J. Catsky and P.J. Jarvis (Ed). Dr. W. Junk N.V. Publ. The Hague.
- Sandhu, A.S., and H.H. Lande. 1958. Tests of drought and heat hardiness of winter wheat. *Agron. J.*, 50: 78-81.
- Stocker, O. 1960. Physiological and morphological changes in plants due to water deficiency. *In: Plant water relationships in arid and semi-arid conditions*. *Rev. Res.*, 15: 63-104.
- Valenti, S.G., L. Melone, O. Orsi, and F. Riveros. 1992. Anatomical changes in *Prosopis cineraria* L. Druce seedlings growing at different levels of NaCl salinity. *Annals of Botany*, 70: 399-404.

Breeding for Salt Tolerance in Barley

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ABSTRACT

In the mid-eighties, a breeding program was started with the aim of developing salt tolerant barley (*Hordeum vulgare* L.) lines. In the early years of the program, much effort was put in devising a reliable screening methodology through which truly salt-tolerant breeding materials can be identified and used properly in the improvement program. Later, the responsible team proposed the use of a naturally salinized field technique, which involved planting frequent checks alternated with the genotype under study. This method proved successful for screening purposes. Researchers were able to identify a salt-tolerant line, introduced originally from ICARDA. The method was used also to study the phenology of certain barley cultivars under naturally salinized field conditions compared with those in non-saline fields. Leaf-area index showed a curvilinear relationship with time under a non-saline environment, whereas under a saline environment, the relationship becomes linear. Other aspects of the improvement program are discussed.

INTRODUCTION

Barley is the second most important crop after wheat in Iraq, in both the northern part (rainfall 200-350 mm) and the central and southern parts (irrigated with Tigris and Euphrates rivers). Both green forage and grain of barley are used in feeding sheep and cattle. In the rain-fed zone, the limiting factor is the amount of precipitation and its distribution throughout the season, *whereas in the irrigated zone the most limiting factor is salinity*. The area planted with barley in the irrigated zone is approximately 400,000 ha, with average productivity of about 1000 kg/ha. Small farmers in these areas practise either direct grazing or clipping (usually when the crop is about 30 cm in height). Big farms usually grow barley for grain.

A number of barley cultivars, old and newly introduced, are grown under irrigation, among which are Arivat, Numar, IPA 99 and others, in addition to some landraces (mostly mixtures) that are adapted to grazing and/or clipping. Most of the area planted with barley is salt-affected. Salt accumulation in these lands is caused mainly by irrigation water and groundwater, as these are the main sources of salts.

According to Mass and Hoffman (1977), barley is classified among the most tolerant crops to salinity. In order for plant breeders to improve plant tolerance to salt, they must have populations with sufficient genetic variability. Genetic variability for salt tolerance is known to exist among cultivars of various crops among

which is barley. Response to salt stress may vary from one stage to another in a given cultivar (Al-Shamma, 1979). However, the barley cultivar "California Mariout", which came originally from Egypt, was found to be tolerant to salinity throughout its life cycle. This makes it a potential genotype to include in any improvement program that aims at developing salt-tolerant lines.

The genetics of salt tolerance is not fully investigated. The few reports available indicate the complexity of the inheritance of this characteristic, at least in barley. This could very well be due to the fact that it is largely affected by the environment. In spite of this, several attempts were made to improve salt tolerance through crossing and selection. A group from California was able to develop a number of barley lines that could complete their life cycle under salinity levels of 70-90‰ seawater. One of these genotypes yielded 1580 kg/ha compared to 2070 kg/ha for the world average (Epstein et al., 1979).

BREEDING EFFORTS

In Iraq, efforts in this respect, i.e., breeding for salt tolerance in barley, were initiated in mid-1980s with the aim of developing new barley lines that could tolerate moderate levels of salinity (15 dS/m) without reduction in yield, using classical breeding methodology, i.e., *crossing and selection*. The program also aimed at conducting some basic research to gain additional knowledge about salt tolerance, which could be employed later to upgrade both practical and applied work. In recent years, another dimension was added to the program, and that is the use of DNA markers as an analytical tool to assist selection.

The breeding scheme involves the selection of parental lines from a collection of germplasm (introduced from ICARDA and CIMMYT) after being screened and evaluated under saline conditions. Crosses are then made between these lines and the cultivar "California Mariout". F1's are planted to get F2's; the latter are bulked to obtain F3's and then F4's. In the F4, generation there are enough seeds for the screening. The F4 populations are then planted in a naturally salinized field (according to a technique devised by the team earlier) for screening and selection. Promising lines that are generated from this plan can then either go directly to multiplication and large-scale testing, or are crossed among themselves, repeating the same cycle once again. The long-term plan involves making a composite cross with the selected parents. This should make a good base for selection.

Screening under Naturally Salinized Field Conditions

During the early days of the program, the responsible team was occupied with testing different methodologies for screening barley genotypes under saline environments. The idea was to devise a proper method with higher accuracy in the detection of variability for salt tolerance. The identification of a genotype with a potential to tolerate a given stress requires that all lines be subjected equally to the stress, otherwise breeding efforts may prove unsuccessful. The response of a given genotype or cultivar may not be consistent from one environment to another. In other words, a promising line selected under a controlled environment may not prove so when transferred to a naturally salinized field. This is because salt tolerance is largely affected by the environment.

Environmental factors such as *temperature* (Francois and Goodin, 1972), *relative humidity* (Hoffman and Jobes, 1987), *soil fertility* (Bernstein et al., 1974), *soil moisture* (Wagenet et al., 1980), *oxygen level* around the plant (Aubertin et al., 1968), and *light* (Nieman and Paulsen, 1971) have all been reported to alter plant response to salinity. Therefore, it would seem logical to have genotypes tested on naturally salinized fields to ensure that all plants are subjected to salinity under variable and changing environmental conditions; after all, the final destination of any recommended cultivar is the farmers field.

There is, however, one major obstacle to accurate identification of truly tolerant cultivars or genotypes, and that is the lack of uniform distribution of salt in the soil. To overcome this problem, a test scheme based on planting frequent check rows alternated with the cultivar under study was proposed. This provides an opportunity for taking more readings in a single plot. The idea is to minimize the experimental error, which may arise from the lack of uniformity of salt concentration in the soil.

An experiment was conducted at two locations in the central region over two growing seasons, 1984/1985 and 1985/1986 (Al-Shamma et al., 1997) of Iraq. The two locations were Fudheiliah Experiment Station, 130 km southeast of Baghdad and Dalmaj Experiment Station (180 km south of Baghdad). At both locations, the experiment sites were selected in fields with soil electrical conductivity ranging from 15 to 25 dS/m. Seven spring barley cultivars were used: "California Mariout" (as a check), CM-67, Numar, Arivat, Clipper, Prior, and Weeah. A total of eight rows, spaced at 20-cm apart, of each cultivar and its check were planted in 3.2 × 4 meter plots. At harvest, 1-m long samples were taken from each cultivar and from its adjacent check at two sites within the plot.

Data on every cultivar were individually and statistically analyzed as unpaired observations with the data of the check cultivar following the procedure devised by Steel and Torrie (1960). Coefficients of correlation among the various characteristics were calculated using

11 data-sets extracted from four different environments. The following are the main findings of this experiment:

1. The cultivars CM-67 and Numar performed as well as the salt-tolerant check cultivar "California Mariout", which is not surprising since both cultivars were bred from crosses involving California Mariout (Arias et al., 1983). These two cultivars exhibited good tolerance to salt as they maintained a stable performance across the four environments.
2. Arivat is considered sensitive to salinity in this study, although an earlier report (Al-Shamma and Sabir, 1986) indicated moderate response when grown in salinized nutrient solution in a controlled environment. This discrepancy may explain the belief that response of plants to salinity *per se* (where all other factors are fixed) differs from their reaction to salinity when grown under variable and changing environmental conditions, i.e., in a naturally salinized field.
3. In general, the reduction in grain yield among the sensitive cultivars (Arivat, Clipper, Prior, and Weeah) is mainly due to a reduction in the number of kernels per head. The other two yield components, number of heads per unit area and 1000-kernel weight, seem to be more stable.
4. Generally, yield component compensation under salinity is not evident. However, two types of relationship are shown: (I) *zero correlation*, when components behave independently, as with number of heads per meter and 1000-kernel weight, and (II) a tendency for *positive correlation*, such as number of kernels per head and 1000-kernel weight.
5. Consistency of relationships among the various characteristics under salinity may vary with data group. Relationships can be classified according to their stability as follows:
 - *Highly stable*. Relationships between number of heads per meter and 1000-kernel weight and grain yield, between number of kernels per head and 1000-kernel weight, and between 1000-kernel weight and grain yield.
 - *Moderately stable*. Relationships between harvest index and grain yield and its components. Also between number of heads per meter and number of kernels per head.
 - *Unstable*. Relationship between number of kernel per head and grain yield.

Since the screening technique in the naturally salinized field was introduced, tens of genotypes were tested. Researchers were able to identify one genotype, which was comparable in salt tolerance with the check California Mariout. This genotype (IPA 7) was even better than the check in other characteristics such as lodging resistance, tillering capacity, and 1000-kernel weight. Moreover, IPA 7 yielding ability under non-saline conditions was much higher than "California

Mariout". The program intends to release this line and to be recommended for cultivation in farms with pre-planting soil electrical conductivity of up to 20-25 dS/m. Productivity of IPA 7 ranged from 3 to 5.5 t/ha at 15 dS/m to 3 dS/m soil electrical conductivities, respectively.

BARLEY PHENOLOGY UNDER SALINE/NON-SALINE CONDITIONS

The naturally salinized field technique was employed to study the phenology of five barley lines, i.e., Numar, Arivat, Prior, IPA 99, and IPA 92, under saline and non-saline environments. The lines were planted alternately with the check "California Mariout" in 4 × 5 meter plots in both sites, saline (EC 15-25 dS/m) and non-saline (EC < 3 dS/m). One-foot long samples were taken from each line and from its adjacent check at two sites within the plot every 20 days. This practice was continued until 140 days after planting.

Results showed that dry matter accumulation (Fig. 1) of all cultivars and the check cultivar California Mariout was reduced under saline compared with that under non-saline conditions. The reduction in the check was relatively lower than in the four cultivars, indicating the superiority of this cultivar in terms of tolerance to salt.

The difference in performance of all cultivars under saline and non-saline environments was more pronounced in terms of leaf area index (Fig. 2). Leaf area index under non-saline environment was about three-fold larger than that under saline environment, especially in the early stages of growth. It is also shown that the relationship of LAI with time is a curvilinear one under non-saline environments, whereas under saline environment the relationship becomes somewhat linear.

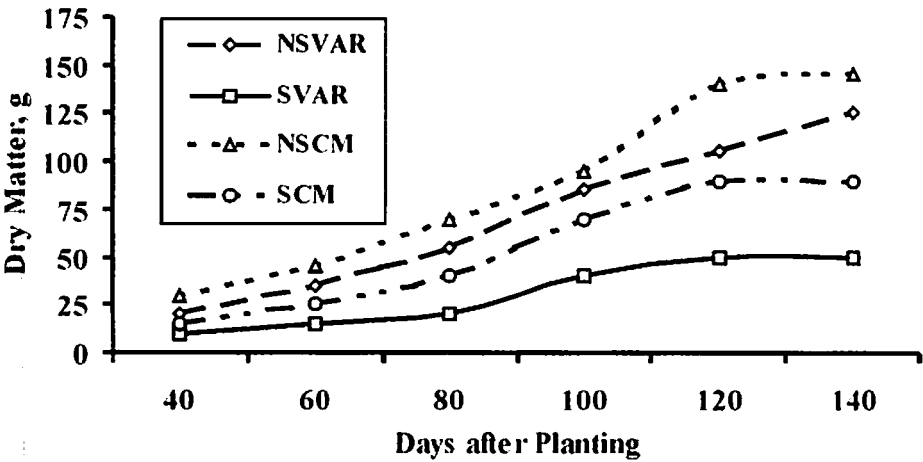


Fig. 1. Dry matter accumulation over time in four barley cultivars compared with the check cultivar California Mariout under saline (S) and non-saline (NS) environments.

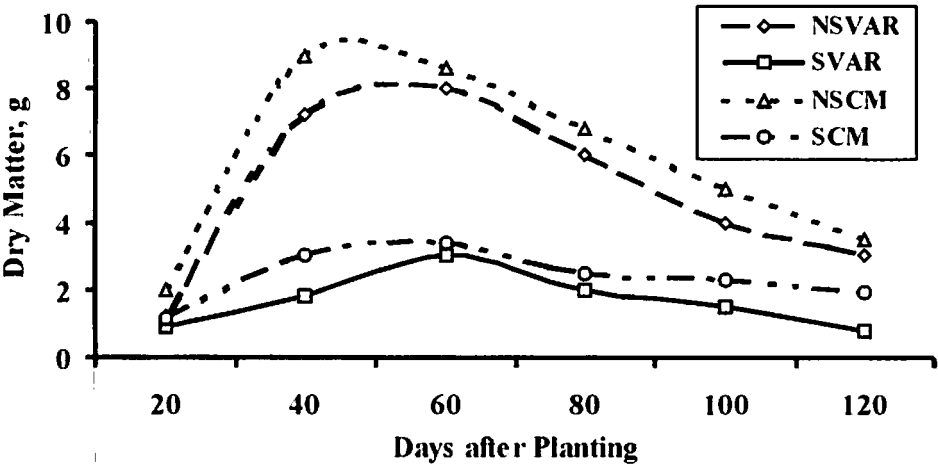


Fig. 2. Leaf area index (LAI) changes over time in four barley cultivars compared with the check cultivar California Mariout under saline (S) and non-saline (NS) environments.

Hulled vs. Hulless Seed

In general, salinity decreases the percentage of germination (Al-Shamma, 1979), lengthens the time of germination, and delays the emergence of seedlings (Donovan and Day, 1969). The reduction and delay in germination might be due to a reduction in the amount and rate of imbibition (Chapman et al., 1978). The latter could be related to the reduced mobility of water in the salinized medium. It has been reported earlier that sodium and chloride ions accumulate in the lemma and palea of barley seeds grown in salinized medium (Al-Shamma, 1982). This type of observation led to the belief that the lemma and palea may play a role in altering the response of barley seeds to salinity. In this regard, an experiment was conducted, in which, the seeds of nine barley cultivars were compared with and without hulls under salinity using NaCl levels of 0, 1.0, 1.5, and 2.0% (Al-Shamma et al., 1985).

The following are the main findings of this experiment:

1. The removal of the hull appears to improve germination percentage and rate of germination. The response is more obvious at higher NaCl concentrations.
2. No effect of the hull removal on seminal root length was observed, indicating that root elongation is independent of the presence or absence of the lemma and palea.
3. Cultivars responded differently to the hull removal. Such variability could be utilized in breeding for improved salt tolerance in barley.

Screening Methodology

An effective approach to screening salt-tolerant plants must take into account that soil salinity varies across the field, i.e. lack of uniform distribution of salt ions in the soil, and that salt tolerance is a polygenic trait; it is largely affected by the environment, e.g., temperature (Francois and Goodin, 1972), relative humidity (Hoffman and Jobes, 1987), soil fertility (Bernstein et al., 1974), soil moisture (Wagenet et al., 1980), oxygen level around the plant (Aubertin et al., 1968), and light (Neiman and Paulsen, 1971). These factors are found to alter response of plants to salinity, in other words, the response of a given cultivar or genotype may not be consistent from one environment to another. Using artificial media under controlled environment may not be adequate. Therefore, an appropriate methodology for the identification of salt-tolerant genotypes must involve screening under naturally salinized fields, where plants are subjected to variable and changing environmental conditions.

REFERENCES

- Al-Shamma, A.M. 1979. A genetic study of salt tolerance in barley (*Hordeum vulgare* L.) M.S. Thesis. Michigan State Univ., USA.
- Al-Shamma, A.M., 1982 Breeding for salt tolerance in barley (*Hordeum vulgare* L.) Ph.D. Dissertation, Michigan State Univ. . USA.
- Al-Shamma, A.M., H.K. Khrbeet, A. Okasha, and S. Saeed. 1985. Role of the hull and different levels of sodium chloride in the germination of some barley cultivars (*Hordeum vulgare* L.) J. Agric. Water Resources Res. 4 (3): 11-24.
- Al-Shamma A.M., and A.A. Sabir. 1986. Performance of barley cultivars under salinization using three different techniques. p. 687-696. In: Proc. Fourth Conf., Scientific Research Council, Baghdad, Iraq. 1986, Vol. 1, Part 2
- Al-Shamma, A.M., B.A. Al-Rawi, and S. Saeed. 1997. Screening barley (*Hordeum vulgare* L.) genotypes for salinity tolerance under naturally salinized field conditions. p. 120 -131. In: N. Haddad, R. Tutwiler, and E. Thomson (Ed.). Improvement of crop-livestock integration systems in West Asia and North Africa. Proc. Regional Symposium on "Integrated Crop-Livestock Systems in the Dry Areas of West Asia and North Africa", 6-8 Nov. 1995, Amman, Jordan. ICARDA, Aleppo, Syria.
- Arias, G., L. Reiner, A. Penger, and A. Mangstl. 1983. Directory of barley cultivars and lines. Eugen Ulmer GmbH, Germany.
- Aubertin, G.M., R.W. Rickman, and J. Letey. 1968. Differential salt-oxygen levels influence plant growth. Agron. J. 60: 345-349.
- Bernstein, L., L.E. Francois, and R.A. Clark. 1974. Interactive effects of salinity and fertility on yields of grains and vegetables. Agron. J. 66: 412-421.
- Chapman, S.R., L. Hart, and B. Nardi. 1978. Rate of imbibition as a tool in screening for salt tolerance. Cereal Res Commune. 6 (3): 241-247
- Donovan, T., and A.D. Day. 1969. Some effects of high salinity on germination and emergence of barley (*Hordeum vulgare* L. emend Lam.). Agron. J. 61: 236-238.
- Epstein, Emanuel, R.W. Kingsbury, J.D. Norlyn, and D.W. Rush. 1979. Production of food crops and other biomass by seawater culture. In: A. Hollaender (Ed.) The biosaline concept, an approach to the utilization of under exploited resources. Plenum Press. New York.
- François, L.E., and J.R. Goodin. 1972. Interaction of temperature and salinity on sugar beet germination. Agron. J. 64: 272-273.
- Hoffman, G.J., and J.A. Jobes. 1978. Growth and water relations of cereal crops as influenced by salinity, and relative humidity. Agron. J. 70: 765-769.
- Mass, E.V., and G.J. Hoffman. 1977. Crop salt tolerance - current assessment. J. Irrig. Drain. Div., 103, 115-134.
- Nieman, R.H., and L.L. Paulsen. 1971. Plant growth suppression on saline media: Interaction with light. Botanical Gazette. 123: 279-285.
- Steel, R.G.D., and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, New York.
- Wagenet, R.J., W.F. Campbell, A.M. Bamatraf, and D.L. Turner. 1980. Salinity, irrigation and fertilization effects on barley growth. Agron. J. 72: 969-974.

Selecting Barley for Drought Tolerance in Jordan's Low Rainfall Areas

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ABSTRACT

An experiment was conducted in Jordan at five locations: Khanasri (150 mm), Ramtha (225 mm), Muwaqar (150 mm), Rabba (350 mm), and Ghweer (250 mm) during the 96/97 growing season, to evaluate yield performance and some of the agronomic traits of 84 barley breeding lines and three long-term checks: Zanbaka, Arta, and Klaxon for drought tolerance. An a-lattice design was used with two replication and six incomplete blocks for each replication.

No grain yield was total obtained at Muwaqar. The genotypes elsewhere were found to differ in their biological, straw, and grain yields, indicating that the necessity to practice selection in the target environment. Genotype No. 6 (WI 2291/Tadmor) was superior in grain and biological yield to the best check (Arta) at the two wettest locations (Rabba and Ghweer). Genotype No. 21 (Mo.B1337/ WI2291/ 5/ Emir.) outyielded others at the driest location (Khanasri) while Genotype 61 (Salmas /Arabi Aswad) produced a higher grain yield than the check (Zanbaka) at Ramtha.

The correlation between grain yield, biological yield, straw yield, plant height, and harvest index was always significant and positive regardless of the location. The correlation between days-to-heading, days-to-maturity and grain yield was significant at the two driest locations only. This would suggest that a different phenology is required to maximize grain yield in the wet and dry environments. Also, the relationship between grain yield and the length of grain-filling period was positive in the wettest location (Rabba), negative in the driest Khanasri and not significant at the two intermediate locations.

These results emphasize the importance of selection in the target environment and show the necessity to develop early-maturing genotypes as a way to escape from drought and high temperatures during grain-filling period. Combined analysis showed that genotypes differed in their genetic potential for grain yield. There was also a high significant variety $\times$ location interaction, but less than that of variety, indicating that there were consistent location effects for differential variety responses.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is a widely adapted and important crop in Jordan. In the dry areas it grows under low soil fertility levels and moisture-stress

conditions where wheat performs poorly or fails to survive. It is grown for food, feed, malt, or grazing. In addition, under stresses such as drought and cold, the yield of barley is much higher than that of oat, wheat, or rye (Chapman and Carter, 1976).

During the period 1990 to 1997 the average barley harvested area in Jordan was 57,300 ha. The average productivity was about 880 kg/ha, while the average productivity in major regions of the world was about 2650 kg/ha. Therefore, research is needed to increase the productivity of barley per unit area in Jordan. Increasing water limitation is one of the most serious constraints which severely decrease grain yield in many cereal-growing regions, and the resulting fluctuations in world food and feed supply have serious repercussions, particularly on rural poor.

Therefore, attempts have been made by agronomists, plant breeders, and physiologists to improve growth, productivity, as well as stability of production by increasing agronomic production technology, studying varietal characteristics that may enable cereals to yield more consistently under drought-prone environments, and evaluating and selecting more suitable and drought-tolerant cultivars. Productivity could be increased by better agricultural practices and by improving the genetic make-up of plants. The objective of barley breeding in dry areas is yield as well as to improve yield stability. Yield is considered as total biological yield (grain + straw) since, in most dry areas, the barley crop is used for grazing by sheep in the field or harvested for animal feed.

Because drought resistance cannot yet be defined physiologically, grain yield and yield stability under environmental stress remain a major selection criteria for stress tolerance in many breeding programs (Bruckner and Frohberg, 1987). Ketata (1987) concluded that seasonal rainfall is one of the most important factors affecting yields in the dryland areas of North Africa and Middle East. Due to seasonal rainfall in areas with precipitation between 133-454 mm, great differences in grain yield were reported. He also concluded that 11-19 kg/ha of grain yield has being produced for each additional millimeter within the range mentioned above.

The most widely used selection criteria for high and stable performance are mean yields, regression response on-site mean yield, and deviations from regression (Nurminiemi et al., 1996). Finlay and Wilkinson (1963) described stability of genotypes in terms of linear regression of genotype means over

environmental means. They proposed that regression coefficients approximating 1.0 indicate average stability, while regression values increasing above 1.0 describe varieties with increasing sensitivity to environmental change, and greater specificity of adaptability to high-yielding environments. Regression coefficients below 1.0 provide a measure of greater resistance to environmental change, and therefore increasing specificity of adaptability to low-yielding environment.

Genotype-environment (GE) interaction exists whenever the differences between a number of genotypes change with changes in the environment. The presence of high GE interaction complicates breeding work because it makes it difficult to predict how genotypes selected under a given set of conditions will perform in a different set of conditions (Ceccarelli, 1989).

A drought-susceptibility-index (DSI), which provides a measure of stress resistance based on minimization of yield loss under stress as compared to optimum conditions rather than on yield level under stress *per se*, has been used to characterize relative drought tolerance (Fischer and Maurer, 1978; Bruckner and Froberg, 1987; Ceccarelli, 1987). The DSI index was high negatively correlated with grain yield at the driest sites, indicating that larger yields were associated with higher levels of drought tolerance or with higher stability (Ceccarelli, 1987).

Low-rainfall areas are characterized by a high year-to-year variability. Therefore, almost half of the area where barley is grown is a high-risk area, where crop failures are common and affect resource-poor farmers who have little or no other options but barley. Consequently, the development of barley genotypes that have greater stability and ability to produce substantially higher yield in the presence of drought stress is the most economic solution. Therefore, the objectives of this study were to evaluate 84 genotypes for drought tolerance and assess the stability of barley genotypes in Jordan.

MATERIALS AND METHODS

Barley breeding lines or entries (71 two-row and 13 six-row), covering a wide range of genotypic variation were sown for one season, 1996/97. All lines were obtained from the International Center for Agricultural Research in the Dry Areas (ICARDA). The entries contained Australian genotypes adapted to terminal drought stress, Syrian and Jordanian landraces, lines from the barley-breeding program at ICARDA, and European cultivars. The five sites in Jordan, differing in mean annual precipitation, were:

- **Muwaqar:** It is located about 30 km southeast of Amman and 14 km east of Muwaqar Village. This station lies at 31° 84' N latitude and 36° 06' E longitude, with an elevation of 928 m above sea level. The climate of this area is arid, with an average annual rainfall of 150 mm. The soil type is a silty clay loam with obvious surface crust formation due to its poor structural stability; the soil has low

organic carbon content, poor aggregation, high silt content, and strong surface (Taimch, 1988).

- **Ramtha:** It is located about 10 km south of Ramtha city in north Jordan at 32° 46' N and 33° 45' E, with an elevation of 590 m above the sea level. The climatic conditions are characterized by cold winters and hot summers, with an average annual rainfall of 225 mm. The soil of this station is a silty clay.
- **Ghweer:** It is located about 10 km southeast of Karak city in south Jordan at 31° 14' N and 35° 45' E, with an elevation of 820 m above sea level. The climatic conditions are characterized by cold winters and hot summers, with an average annual rainfall of 250 mm. The soil type at this station is a silty clay.
- **Khanasri:** It is located about 25 km southeast of Ramtha city. This station lies at 32° 24' N and 36° 03' E, with an elevation of 860 m above sea level. The climatic conditions are characterized by cold winters and hot dry summers with an average annual rainfall of 150 mm. The soil type is a silty clay.
- **Rabba:** It is located about 20 km north of Karak city in south Jordan at 31° 16' N and 35° 45' E, with an elevation of 870 m above sea level. The average annual rainfall is about 325 mm. It is the most favorable of the five sites. The soil type at Rabba is a heavy clay (Vertisol).

Planting Methods

In all locations, the soil was plowed twice using the chisel plow, and the planting rows were opened by hand. The seeds from each genotype were planted in two rows 2.5 m long with 30 cm spacing. At Ghweer and Rabba, a diammonium phosphate fertilizer was added before planting at a P_2O_5 rate of 5 kg/du (2.3 kg P/du). Experiments were sown between 17 and 27 November 1996. The planting dates were Nov. 17, 20, 23, 25, and 27 at Rabba, Ramtha, Ghweer, Muwaqar and Khanasri, respectively.

Daily maximum and minimum temperatures and rainfall were recorded during the growing season, with the exception of Khanasri station where temperatures were not taken because a thermometer was not available.

The experimental design used was an α -lattice design with two replications and six incomplete blocks for each replications, with each block contained 14 entries. Each replication contains 84 entries (treatments), and the total number of plots were 168 ($6 \times 14 \times 2 = 168$). Three long-term checks were used these were: Arta, Klaxon, and Zambaka.

The following agronomic characteristics were recorded: Days-to-heading, days-to-maturity, grain-filling period (days), plant height (cm), grain yield (g/plot), biological yield (g/plot), harvest index, straw yield (g/plot), and stability parameters; the generalized formula proposed by Eberhart and Russell (1966) was

used as an estimate of stability of grain yield of genotypes, in which

$$Y_{ij} = \mu_i + \beta_{ij} + \delta_{ij}$$

Where: Y_{ij} is the variety mean of the i th variety at the j th environment, μ_i is the mean of the i th variety over all environments, β_i is the regression coefficient that measures the response of the i th variety to varying environments, δ_{ij} is the deviation from regression; and I_j is the environmental index obtained as the mean of all varieties at the j th environment minus the grand mean.

The regression coefficient or slope (b) is the measure of varietal response to change in an environment. The coefficient of determination (r^2) gives a measure of the amount of variation which is expressed by the linear regression over environments. Drought susceptibility index (DSI) was used to characterize each genotype in the stress environments. The index was calculated using the generalized formula (Fisher and Maurer, 1978): $S = (1 - Y_D/Y_P)/D$, where Y_D and Y_P were mean grain yield in drought (Khanasri) and non-drought (Rabba) sites, respectively; and $D = \text{environment stress intensity} = 1 - (\text{mean } Y_D \text{ of all genotypes} / \text{mean } Y_P \text{ of all genotypes})$.

Statistical Analysis

Analysis of variance was performed for each measured or scored character according to Patterson and Williams

(1976) and Cochran and Cox (1992) using the spreadsheet QPPO. The least significant difference (LSD) mean separation was used to assess the differences in adjusted means. Correlation coefficients were calculated to assess the interrelationships among different plant characters for each location except Muwaqar, because no grain was obtained there. Regression analysis was used to estimate stability of grain yield as described above.

RESULTS AND DISCUSSION

Grain Yield

Statistical analysis for grain yield at Rabba showed significant differences among the genotypes (Table 1). Genotype No. 6 (WI2291/ Tadmor) ranked first in grain yield (536 g/plot) and 71 (Avt/ Attiki/ Aths) the lowest (112 g/plot) (Table 2). WI2291/ Tadmor is derived from the cross between WI2291 (a pure line improved from Waite Agricultural Research Institute in Australia) and Tadmor (developed at ICARDA by pure-line selection from the local landrace Arabi Aswad). There are 15 sister lines of WI2291/ Tadmor obtained by SSD from the same cross. (WI2291/ Tadmor) outyielded the best check (Arta) by 49%. The average grain yield at Rabba was 289.6 g/plot (ranging from 536.6 to 112.9 g/plot).

At Khanasri, there were also significant differences between genotypes. Genotype No. 21 (Mo. B1337/WI2291/5/Emir.) had highest yield (164.7 g/plot), whereas genotype No. 18 (Rihane 03/3/Harma) had the lowest grain yield (31.2 g/plot). Genotype No.

Table 1. Summary of the statistical significance of grain yield and some traits of 84 barley lines tested at four locations.

Traits	Rabba	Khanasri	Ghweer	Ramtha
Grain yield	**	**	NS	**
Biological yield	*	**	**	**
Straw yield	NS	NS	**	**
Plant height	**	**	**	**
Harvest index	*	**	**	**
Days-to-heading	**	**	*	**
Days-to-maturity	**	**	**	**
Grain-Filling period	**	**	**	**

*, **Significant at 0.05 and 0.01 probability levels, respectively; NS, not significant.

Table 2. Mean Crop Parameters at four contrasting locations in Jordan.

Traits	Rabba	Khanasri	Ghweer	Ramtha	Mean
Grain yield (g/plot)	289	95	154	129	167
Biological yield (g/plot)	994	423	807	639	716
Straw yield (g/plot)	705	327	653	509	548
Plant height (cm)	59	33	47	56	49
Harvest index (%)	29	22	19	21	23
Days-to-heading (days)	118	110	85	128	110
Days-to-maturity (days)	152	137	113	155	139
Filling period (days)	31	24	26	24	26

*Data are the means of 84 barley lines during 1996/97 growing season.

21 outyielded the best check (Arta) with an increase of 39.8%. This line is a good promising line because of high grain yield under the driest location, which suffered severe drought conditions. The average grain yield at Khanasri was 95.9 g/plot (ranging from 164.7 to 31.2 g/plot).

At Ghweer, Genotype No. 6 (WI2291/ Tadmor) ranked first (321.2 g/plot), while genotype No. 37 (Morocco 9-75/Arabi Aswad/H. Spont. 41-1) had the lowest grain yield (51.8 g/plot). WI2291/Tadmor also ranked first at Rabba. Therefore, this line showed a good performance in high-yielding sites (responds well to favorable conditions). Genotype No. 6 produced more grain than the best check (Arta), with an increase of 131.4 g/plot or (69.2%). The average grain yield in Ghweer was 154.0 g/plot (ranging from 312.2 to 51.8 g/plot).

At Ramtha, there were significant differences among the genotypes. Genotype No. 61 (Salmas/Arabi Aswad) had the heights grain yield (261.1 g/plot) and No. 25 (Klaxon) the lowest (35.5 g/plot) (Table 2). Genotype No. 61 out yielded the best check (Zanbaka) with an increase of 22.7 g/plot or (11.7%). Average grain yield in Ramtha was 129.5 g/plot (ranging from 216.1 to 35.3 g/plot).

At Muwaqar, no grain yield was obtained. Crop failure was due to the following factors: (1) Total amount of rainfall was 139.5 mm, this quantity is less than the crop requirements as noticed by Arar (1985) and Arnon (1972); (2) Poor distribution of the rainfall (more than 34% of precipitation was received during the month of November); (3) Crust formation at the soil surface which is the main feature of the Muwaqar area; and (4) moisture stress with low temperatures caused delay and poor emergence;

The ranking of grain yield among locations showed that Rabba ranked first and was followed by Ghweer, Ramtha, and Khanasri. The location means were 289.6, 154.0, 129.5 and 95.9 g/plot, respectively (Table 2). The average grain yield in wettest location (Rabba) was almost three times greater than the driest one (Khanasri). Low grain yields obtained at Khanasri and Ramtha were due to low temperatures (frost) when the crop was at full-heading stage, and drought conditions prevailed at filling and maturity, while at Rabba and Ghweer, the total amount of rainfall was high and the frost wave occurred when the crop was at late stem-elongation stage.

The overall mean across the four locations was about 167.3 g/plot. Genotype (6) (WI2291/ Tadmor) was the highest in grain yield, followed by Genotype No. 61 (Salmas/Arabi Aswad) while, the Genotype 48 had the lowest grain yield.

Correlation: Grain Yield and Agronomic Traits

At Rabba, grain yield was significantly correlated with total biological yield ($r = 0.79^{**}$). This is expected where more assimilates available to grain development are associated with more vegetative growth; this shown

by genotype No. 6 (WI2291/ Tadmor), which produced more biological yield and more grain yield. Grain yield was correlated significantly and positively with straw yield, harvest index and filling period ($r = 0.60^{**}$, 0.53^{**} and 0.22^{*}) respectively. This result agreed with Acevedo et al. (1991). Also, a positive but not significant correlation was found between grain yield and days-to-maturity ($r = 0.13$).

Khanasri, correlation coefficients revealed significant positive association between grain yield and harvest index, biological yield, straw yield, and plant height; this agrees with those by Gomma (1990) and Sarfraz et al. (1990). Grain yield showed a highly significant negative correlation with days-to-maturity, days-to-heading and length of grain-filling period. The negative association between earliness and yield is shown by Genotype No. 25 (Klaxon), which was the lowest in days-to-heading (117 days) and produced less grain yield (34.5 g/plot).

So, earliness is a very important character under low-rainfall conditions, as shown by Ceccarelli and Grando (1991), Hadjichristodoulou (1974), and Van Oosterom and Acevedo, (1992). At Ghweer, grain yield was strongly and positively correlated with biological yield, harvest index and plant height. Genotype (6) (WI2292/ Tadmor) as observed at Rabba, produced more biological and grain yield.

At Ramtha, harvest index and biological yield were strongly correlated with grain yield ($r = 0.76^{**}$, and 0.63^{**} , respectively). Also, grain yield was significantly correlated with plant height ($r = 0.22^{*}$). Days-to-heading and days-to-maturity were strongly and negatively correlated with grain yield ($r = -0.39^{**}$ and -0.47^{**}). This result supports the importance of earliness under drought conditions, as observed by many researchers (Blum, 1988; Acevedo et al., 1991).

Variation of Correlation Coefficients with Locations

The correlation between grain yield, biological yield, straw yield, plant height and harvest index was always significant and positive regardless of the locations. The correlation between days-to-heading, days-to-maturity, and grain yield was significant at the two driest locations only. This would suggest that a different phenology is required to maximize grain yield in the wet and dry environments. This is even clearer looking at the relationship between grain yield and length of grain-filling period, which was positive in the wettest location (Rabba), negative in the driest (Khanasri) and not significant in the two intermediate locations (Ghweer and Ramtha).

Stability Parameters Estimates

Stability of yield is defined as the ability of a genotype to avoid substantial fluctuation in yield over a range of environments. Variance component estimates from combined analyses for the grain yield were significant

for varieties, indicating that genotypes differed in their genetic potential for grain yield. This result is in accordance with Campbell and Lafever (1977) and Liang et al. (1966). There were also a high significant variety $\times$ location interaction, which indicates that there was consistent location effects for differential variety responses. The large variance components for variety $\times$ location interactions were expected since the environmental conditions among locations were widely different. These results are in agreement with those observed by Rasmussen and Lambert (1961) and Campbell and Lafever (1977).

The generalized formula proposed by Eberhart and Russell (1966) was used as an estimate of stability in grain yield. An environmental index (*I_j*), which is the deviation of the location mean from the overall mean (grand mean), was calculated. For Rabba, *I_j* was 122.33 and -71.43 for Khanasri, while Ghweer was -13.22, and Ramtha -37.77. The mean yield of each genotype was then regressed upon the environmental index to estimate two stability parameters: regression coefficient (*b*), and standard deviation from the regression (*S²di*).

Based on mean yields, unit regression coefficient (*b* $\approx$ 1), and deviation from regression (*S²di*) small as possible, four genotypes were classified as high stability or wide adaptability (Table 3). These were: Genotype 7 (W12291/Tadmor), No. 12 (W12291/Tadmor), No. 17 (W12291/ Tadmor) and No. 52 (Zanbaka /5/Pitayo/Cm//Art...). Genotypes No. 7, No. 12 and No. 17 are sister lines. Generally, Genotypes with small "b" showed a low mean yield, while genotypes with greater "b" showed a high mean yield. This result is in agreement with that observed by Eberhart and Ressel (1966), Jowett (1972), and Keim and Kronstad (1979).

used to estimate relative drought tolerance of the 84 barley genotypes. Rabba was considered as a high-yielding site or potential yield (*Y_p*) and Khanasri as low yielding or drought yield (*Y_D*). Drought intensity ($(1-X_D/X_P)$) was 0.66.

The variation in drought susceptibility index among genotypes was significant, and the means values were ranged from 0.55 for genotype No. 80 (Zanbaka//Harmal-02/Lignee/3/) to 1.33 for genotype No. 54 (CI 07117-9/Deir Alla/06....). Since smaller mean value of DSI indicates drought tolerance, genotype No. 80 (Zanbaka//Harmal-02/Lignee/3/) (DSI= 0.55) was the most tolerant genotype followed in order by No. 23 (W12197/CI/3520//SLB39-60) (DSI = 0.59), No. 5 (W12291/Tadmor) (DSI = 0.65), No. 51 (Morocco 9-85/Arabi Aswad//JLB37-66) (DSI = 0.68) and No. 35 (OP//DL 71/Strain...) (DSI = 0.68).

The small DSI values of these genotypes indicating that percentage reduction in grain yield due to drought compared with grain yield under favorable condition (yield potential) was low. While, Genotype No. 54 (CI 07117-9/Deir Alla/06....) (DSI = 1.33) followed by No. 81 (RihaneI - 3/3/Harma -20....) (DSI = 1.32), No. 69 (Rihane//Bc/Coho/3/Deir Alla/06....) (DSI=1.29) No. 74 (M126/CM67// As...) (DSI = 1.27) and No. 68 (Rihane-03/3/Harma-02....) (DSI = 1.24), were the most drought susceptible genotypes.

REFERENCES

Acevedo, E., P.Q. Craufurd, R.B. Austin, and P. Perez-Marco. 1991. Traits associated with high yield in barley in low-rainfall environments. *J. Agric. Sci. Camb.* 116: 23-36.

Table 3. Genotype mean grain yield (Y), regression coefficient (b), standard deviation from regression (S²di), and coefficient of determination of ten genotypes (r²).

Genotype Name / No.	Y	b	S ² di	r ²
		-----g/plot-----		
(7) W12291/ Tadmor	221	1.2	2.0	0.99
(12) W12291/ Tadmor	158	0.90	2.3	0.99
(17) W12291/ Tadmor	191	0.99	8.9	0.99
(52) Zanbaka/5/Pitayo....	169	1.05	10.5	0.99
(78) Aths/Lignee 686/3/...	142	0.44	72	0.28
(10) SLB39 - 10	148	0.63	8.38	0.98
(20) SLB 39 - 60	102	0.62	14.1	0.96
(6) W12291/ Tadmor	285	2.2	55.2	0.94
(22) SLB 45 - 95/3/...	184	1.75	52.7	0.92
(42) Arta/3/ER/APM...	196	1.71	35.0	0.96

Drought-Susceptibility-Index

Based on relationship of the relative yield reduction ($(1-Y_D/Y_P)$) of an individual genotype to the mean relative yield reduction of all genotypes ($(1-X_D/X_P)$), DSI was

Blum, A. 1988. Plant breeding for stress environments. CRC Press, Inc. Florida.

Bruckner, P.L., and R.C. Frohberg. 1987. Stress tolerance and adaptation in spring wheat. *Crop. Sci.* 27: 31-36.

- Campbell, L.G., and H.N. Lafever. 1977. Cultivar by environment interactions in soft red winter wheat yield tests. *Crop. Sci.* 17: 604-608.
- Ceccarelli, S., S. Grando, and J.A.G. Van Leur. 1987. Genetic diversity in barley landraces from Syria and Jordan. *Euphytica* 36: 389-405.
- Ceccarelli, S. 1989. Wide adaptation: How wide? *Euphytica* 40: 197-205.
- Ceccarelli, S., and S. Grando. 1991. Environment of selection and type of germplasm in barley breeding for low-yielding conditions. *Euphytica* 57: 207-219.
- Chapman, S.R., and L.P. Carter. 1976. Crop production principles and practices. W.H. Freeman and Co., San Francisco, USA.
- Cochran, W.G., and G.M. Cox. 1992. Experimental designs, 2nd edition. John Wiley and Sons. New York.
- Eberhart, S.A., and W.A. Russell. 1966. Stability parameters for comparing varieties. *Crop Sci.* 6: 36-40.
- Finlay, K.W., and G.N. Wilkinson. 1963. The analysis of adaptation in plant-breeding programme. *Aust. J. Agric. Res.* 14: 742-754.
- Fischer, R.A. and Maurer. 1978. Drought resistance in spring wheat cultivars. I: Grain yield response. *Aust. J. Agri. Res.* 29: 897-912.
- Gomma, F.G. 1990. Association of some morphological characters with barley grain yield under dryland conditions in Libya. *Rachis* 9(1): 8-9.
- Hadjichristodoulou, A. 1974. Breeding barley for drought tolerance. p. 369-383. In: *Proc. First FAO/SIDA Seminar on "Improvement and Production of Field Feed Crops for Plant Scientists from Africa and Near East"*, Cairo.
- Jowett, D. 1972. Yield stability parameters for sorghum in East Africa. *Crop Sci.* 12: 314-317.
- Keim, D.L., and W.E. Kronstad. 1979. Drought resistance and dryland adaptation in winter wheat. *Crop Sci.* 19: 574-576.
- Ketata, H. 1987. Actual and potential yields of cereal crops in moisture-limited environments. p. 55-61. In: J. Srivastava et al. (Ed.) *Drought tolerance in winter cereals*. ICARDA. John Wiley and Sons Ltd.
- Liang, H.L., E.G. Heyne, and T.L. Walter. 1966. Estimates of variety by environmental interactions in yield tests of three small grains and their significance on the breeding programs. *Crop Sci.* 6: 135-139.
- Levit, J. 1980. Water stress, dehydration, and drought injury. In: J. Levitt (Ed.), *Response of plants to environmental stress*. Academic Press. New York.
- Nurminiemi, M., A. Bjørnstad, and O.A. Rognli. 1966. Yield stability and adaptation of Nordic barleys. *Euphytica* 92: 191-202.
- Patterson, H.D., and E.R. Williams. 1976. A new class of resolvable incomplete block designs. *Biometrika* 63: 83-92.
- Rasmussen, D.C., and J.W. Lambert. 1961. Variety by environment interaction in barley variety tests. *Crop Sci.* 261-262.
- Sarfraz, A., J.D.H. Keatinge, B. Roidar Khan, and A. Asghar. 1990. Evaluation and selection of barley lines for the Baluchistan highlands, Pakistan. *Rachis* 9(1): 5-7.
- Taimah, A.Y. 1988. Agriculture production in the semi-arid to arid land and areas suffering from desertification. University of Jordan Press. Amman.
- Van Oosterom, E.J., and E. Acevedo. 1992. Adaptation of barley (*Hordeum vulgare* L.) to harsh Mediterranean environments. *Euphytica* 62: 29-38.

Ethylene in Tomato: Yield and Ripening

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ABSTRACT

Tomato (*Lycopersicon esculentum* Mill.) plants, cv. Castle Rock, were flower sprayed with 100-ppm ethrel, 0.5 mM AOA (aminooxyacetic acid) or water (control) 2 days after anthesis. Fruit period of cell division (CD) was extended up to 16-18 days after anthesis with ethrel application, but reduced from 10-12 days (control) down to only 6-8 days with AOA application.

In an opposite trend to AOA application, fruits receiving ethrel treatment were of higher ethylene and ACC (1-aminocyclopropane-1-carboxylic acid) levels than the control. This was noticed not only during the first 2 weeks after anthesis, but also during fruit climacteric phase. Misocarp cells of ethrel-treated fruits were greater in number/mm², but smaller in size than the control while an opposite trend was obtained with AOA application. This was observed for a period of 18 days after anthesis. Only by that time or at earlier ages, fruits of AOA treatment were larger in size and heavier than control, and both were larger and heavier than ethrel-treated ones.

Five weeks after anthesis, and thereafter, fruit response to all treatments was totally reversed since early ethrel-treated fruits became significantly larger in size and heavier with ripening delay by about 10 and 15 days than those of control and AOA-treated ones, respectively. When the same treatments were applied to the whole plant, similar results were obtained, since early ethrel application increased fruit yield by about 15% over control with a pronounced ripening delay, while an opposite trend was obtained with AOA application. No significant differences were found among treatments in terms of flower or fruit abscission or fruits number/plant.

The data suggest that ethylene regulates tomato fruit transmission from CD to cell enlargement (CE). In addition, fruit CD is terminated only when endogenous ethylene decreases to its basal level allowing CE to dominate and proceed, as in the case of early AOA application. The ripening delay of ethrel-treated fruits may be due to the longer time required for the increased cell numbers to reach maturation. Low level of ethrel application at tomato early-fruitletting stage may be used for increasing fruit yield through increasing fruit size and consequently its quality.

INTRODUCTION

During its ontogeny, tomato fruit passes through certain developmental stages. First and directly after set, fruit passes through a short period of growth characterized by a slow rate. This slow rate of growth during such very early period due entirely to the dominant process of CD (Davies and Cooking, 1985; Gillaspay et al., 1993). Fruit then passed through a long period of rapid growth as fruit cells transmit to the stage of CE (Iwahori, 1967, Nitsch and Nitsch, 1961). The length of such rapid growth period is strongly controlled by either cultivar or environmental factors (Lacheene, 1990). The third developmental stage then occurs and lasts for about 2 additional weeks of a slow growth rate by which the fruit gains little more weight and reaches maturity (Abdel-Rahman, 1977). Two or three days later, fruit ripening is initiated (Atta-Aly et al., 1992).

These facts strongly indicated that tomato fruit growth pattern follows a single sigmoid growth curve (Rhodes, 1980). This may also lead to the demonstration that the ultimate size of tomato fruit is determined during its very early stages of development (Houghtaling, 1935). The extent and relative importance of CD and expansion may, therefore, play a pivotal role, as key factors, in controlling not only tomato fruit size and shape, but also fruit total yield.

Ethylene, as a plant hormone, is produced by many fruits even during their early stages of growth and development (Atta-Aly, 1988; Burg and Burg, 1965). It was thought that this early production of ethylene is responsible for young fruit abscission until Maxie and Crane (1968) revealed that the increased level of ethylene produced by young fig fruit was the reason behind early fruit growth. It was then believed that ethylene might have major and significant roles in fruit development during its ontogeny. The increased levels of ethylene production during fruit early stages of development was observed in many fruit species, including tomato (Abdel-Rahman, 1977; Atta-Aly, 1988; El-Beltagy et al., 1976), sycamore, fig (Maxie and Crane, 1968), peach (Looney et al., 1974), and apple and cherry (Blanpied, 1972).

In tomato, the early peak of endogenous ethylene occurred during the very early stage of fruit development, shortly followed by a gradual decrease, reaching a stable low level until ripening onset, when another increase occurs with the beginning of climacteric rise (Abdel-Rahman, 1977; Atta-Aly, 1988; El-Beltagy et al., 1976). The same trend was also found regarding tomato fruit content of ACC (Atta-Aly, 1988) as an immediate ethylene precursor (Adams and Yang, 1979).

It has been reported that exogenous ethylene application induced CD in potato tubers (Ilker et al., 1977), pine (Barker, 1979) and aquatic plants (Metzer, 1984) as well as CE in rice (Ku et al., 1970; Smith and Robertson, 1971), aquatic plants (Metzer, 1984) and fig fruits (Maxi and Crane, 1968). In pea apex and root (Apelbaum and Burg, 1972) as well as fig fruit (Maxi and Crane, 1968), however, exogenous ethylene application depressed only CD, but increased CE. Increasing or inhibiting ethylene levels at a certain developmental stage may therefore be used as a tool for magnifying or modifying fruit growth pattern.

This present work, therefore, was designed to study the impact of modifying tomato fruit ethylene level during its very early developmental stages on fruit CD and consequently final fruit size, ripening and yield.

MATERIALS AND METHODS

Plants

Tomato (*Lycopersicon esculentum*, Mill. cv. Castle Rock) seeds were sown in foam trays filled with a mixture of peatmoss and vermiculite (1:1 volume) on March 1, 1994 and 1995, for the first trial, and on March 17, 1995 and 1996, for the second trial. Trays were then kept under unheated greenhouse conditions at Shalakan Farm, Faculty of Agriculture, Ain Shams University, Egypt. One tray was sown 15 days ahead to serve as an indicator for monitoring seedling water needs in the greenhouse, as well as plant flowering dates and other fruit development stages in the field.

During soil preparation, the experimental field of each trial was designed as a complete randomized blocks in four replicates, each of 42 m² in area. Thirty-day-old seedlings were transplanted 50 cm apart in 7.5-m long rows of 80 cm width with a capacity of 7 rows / replicate. All agricultural management practices were then carried out as usually recommended for tomato production in the open field.

Treatments

When flowers of the first cluster reached their maximum blooming, they were tagged. Tagging was also carried out for the subsequent blooming clusters continuously for a period of 2 weeks (the last 2 weeks of May and the first 2 weeks of June for the first and second trials, respectively). This was carried out to ensure enough fruits required during the first trial for different laboratory analysis, particularly during the early stages of fruit development, or for calculating the percentage of abscised flowers during both trials.

In the first trial, tagged flowers were sprayed at early morning with distilled water (control), 100 ppm C₂H₄, or with 0.5 mM AOA, until the solution runoff the flowers. These treatments were conducted 2 days after tagging (anthesis), which is the approximate time for tomato fruit set (El-Beltagy et al., 1976). The same treatments were carried out during the second trial, but the freshly prepared solutions were used for spraying

the whole plant one week after the anthesis of the first cluster's flowers.

While fruits of the first trial were periodically harvested and analyzed in four replicates throughout the subsequent stages of fruit development, fruits of the second trial were left for recording flower or fruit abscission, fruits number / plant, fruit average weight and total fruit yield.

Flowers or Fruits Abscission

Using randomly selected 10 plants in each replicate, fruits and the previously rung paper labels (flowers) were counted 3 weeks after tagging, and the percentage of abscised flowers and fruits was calculated in both trials. In the first trial, plants selected for abscission recording were left without fruit sampling.

Fruit Analysis

Fruit Fresh Weight

Fruits were harvested with calyx attached throughout the whole period of fruit development, starting 2 days (6 h after application) up to 55 days after anthesis. Fruits were harvested and directly weighed every other day during the first 12 days, followed by 6-day intervals during the subsequent 18 days and then every 5 days until fruits reached 53-days old (55 days after anthesis). Ten fruits were used in each replicate for measuring average fruit weight during the first 12 days. This number was reduced to four fruits/ replicate during the subsequent stages (18-55 days after anthesis) of fruit development.

Fruit Dry Weight

After fresh weight recording, the same fruits were exposed to 70°C / 72 h and re-weighed again for determining average fruit dry weight. Fruit fresh and dry weights were then recorded in grams.

Fruit Diameter

Ten days after anthesis, 15 fruits were re-tagged in each replicate, using labels of colored paper. These fruits were then used, while attached, for measuring fruit diameter development, following the same age order of the fruit as previously described in fruit fresh weight measurements. The first 8 days after anthesis were excluded in this analysis due to the minute differences between treatments.

Ethylene and ACC Sampling and Analysis

Following the same sampling procedures and capacity previously described for fruit fresh weight recording, fruits were harvested at the same ages and divided into two equal groups. Fruits of the first group were incubated for ethylene analysis, while those of the second group were immediately dipped in liquid nitrogen and then kept at -20°C for ACC analysis.

For ethylene analysis, fruits younger than 22-days old were placed, immediately after harvesting, inside 225-mL glass vessels, while older fruits were incubated inside 375-mL glass jars. The incubating containers were directly sealed and transferred to the Horticultural Department of the above-mentioned institute. One-mL gas samples were withdrawn, after an incubation period of 4 h, from the incubator headspace and injected into a Varian 6000 gas chromatograph for ethylene analysis. Data were then recorded as nL of C_2H_4 / g. h.

Frozen fruit tissues (2-g samples) were homogenized in 10-mL TCA (trichloroacetic acid) for ACC analysis using a mortar and pestle (a little washed silica sand was used to assist the grinding). The mixture was centrifuged at 7000 rpm for 10 min. The supernatants were decanted and the aliquots were assayed for ACC using the procedure of Atta-Aly et al. (1987) as a modified version of Lizada and Yang (1979). Data were then recorded as nM / g.

Anatomical Measurements

Tomato fruits were harvested 6, 9, 12, 15 and 18 days after anthesis. Triangular pieces from the middle portion of fruit pericarp tissues were cut into transverse sections using a shaving stainless steel blade and immediately immersed in killing and fixing solution FAA (Formalin 5 mL, acetic acid 5 mL, and 90 mL 70% ethyl alcohol). The normal procedures of paraffin method technique (Johansen, 1940) was followed. Sections of paraffin-embedded samples were obtained using a rotary microtome. Transverse sections of 10-12 microns were fixed on microscopic slides by means of albusol adhesive (Sass, 1951). Staining was attained using a double combination of saffranin and light green. Sections were then mounted in Canada balsam. Photomicrographs were then obtained using a camera mounted on CARLZEISS (Jena) microscope. Using micrometer slides, cell numbers, as well as enlargement, were examined and calculated.

Cell numbers of the mesocarp were estimated in one mm². Using five randomized replicates of the external mesocarp (distance between exocarp and vascular bundles), cell numbers was calculated. The same procedure was also used to estimate cell numbers of the internal mesocarp (distance between vascular bundles and internal epidermis). For CE, measurements, 20 randomized cells were measured at the maximum cell length, using different loci of external and internal mesocarp.

Days to Reach Red-Ripe Stage

This was calculated in days starting 2 days after tagging (fruit set) until fruits reached red-ripe stage using the same 10 plants used for recording flower abscission and left without fruit sampling.

Fruit Yield

With ripening initiation, fruits of the second trial were harvested at weekly intervals. At each harvest, fruits of each replicate were counted and weighed. At experiment termination, average fruit weight (g), fruit numbers / plant and total fruit yield (kg / plot) were calculated and recorded.

Experimental Design and Statistical Analysis

Experiments were of a complete randomized blocks in four replicates. Data means were paired as combined analysis for the results of each trial (two seasons). Since the results followed a similar trend, they were analyzed for significant statistical differences using LSD test at 5% level (Little and Hills, 1978).

RESULTS

First Trial

Tomato fruit diameter (Table 1) as well as fresh and dry weights showed an early period of slow growth during the first 6-8 days after anthesis. These parameters of tomato fruit growth significantly increased during the period of rapid growth when fruit passed the age of one week after anthesis and lasts for three additional weeks. By that time, a second period of slow fruit growth occurred and dominated until fruit reached its maturity (Tables 1 & 2).

When tomato flowers were exposed to ethrel or AOA application 2 days after anthesis, all measured parameters of fruit growth showed a strong response to both treatments. During the early period of fruit growth (2-4 weeks after anthesis), fruits of AOA treated flowers produced fruits of the largest diameter (Table 1) and heaviest fresh and dry weights (Table 2), while those received 100 ppm ethrel resulted in the smallest and the lightest fruits, as compared to those of control (H₂O - treated flowers). Furthermore, no significant differences were found among treatments in terms of flower or fruit abscission measured 3 weeks after anthesis ($33 \pm 2\%$ abscission for all treatments).

Such significant descending order of fruit growth obtained with AOA, H₂O and ethrel applications diminished 4 weeks after anthesis and totally reversed to an ascending order as fruit age passed 30 days after anthesis (Table 1). This new ascending significant order strongly was emphasized as fruit reached its red-ripe stage (Tables 1 & 2). Furthermore, fruits of AOA-treated flowers reached red-ripe stage faster than the control, and both were faster than those resulted from ethrel treated flowers (i.e., 45, 50 and 60 days after anthesis, respectively) following the same growth ascending order. It was also noticed that the time between red color initiation (breaker) and red-ripe stages was also extended, but only in the fruits of ethrel-treated flowers, compared to other treatments (10 vs. 5 days, respectively).

Table 1. Flower treatment effects 2 days after anthesis on tomato fruit diameter during its subsequent growth.

<u>Days After Anthesis</u>	<u>Control (water)</u>	<u>Ethrel (100 ppm)</u>	<u>AOA (0.5 mm)</u>
10	1.25 b	1.14 b	1.56 a
12	2.51 b	2.18 c	2.79 a
18	3.11 b	2.93 b	3.67 a
24	4.64 b	4.57 a	4.83 a
30	5.15 b	5.71 a	5.06 b
35	5.33 b	5.87 a	5.23 b
40	5.51 b	6.14 a	5.39 b
45	5.86 b	6.45 a	5.75 b
50	6.42 b	6.93 a	5.86 c
55	6.49 b	6.98 a	-

Means within each row followed by the same letter are not statistically different at the 5% level.

Table 2. Flower treatment effects 2 days after anthesis on tomato fruit fresh and dry weights during its subsequent growth and development and on the time required for the fruits to reach breaker and red-ripe stages.

<u>Days After Anthesis</u>	<u>Fruit Fresh Weight</u>			<u>Fruit Dry Weight</u>		
	<u>Control</u>	<u>Ethrel</u>	<u>AOA</u>	<u>Control</u>	<u>Ethrel</u>	<u>AOA</u>
	(water)	(100 ppm)	(0.5 mm)	(water)	(100 ppm)	(0.5 mm)
2	0.2 a	0.1 a	0.2 a	0.02 a	0.02 a	0.02 a
4	0.4 a	0.3 a	0.4 a	0.05 a	0.03 a	0.03 a
6	1.9 a	1.6 a	3.7 a	0.11 a	0.07 a	0.10 a
8	3.3 a	2.6 b	11.3 a	0.31 b	0.21 b	0.44 a
10	11.2 b	10.1 c	14.7 a	1.07 b	0.65 c	1.63 a
12	21.5 b	17.1 c	24.5 a	1.64 b	1.19 c	2.24 a
18	35.1 b	27.8 c	49.5 a	3.25 b	2.20 c	4.65 a
24	50.7 a	45.7 b	53.5 a	4.54 a	3.90 b	4.97 a
30	71.9 a	72.3 a	71.9 a	6.01 a	6.05 a	6.01 a
35	85.6 b	91.6 a	79.5 c	7.89 b	8.54 a	6.12 c
40	98.4 b	119.9 a	83.9 c ¹	7.63 b	8.60 a	6.73 c
45	102.0 b ¹	131.5a	91.5 c ²	7.80 b	8.64 a	6.77 c
50	105.7 b ²	139.9 a ¹	92.5 c	7.84 b	8.97 a	7.12 c
55	105.0 b	140.5 a	-	7.83 b	9.12 a	-
60	-	141.0Y	-	-	9.15	-

Means within each row for each parameter followed by the same letter are not statistically different at the 5% level.

¹Time between anthesis and breaker stage. ²Time between anthesis and red-ripe stage.

According to the histological studies, the transaction of tomato fruit during its early stages of growth and development showed that fruit pericarp tissues consisted of exo and mesocarp tissues. Exocarp tissue is formed from unicucate parenchymatous cells coated with cuticle with 2-3 layers of cells located under the epidermis called the hypodermis. Mesocarp tissue, on the other hand, was formed from two different layers defined as outer and inner mesocarp layers. The outer mesocarp layer is located in the distance between the hypoderms and the vascular bundle of pericarp tissues, while the inner mesocarp tissue is a entirely parenchymatous cell located under the vascular bundle and extended to reach the loci of the ovules. It was also

noticed that the transition phase from CD to CE occurs mostly happened in the outer and inner mesocarp layers.

Fruits from ethrel-treated flowers showed the highest level of CD in the outer mesocarp, followed by control, while fruits of AOA-treated flowers were significantly the lowest. The inner mesocarp, however, did not show CD activity 6 days after anthesis in any treatment, with the exception of ethrel treatment. To define such results, number of cells /mm² were counted as presented in Table 3. Number of cells /mm² were significantly higher with ethrel application than that of control, while AOA significantly produced the lowest cells number.

Table 3. Flower treatment effects 2 days after anthesis on tomato fruit mesocarp cell numbers and elongation during early stages of fruit growth and development.

Days After Anthesis	Cells Number / mm ²			Cell Length (μm)		
	Control (water)	Ethrel (100 ppm)	AOA (0.5 mm)	Control (water)	Ethrel (100 ppm)	AOA (0.5 mm)
External mesocarp						
6	1333 b	1867 a	1035 c	53 b	49 b	64 a
9	1261 b	1459 a	815 c	64 b	53 c	87 a
12	898 b	1219 a	658 c	90 b	74 c	104 a
15	702 b	873 a	533 c	105 b	94 c	127 a
18	549 b	733 a	455 b	135 b	108 c	148 a
Internal mesocarp						
6	428 b	973 a	78 c	70 b	34 c	114 a
9	141 b	235 a	47 c	128 b	79 c	192 a
12	92 b	141 a	42 c	213 b	143 c	241 a
15	45 b	110 a	39 b	249 b	206 c	285 a
18	24 b	78 a	25 b	288 b	264 c	324 a

Means within each row in each parameter followed by the same letter are not statistically different at the 5% level.

These results were existed in both inner and outer mesocarp up to 12 days after anthesis. Number of cells / mm² in outer mesocarp remained significantly higher with ethrel application than those of control up to 18 days after anthesis, and both were significantly higher than AOA treatment. In the inner mesocarp tissues however, number of cells / mm² in fruits of ethrel application remained significantly higher than other treatment, while the differences between control and AOA treatments diminished 15 days after anthesis.

It was also noted that the outer mesocarp exhibited higher cell numbers/mm² than those of inner mesocarp. On the other hand, CE can be easily observed as early as 6 days after anthesis with AOA treatments and it was more pronounced in internal than external mesocarp in comparison with those of control and ethrel treated ones. In addition, AOA treatment showed the highest level of CE, in both outer and inner mesocarp, followed by control, while the lowest level was occurred with ethrel application as early as 6 days after anthesis (Table 3).

In terms of ethylene production, tomato fruits produced their highest ethylene level at the stage of fruit set (2 days after anthesis). At this stage, fruits of ethrel-treated flowers produced superior ethylene level as compared to those of control. Meanwhile, fruits of AOA-treated flowers produced significantly the least ethylene level. Shortly after anthesis, ethylene production was sharply reduced to its basal level (the lowest constant level). Fruits of AOA-treated flowers were the first in reaching their basal level of ethylene production, since the time required was only 6 days after anthesis.

Fruits of control and ethrel treated flowers, however, reached their basal level, which was comparable to that of AOA treated flowers, 10 and 18 days after anthesis, respectively. Furthermore, ACC content in the fruits of all treatments followed the same pattern of

ethylene production. The only exception was that ACC gradual increased during the first 8-10 days after anthesis, which was parallel to the ethylene continuous, drop.

Ethylene production and ACC content of the fruits resulting from all treatments remained in their basal level until fruit reached the age of 35 days after anthesis. At the age of 40 days after anthesis, however, both ethylene and ACC levels restored their significant increases following the same significant order noted with AOA, H₂O and ethrel treatments during the early stages of fruit development.

Second Trial

When tomato plants received AOA, H₂O or ethrel treatment, only one week after flowers anthesis of the first cluster, fruit of AOA-treated plants reached their harvest peak 4 and 12 days earlier than that of control or ethrel-treated plants, respectively. Furthermore, fruit yield of AOA-treated plants was significantly higher than other treatments only during early harvests. An opposite trend, however, was obtained in the late harvests when ethrel-treated plants became superior in their yield to those of control and both were significantly higher than AOA-treated plants.

In addition, no significant differences were found among treatments in terms of flower or fruit abscission, which emphasize the results obtained during the first trial. Similarly, no significant differences between treatments were found in terms of fruit numbers /plant. Average fruit weight, however, significantly was reduced with AOA application, but markedly increased with ethrel application compared to that of control. Fruit yield followed the same pattern of average fruit weight, since AOA application reduced tomato fruit yield by about 7%, while a 15% increase was obtained with plant ethrel application.

DISCUSSION

First Trial

Parameters of tomato fruit growth, measured as fruit diameter as well as fresh and dry weights, showed a period of slow growth during the first week after anthesis. This was followed by a period of rapid growth up to 40 days after anthesis, when the second slow growth period occurred and lasted until fruit reached its maturity. During the early period of tomato fruit slow growth, CD takes place (Davis and Cooking, 1965; Gillaspay et al., 1993), while fruit rapid growth period due entirely to CE (Iwahori, 1967; Nitsch and Nitsch, 1961). Histological data showed an almost termination of CD activity with a rapid progress in CE 6 days after anthesis. This was noted in a time parallel to the remarkable drop in ethylene production.

These findings, therefore, strongly suggested that the transition phase from CD to CE in tomato fruit, cv. Castle Rock, might be an ethylene-dependent process. It was also found that tomato fruit produced a remarkable level of ethylene during the stage of CD, while an opposite trend occurred during CE, and the remarkable drop in ethylene level was parallel in time to the noted transition phase between both developmental processes.

It has been reported that ethylene induced CD in rice (Metzer, 1984), pine (Barker, 1979), and potato tubers (Ilker *et al.*, 1977), while an opposite result was obtained by Apelbaum and Burg (1972) in pea apex and its root meristem. Oppositely, Maxie and Carne (1968) reported that ethylene inhibited CD and promoted CE in fig fruit. In addition, El-Beltagy *et al.* (1976) suggested that ethylene induced the transition from CD to CE during early stages of fruit development by inhibiting the first and promoting the last process.

In a preliminary experiment, conducted earlier in this work, it was found that applying ethrel, as an ethylene releaser, to tomato flowers 2 days after anthesis, with concentrations higher than 100 ppm, induced flower abscission, while concentrations of 50 ppm or less had no impact on fruit growth as measured by fruit diameter and fresh weight. Applying 100 ppm however, proved to be the best ethrel concentration to be used in terms of eliminating flower abscission and shifting fruit growth pattern measured as fruit diameter and fresh weight.

Therefore, and to test the impact of ethylene on CD and CE as well as the transition phase between both developmental processes, tomato flowers were sprayed at set (2 days after anthesis as previously reported by El-Beltagy *et al.*, 1976) with 100 ppm ethrel, 0.5 mM AOA and H₂O (as control). AOA is known by its inhibition to ethylene biosynthesis through inhibiting ACC synthesis (Yang, 1980). It has also been found that 0.5 mM is the most suitable concentration of AOA to be used for inhibiting ethylene biosynthesis in tomato fruits (Atta-Aly, 1992).

According to the growth parameters measured during the early stages of tomato fruit growth and development, it was found that fruit of AOA - H₂O - and ethrel

- treated flowers followed a significant descending order, in the order mentioned, in their growth parameters measured as fruit diameter (Table 1), fruit fresh and dry weights (Table 2). This significant descending order of growth occurred as early as 8-10 days, and lasted up to 24 days after anthesis. This was strongly established through the significant increase in fruit cell size which occurred with AOA application and measured as cell elongation in fruit outer and inner mesocarp tissues.

In contrast to the parameters of fruit and cell growth described above, fruits of ethrel-treated flowers showed the most significant CD activity followed by control and then fruits of AOA treated flowers. This was true for the outer mesocarp tissue. In the inner mesocarp tissue, however, CD was terminated 6 days after anthesis in treatments other than ethrel, which indicated the expanded period of CD, occurred with ethrel application.

In contrast to the results obtained by Maxie and Crane (1968) on fig fruits which reported that ethylene inhibited CD and promoted CE, AOA treatment shortened the period of CD and accelerated fruit transition to CE. This may due to the differences between tomato and fig fruits in their response to their basal level of ethylene. In addition, number of cells / mm² in outer and inner tomato mesocarp tissues showed that fruits of ethrel-treated flowers significantly produced the highest cells number / mm², followed by control, while the lowest cell number was produced by the fruits of AOA-treated flowers.

These data strongly indicated that ethrel exogenous application at the stage of tomato fruit set, induced CD and delayed the transition phase to CE by extending the period of CD. Inhibiting ethylene biosynthesis, however, shortened the period of CD and strongly induced CE. This was also supported by measuring ethylene emanation by such fruits since, in all treatments, the onset of fruit rapid growth period, as well as the significant increase in CE and the almost termination of CD coincided with the time of ethylene drop to its basal level. Fruits of AOA-treated flowers reached its basal level of ethylene production as early as 6-8 days after anthesis. By that time, such fruits reached the onset of its rapid growth period as indicated by the significant increase in fruit fresh and dry weights, and CE as well as the almost termination of its CD (Table 3). This was also noted in control and in fruits of ethrel-treated flowers, but after 10 and 18 days from anthesis, respectively.

It is of interest to note that the early drop in ethylene production, regardless of treatment, was due mainly to the strong inhibition of ethylene biosynthesis since the level of ACC followed the same pattern of C₂H₄ drop by a period of about 24 h. Fruits of AOA-treated flowers showed the earliest ACC drop, noticed 10 days after anthesis, followed by control and those of ethrel applied fruits 12 and 18 days after anthesis, respectively.

The higher ethylene and ACC levels noted during the early stage of fruit development with ethrel application, in comparison to those of control or AOA treated ones, may due to the higher levels of ethylene positive feed-back mechanism (Atta-Aly *et al.*, 1994). On the other hand, the significant increase in ACC level of all treatments during fruit early development may due to the low levels of ACC conversion to C_2H_4 , since a marked drop in ethylene production was obtained during such period. It is also of interest to note that the degree of ACC accumulation during such period negatively correlated with ethylene production as affected by the different flower treatments.

Differences in the parameters of fruit growth obtained with AOA, H_2O and ethrel application at fruit set (i.e., fruit fresh and dry weights as well as diameter) were eliminated 30 days after anthesis. Furthermore, the descending order in fruit growth noted with AOA, H_2O and ethrel treatments, respectively, as mentioned, during the first 4 weeks after anthesis, was reversed to an ascending order 35 days after anthesis until fruit reached "red-ripe" stage. Therefore, delaying or enhancing the transition phase from CD to CE in tomato fruit with AOA or ethrel application, respectively, strongly affected fruit growth pattern toward maturity.

Based on fruit response to C_2H_4 - releaser or inhibitor applied at fruit set, fruit growth, therefore, can be divided into two periods of response. First is the period when fruit growth negatively responded to C_2H_4 , which occurred after fruit, set up to 30 days after anthesis. Second, is the period of positive growth response to C_2H_4 and occurred 30 days after anthesis until fruit maturity? During the first period of growth, inhibiting C_2H_4 production by the fruit with AOA application at fruit set shortened the period of CD and accelerated CE process. Such treatment resulted in higher rates of fruit growth, only during the first period of growth while an opposite trend was obtained with ethrel application.

During the second period of growth however, fruits of AOA-treated flowers became limited in their growth and cell numbers as a result of CD short period. In contrast, fruits of ethrel-treated flowers passed through longer period of CD and produced larger fruits as they reach maturity or "table-ripe" stage. It was also evident, based on the data presented (Tables 1&2), that ethrel application, at fruit set, produced fruits larger in diameter and heavier in fresh weight than those of AOA treated flowers by about 19% and 52%, respectively. These values were reduced down to 8 and 34%, respectively, but still highly significant compared to those of control, respectively.

It seems that there is a positive correlation between the period fruit spent in CD and days to reach "red-ripe" stage, since extending the period of CD by ethrel application delayed fruit ripening by about 15 days longer than those of AOA-treated flowers and by about 10 days compared to control fruits. This may also

indicate that ethrel application, at fruit set, extend not only the period of CD, but also the period of CE and fruit maturation.

Fruits of ethrel-treated flowers kept their level of C_2H_4 production and ACC content higher than those of control or AOA-treated flowers during fruit early and last period of growth. It has also been suggested by Atta-Aly (1988) that tomato fruit ripened when its sensitivity to C_2H_4 rose up to meet its basal C_2H_4 level. Increasing fruit basal level of C_2H_4 with early ethrel application, therefore, may increase the gap between ripening sensitivity and the new basal C_2H_4 level and this may be the reason behind ripening delay in the fruits of ethrel-treated flowers and the ripening enhancement of those produced from AOA-treated flowers. This was also emphasized by the time required for breaker fruits resulting from ethrel application to reach "red-ripe" stage compared to those obtained with AOA application.

It could be concluded from such results that ethrel application, at fruit set, extended the period of tomato fruit CD and delayed the transition phase to CE as well as increasing fruit size and fresh weight with pronounced delay in ripening, while an opposite trend was obtained with the early inhibition of C_2H_4 production by AOA application.

Second Trial

Ethrel application to tomato flowers proved to be a promising treatment in increasing tomato fruit size and may delay ripening as found in the first trial. It is also of interest to note that ethrel has been internationally registered for pre- and post-harvest uses in several fruits including tomatoes (Abeles *et al.*, 1992). It was also found that flower application 2 days after anthesis is not a practical way for commercial treatment. Tomato plants, therefore, were exposed to the same treatments of the first trial one-week after anthesis of the first flower cluster. By that time, flowers of the third cluster were close to anthesis stage and the corolla was opened in the fourth cluster, meaning that the majority of the flowers may benefit from such application.

Ripening acceleration and delay obtained in the first trial were also emphasized during the second trial when AOA and ethrel were, respectively, applied to tomato plants and not to flowers. This was based on the fact that tomato fruit yield during the early harvests was superior with AOA application, but higher superiority was obtained with ethrel application at late harvests. Furthermore, AOA, H_2O and ethrel applications showed the same ascending order found in the first trial, but in terms of the time for harvesting peak. The increase in average fruit weight found with ethrel application without affecting flower or fruit abscission as well as fruit numbers / plant strongly increased tomato fruit yield of the second trial. This increase was about 15% over the control, while a significant reduction by about 7% was obtained with AOA application. It is

indicated, therefore, that the yield increase or decrease obtained with ethefl or AOA application, respectively, was due entirely to the size variability of the fruit. This resulted from modifying fruit CD, and consequently growth pattern with modifying fruit basal C_2H_4 level during the early stages of fruit development.

Based on the results obtained from both trials, it can also be indicated that ethefl application during flowering or tomato fruit-set stage increased not only fruit yield, but also fruit size as one of the fruit major quality factors.

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REFERENCES

- Abdel-Rahman, M. 1977. Patterns of hormones, respiration and ripening of cherry tomato fruits. *Plant Physiol* 39: 115-118.
- Abeles, F.B., P.W. Morgan, and M.E. Saltveit. 1992. Ethylene in plant biology. Academic Press INC, New York, 2nd ed, p. 85-273.
- Adams, D.O., and S.F. Yang. 1979 Ethylene biosynthesis identification of 1-amino-cyclopropane-1-carboxylic acid as an intermediate in the conversion of methionine to ethylene. *Proc. Natl. Acad. Sci.* 76: 170-174.
- Apelbaum, A., and S.P. Burg. 1972. Effect of ethylene on CD and deoxyribonucleic acid synthesis in *Pisum sativum*. *Plant Physiol* 50: 117-124.
- Atta-Aly, M.A. 1988. Effect of saline growing conditions on the post harvest properties of tomatoes. PhD Thesis, Dept. Horticulture, Faculty Agric. Ain Shams University, Cairo, p. 60-100.
- Atta-Aly, M.A. 1992. Ethylene production by different tomato fruit tissues at different ripening stages. *Egypt J. Hort.* 19:137-147.
- Atta-Aly, M.A., J.K. Brecht, D.J. Huber. 1994. Ethylene feedback mechanisms in tomato and strawberry fruit tissues. Postharvest physiology, pathology and technologies for horticultural commodities: recent advances. Institut Agrono. & Vet. Hassan II, Agadir, Morocco.
- Atta-Aly, M.A., M.E. Saltveit, and G.E. Hobson. 1987. Effect of silver ions on ethylene biosynthesis by tomato fruit tissue. *Plant Physiol* 83: 44-48.
- Barker, J.E. 1979. Growth and wood properties of *Pinus radiata* in relation to applied ethylene. *New Zealand J. Sci.* 9:15-19.
- Blanpied, G.D. 1972. A study of ethylene in apple, red raspberry and cherry. *Plant Physiol* 49: 627-630.
- Burg, S.P., and E.A. Burg. 1965. Ethylene actions and the ripening of fruits. *Science* 148: 1190-1196.
- Davies, J.N., and E.C. Cooking. 1965. Changes in carbohydrates, proteins and nucleic acids during cellular development in tomato fruit locule tissue. *Planta* 67: 242-253.
- El-Beltagy, A.S., J.P. Patrick, E.W. Hewett, and M.A. Hall. 1976 Endogenous plant growth regulator levels in tomato fruits during development. *J Hort. Sci.* 51: 15-30.
- Gillaspy, G., H. Ben-David, and W. Gruissem. 1993. Fruits: A developmental perspective. *Plant Cell* 5: 1439-1451.
- Houghtaling, H.B. 1935. A development analysis of size and shape in tomato fruits. *Bull. Torr. Bot. Club* 62: 243-253.
- Ilker, R., A.R. Spurr, and H. Timm. 1977. Ethylene pretreatment and blackspot of potato tubers *Solanum tuberosum*: histochemistry and histology of wound healing. *Z Pflanzenphysiol* 83: 55-68.
- Iwahori, S. 1967. Auxin of tomato fruits at different stages of its development with special reference to high temperature injuries. *Plant Cell Physiol.* 8: 15-22.
- Johansen, D.A. 1940. Plant Microtechnique. McGraw Hill Book Co Inc, New York.
- Ku, H.S., H. Sugu, L. Rappaport, and H.K. Pratt. 1970. Stimulation of rice coleoptile growth by ethylene. *Planta* 90: 333-339.
- Lacheene, Z.A. El-S. 1990. Physiological studies on tomato fruit growth and development. PhD Thesis, Dept. Hort., Fac. Agric. Ain Shams Univ., Cairo, p. 53-86.
- Little, T.M., and F.J. Hills. 1978. Agricultural experimentation. John Wiley & Sons Inc, p. 31-52.
- Lizada, C., and S.F. Yang. 1979. A simple and sensitive assay for 1-aminocyclopropane-1-carboxylic acid. *Anal. Biochem.* 100: 140-145.
- Looney, N.E., W.B. McGlasson, and B.G. Coombe. 1974. Control of fruit ripening in peach, *Prunus persica*: action of succinic acid, 2-dimethylhydrazide and 2-chloroethyl phosphoric acid. *Aust. J. Plant Physiol.* 1: 77-82.
- Maxie, E.C., and J.C. Crane. 1968. Effect of ethylene on growth and maturation of the fig (*Ficus carica* L.) fruit. *Proc. Amer. Soc. Hort. Sci.* 92: 255-258.
- Metzer, R.B. 1984. Using "prep" to advance harvest schedule. *Proc. Beltwide Cotton Prod. Res. Conf.* p. 73-82.
- Nitsch, J.P., and C. Nitsch. 1961. Growth factors in the tomato fruit. In: "Plant Growth Regulation " 4th Intern. Conf. Plant Growth Regulation, Yonkers, NY., 1959, Ames Iowa State Univ. Press, p. 687-707.
- Rhodes, M.J.C. 1980. The maturation and ripening of fruits. In: K.V. Thimann (Ed) Senescence in plants. CRC Press, Boca Raton Fla, p. 157-205.
- Sass, J.E. 1951. Botanical microtechnique. 2nd Ed, Iowa State Press, USA.
- Smith, K.A., and P.D. Robertson. 1971. Effect of ethylene on root extension of cereals. *Nature* 234: 148-149.
- Yang, S.F. 1980. Regulation of ethylene biosynthesis. *Hort. Sci.* 15: 238-243.

Wheat Complex Resistance to Stresses

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ABSTRACT

One of priorities in establishing the physiological and biochemical basis for resistance of wheat grown on dry and high drylands of Kazakhstan to stresses is the development of methods of complex resistance to abiotic, biotic, and anthropogenic environmental stresses. Such methods have been developed, and the rights are protected for determination of complex resistance of different wheat varieties to low temperatures in winter time, high temperatures during the period of irrigation and grain-filling at low soil moisture, and also to infection by pathogenic microorganisms.

Thus, the activity increase of cathode isoperoxidase is directly proportional to a degree of frost resistance and inversely proportional to resistance against pathogens. The accumulation of the $\beta 5$ (75) marker component in an electrophoretic spectrum of gliadin reflects the degree of wheat resistance to the high temperatures on drylands. We can now adapt protein markers for wheat resistance to heavy metal influence, such as cadmium and copper; that is especially effective for determination of ecological resistance in our region.

INTRODUCTION

Complex diagnosis of resistance of cultivated genotypes to environmental stress factors is one of priorities in establishing a physiological and biochemical basis for selection of grain crops. Modern instrumental method development, and possibility of mutual addition and combination, extend the field of application for such research and make it possible to evaluate wheat resistance to a complex of stress effects.

Therefore, the object of our investigation was to search for methodical approaches to determine wheat resistance against the abiotic, biotic, and anthropogenic environmental factors. In addition to the determination of grain market quality, it is important for Kazakhstan wheat cultivated in dry conditions with high technological properties not to accumulate heavy metals (Abugalieva et al., 1997).

The study of physiological and biochemical principles of wheat adaptation to the environmental influences and the determination of biochemical resistance markers against the stresses have been made in four directions:

- Quantity and quality changes in the gliadin spectra of grain of the plants cultivated at different natural and ecological conditions.

- Evaluation of resistance against low-temperature abiotic factors and formation of frost resistance based on the level of changes of general peroxidase activity and its electrophoretic forms.
- Correlation between the electrophoretic peroxidase forms and resistance of plants against the agent of brown rust.
- Assessing varieties for soft wheat according to heavy metal accumulation in grain conditioned by its adaptiveness and resistance against the stress factor caused by anthropogenic influences.

MATERIALS AND METHODS

It is known that the standards of genotype reaction to environmental changes (the genotype-environment interaction) are determined by the reaction of typical gliadin biotype for many current wheat varieties. Therefore, for increasing research objectivity, the analysis has been carried out at the typical gliadin biotypes of soft wheat (*Triticum aestivum*), including Bogharnaya 56, Bezostaya 1, Mironovskaya 808, and many others.

Providing works in the first direction, the typical gliadin biotypes, Bogharnaya 56 and Bezostaya 1 have been cultivated in three contrasting ecological sites in the high dry zone (Karaspan, Chimkent region), dry zone (Karoy, Almaty region), and with irrigation at Kazakh Research Institute of Agriculture (Kaskelen, Almaty region). Bezostaya 1 is the common type for cultivation under irrigated conditions. Bogharnaya 56 is the most common type for dryland conditions.

Electrophoresis for gliadins has been made by standard methods, and the correlation of gliadin's components was determined by a densitometer. The components have been calculated as a percentage (%) of the total gliadins. Plants of typical biotype, Mironovskaya 808 (high frost-resistant) and, Bezostaya 1 (weak frost-resistant), were cultivated in the chambers with artificial climate in experiments for studying resistance against low temperatures.

The analyses have been made on the third leaf of 20-day old seedlings, and after cooling in the following regime: control 20-22°C; 8-10°C - 1 day; 3-5°C, 1 day; 0-2°C, 3 days; -5-7°C, 1 day at 10 hour's artificial lighting of 5000 lx. Seedlings with other leaves were used for further cultivation.

According to the third research direction, the plants of typical gliadin biotype Bogharnaya 56 were cultivated under irrigated conditions. Its contamination has been made cover with an artificial population of the agent brown rust. The analysis was made on the second

leaf up to the tillering phase of healthy and infected plants.

Varieties of spring wheat (34), and winter wheat (16) from the various dry cultivation zones (Abugalieva et al., 1997) were been used for determination of heavy metals in grain based on typical gliadin biotypes by the method of emission spectrum analysis. Experiments to determine the influence of various heavy metals on wheat seeding physiology have been carried out according to Tazhibaeva et al., (1999).

The extraction, electrophoresis of cathode iso-peroxidases, calculation of relative activity for isoforms (by Liu), determination of total (ncat) and specific, i.e., ncat/mg of protein (by Lowry) peroxidase activity have been made according to listed methods (Tazhibaeva, 1989). The experimental results have been calculated by the methods of mathematical statistics.

RESULTS AND DISCUSSION

The sharply contrasting conditions for cultivation (high temperature during irrigation and grain development) and low moisture content in soil, especially in the dry zones, have been observed in the changes of accumulation for some gliadin's components and the marker components. $\beta 5$ (75) was identified among them. It points out the degree of reaction for plants of typical biotype variety to the stress factors - high temperatures at formation and grain development. This component increased as the environment become more unfavorable for plants. For example, the content of $\beta 5$ (75) of Bogamaya 56 (adapted to dry zone) is increased with dry cultivation conditions. On the contrary, the content of $\beta 5$ (75) of gliadin component decreased for Bezostaya 1 (adapted to irrigation zone) under dry conditions.

Biosynthesis for gliadin's marker component $\beta 5$ (75) points to suitability of wheat variety to the extreme cultivation conditions. The tendency to accumulate gliadin's marker component $\beta 5$ (75) can be used for rejection of unpromising lines when to select wheat for dry cultivation conditions (Peruansky et al., 1986; Tazhibaeva et al., 1998).

The data (Table 1) have shown that the degree of wheat variety reaction (by increasing activity of cathode isoperoxidases) at the cooling is directly connected

with frost-resistance of its plants of typical gliadin biotype. The break between activity of cathode isoperoxidases of frost-resistant wheat Mironovskaya 808 and slightly frost-resistant wheat Bezostaya 1 increased up to one and a half times when cooling stepped; wheat varieties with greater frost-resistant properties is increased up to three times (Tazhibaeva, 1989).

Therefore, winter wheat returns reaction to the stepped cooling (by measuring activity of cathode isoperoxidase) can be used for valuation of frost-resistance at the initial stages of selection. In addition, the descendants are preserved for the further wheat growth.

By determination of resistance against the contamination by brown rust, it was shown that wheat plants with certain gliadin biotype reacted differently, i.e., increasing activity of cathode iso-peroxidase. Here, the type infection (4 balls) and the degree of infection by rust of leaf plate (5%, 25%, 75%) are identical in respect of control healthy plants.

The special coefficient to determine degree of resistance to the influence of pathogen (here the brown rust) has been introduced. It has been calculated according to activity of cathode isoperoxidases as affected by plant / healthy plant, and it is possible here to select genotypes resistant more to the diseases according to low coefficients unpromising samples when to select wheat at dry cultivation conditions (Peruansky et al., 1986; Tazhibaeva et al., 1998).

According to the data, the first group of plants was more resistant against pathogen than the second one (coefficients at infection of 5% and 25% are respectively 1.10-1.14; 1.70-1.82 against 1.47-1.53; 1.94-2.0).

Previous investigations of wheat variety Geno-fund (variety of 34 spring and of 16 winter wheat) at dry cultivation zones have revealed wide variability in accumulation of 50 metals and associated acids. It is noted that the content of Zn, Pb, Cu, Ni and others metals exceeds the concentration limits. Wheat variety specificity and the differentiation of cultivation zones that could be observed are the result of such an anthropogenic factor as heavy metals.

In laboratory conditions, it was established that the influence of heavy metal application rates (10 and 20 mg/l) is connected with the increasing peroxides activity in shoots and roots. The activity of peroxides

Table 1. Cooling influence on activity of wheat cathode iso-peroxidases.

Cooling Regime	Cathode Iso-peroxidase Activity of Wheat			
	Mironovskaya 808		Bezostaya 1	
	% of total activity	Ncat/mg Protein	% of total activity	Ncat/mg protein
Control				
20 - 22°C	36.4	5382 ± 61	32.9	4616 ± 62
8 - 10°C; 1 day	39.6	9269 ± 117	37.1	7469 ± 93
3 - 5°C; 1 day	43.0	10895 ± 175	40.0	8459 ± 120
0 - -2°C; 3 day	48.7	13024 ± 134	45.0	10006 ± 145
-5 - -7vC; 1 day	63.0	19741 ± 270	53.5	12925 ± 184

increases with heavy metal and is mostly specific to Cd (Lee et al., 1995). Shoots and roots of wheat seedlings are different according to the peroxides activity level, which is closely connected with the frontier-accumulating function of roots and physiological and biochemical changes under the influence of heavy metals (Tazhibaeva et al., 1999).

CONCLUSION

The results obtained are the basis of the method for determination of resistance of wheat genotype against stresses. This method includes wheat cultivation under different dry conditions; genotype comparison by changing content of gliadin components; and analysis of specificity of peroxide activity and its isoforms.

1. Accumulation of $\beta 5$ (75) gliadin component in grain is connected with dry conditions for wheat cultivation.
2. Cathode iso-peroxidase activity is directly proportional to the frost-resistance and inversely to pathogen resistance.
3. Cathode iso-peroxidase activity is the indicator of wheat adaptive properties against to the influence of heavy metals considered as a stress antropogenic factor.

The field of application for the given development is in agriculture, especially for plant selection. It can be used by scientific departments for the development of high productive wheat varieties resistant to phyto-pathogen and environmental factors.

REFERENCES

- Abugalieva, A.I., L.M. Skokbayev, L.M. Dracheva, and V.N. Savin. 1997. Optimization of high quality wheat production zones in Kazakhstan. *Proc. Kazakhstan-CIMMYT Conf.*: Akmola. 49-56.
- Lee, C.S., and K.C. Hwei. 1995. Cd-induced changes in proline level and peroxides activity in roots of rice seedlings. *Plant Growth Regul.* 1: 67-71.
- Peruansky, Yu. V., A.I. Abugalieva, and T.L. Tazhibaeva. 1986. Methods of determination of wheat genotype resistance against stressful factors. Inventor's certificate 1269292 USSR-A.OIHI/04. *Bulletin of Inventions*. V 41: Moscow. 256 p.
- Tazhibaeva, T.L. 1989. Winter wheat leaves peroxidase connected with its frost-resistance. Thesis, *Candidate of Biology*. Tashkent.
- Tazhibaeva, T.L., and Y.V. Peruansky. 1998. Resistance of wheat genotypes against to the stressful factors of an environment. *Physiology and biochemistry - the essential part of selection*. Almaty. 20-24.
- Tazhibaeva, T.L., B.A. Sarsenbaev, A.I. Abugalieva, A.M. Ermagambetov, and O.Y. Golovchenko. 1999. Heavy metals influence on physiological parameters of barley germinating. *Proc. II Beremzhanov Symposium on Chemistry and Chemical Technologies*. Almaty. 1: 98-102.

Drought Resistance of Tunisian Olive Cultivars

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ABSTRACT

The Tunisian climate is mostly arid and semi-arid. Likewise, it is characterized by frequent drought and poor water and soil resources. Olives provided the best capacity in developing these resources. Nowadays, olive production is encountering difficulties, i.e., senescence of traditional olive groves and drought damage, which becomes serious with the degradation of practices affecting water economy. In saving the olive sector, more attention must be paid to drought damage, production suitability of olive tree during favorable periods, and to the concept of a better bio-geographical distribution of the olive species, taking into account its drought and the environment potential. Thus, we aimed to compare the resistance to drought of the main Tunisian olive tree cultivars and to draw on their most interesting characteristics.

The study of the morphology and the anatomy of field-grown olive leaves show the occurrence of some acquired differences, thus distinguishing their resistance capacity. *These characters are density of stomata and trichoma, leaf and palisade tissue thickness, internal and external leaf surface ratio, and the proportion of cell wall in contact with the inter-cellular space.*

The stomatic regulation and transpiration study shows that the daily levels are different between varieties, which depends upon their origin. The general synthesis of the moisture deficit effect related to the different morphological, anatomical and physiological parameters studied allows a clear-cut distinction between cultivars for drought resistance. Thus, the "Chemlali" variety has the most characteristics to develop in dry conditions; "Oueslati" is second. Both "Chemlali" and "Oueslati" should be observed in other environments. These adaptive potentialities could be performed within suitable production environments. The "Chetoui" variety seems to be adapted to rainy areas.

INTRODUCTION

Tunisian olive heritage is very important and rich not only in terms of quantity but as a part of tradition also. For centuries, natural selection of this species has given many ecotypes, which present an optimal balance between use of water by the tree and its dry matter production. The use of this basic information to rationalize growing olive trees in arid and semi-arid areas, which characterize more than 2/3 of Tunisia, requires an assessment of the adaptive potential of this species

toward the water stress. Taking this into consideration, the present work has been conducted to achieve two objectives: compare the resistance of different varieties of olive tree to drought, and determine the most important characters to distinguish between varieties.

MATERIALS AND METHODS

Field Experimental Conditions

This study under natural conditions has been conducted using adult olive trees (20-25 years old), traditionally grown in a dry farming system. Five sites in different bio-climatic stages were chosen on order to cover for all rainfall regimes. These sites are located in the north, center, and south of Tunisia.

North

This area is most representative of Tunis. It belongs to the lower semi-arid Mediterranean bio-climatic stage (Le Houérou, 1993). The yearly average temperature and rainfall are, respectively, 18.2°C and 400 mm. The variety used for this study in this region is called "Chetoui", which is one of the most common by used variety in the north of the country (90-95%).

Center

This region is characterized by two zones: the coast and the countryside. The coastal zone is represented by the station of Enfidha, belonging to the semi-arid Mediterranean bio-climatic stage. The yearly average temperature and rainfall are, respectively, 19°C and 371 mm. The second zone is represented by the Oueslatia and Souassi regions. The experimental site in Oueslatia belongs to the lower semi-arid bio-climatic stage with warm winters. The yearly average of temperature and rainfall are, respectively, 17.83°C and 392 mm. The site at Souassi belongs to the upper arid Mediterranean bio-climatic stage. The yearly average temperature and rainfall are, respectively, 20.8°C and 267 mm.

In the regions of Enfidha and Souassi, the variety that has been used is called "Chemlali", the most important and representative variety in Tunisia. It is found all over the Sahel, center, and south of Tunisia. In Oueslatia region, the "Oueslati" variety has been used in this experimentation.

South

The zone that has been chosen is Gafsa. It belongs to the lower arid bio-climatic stage with moderate temperature. The yearly average temperature and rainfall are, respectively, 21°C and 152 mm. Two varieties were

chosen for this study. Chemlali and Chemchali. The last one is considered as the most used variety in the region of Gafsa.

Experimental Procedure

The characters used in this study are as follow: stoma density (stomata/mm²) noted as SD; stomata length (μ m) noted as SL; trichoma inner-face density (trichomes/mm²) noted as TID; leaf surface, noted as LS; leaf thickness, noted as LT; palisade tissue thickness (μ m), noted as PTT; ratio of leaf internal surface to the external surface, noted as Ames/A; a ratio of mesophyll cell in contact with the inter cellular space per unit of surface of mesophyll cell, noted as Aa/Ames; palisade cell cross-section area (μ m²) noted as PCA; stomatal resistance to the diffusion of water (s/cm) noted as SR, and transpiration mg/m²/s (noted) as TR.

The measurement has been done on leaves developed that year situated and on a branch, which is oriented to the south. For the assessment of the density, and length of the stomates, the trichomes that completely cover the stomates on the lower face of the leaf are taken out. Prints of epidermis are obtained by applying a fine layer of varnish to the lower surface of the leaf. When dried, this layer of varnish is taken out by using the adhesive ribbon and placed on a blade (Jones and Fanjul, 1983). The density of the trichomes was defined on the same samples by counting scars let by the removal of this structure.

The thickness of the leaf and the palisade tissue, the ratio of leaf internal surface to the external surface, the ratio of mesophyll cell in contact with the inter-cellular space per unit of surface of mesophyll cell, and the palisade cell cross-section area were determined by transverse cut of leaves (1-2 μ m of thickness) following the standard scheme of glutanaldehyde fixation, osmium tetroxydez post-fixation, and epoxy resin inclusion (Spurr, 1969). The cuts were done using an ultra-microtone LKBII. The observations were made by computer analysis system of the picture. The method used for measuring the internal surface of the leaf is that of

Jurik (1982).

The leaf surface has been determined by the optic planimeter LICOR. The daily stomatal resistance and transpiration were measured by a steady-state porometer LI 1600 of LI-COR Inc., Lincoln, Nebraska (USA).

The comparison of all average parameters was done using the Tukey test. A computer-analyzing program was used to differentiate of morphological, anatomical, and physiological data within the six cultivars

RESULTS AND DISCUSSION

The comparative survey of the morphological and anatomical characters of the internal and external structure of olive tree leaves done in natural conditions on cultivars of various Tunisian origin point out, better than others, the capacity of this variety to limit, support or avoid the effect of drought. Indeed, according to Table 1, important stomata density variations, as well as the length of theses structures, have been remarked.

About the stomata density, for xerophytes opinions are divided, since some consider that elevated stomatal density allows a cooling of the leaf (Strobel and Sundberg, 1984) and cases the photosynthesis (Levit 1986). For others, the weak values of this parameter do influence the diffusion of water vapor more than CO₂ exchanges because stomatal resistance to the vapor diffusion is more important than the CO₂ one (Van Damme, 1991; Roselli and Verona, 1990). By considering a low number of stomata as a good criterion allowing to limit water losses, we note that Chemchali is better situated between other cultivars to develop vegetatively in dry conditions, followed by the Chemlali of Enfidha, Chetoui, and by Chemlali of Souassi and Gafsa. Oueslati presents the highest number of stomata by leaf surface unit and will be classified at the end (Table 1).

Trichoma are present only on the inner face of the olive tree leaves; and completely cover the stomata; these structures influence the gas diffusion resistance and decrease the wind speed close to the transpiring surface (Smith, 1978; Nobel, 1975; Henchi, 1987).

Table 1. Morphological and anatomical characteristics of Tunisian olive tree leaves of different origin.

Characters	Units	No.	Chetoui	Chemchali	Oueslati	Chemlali		
						Enfidha	Souassi	Gafsa
Stomata density	Stomata/mm ²	40	401 ¹	355 _a	522	372 _a	436 _b	416 _b
Stomata length	μ m	56	13.2 _a	14.1 _a	9.9 _b	11.5 _c	10.6 _b	10.8 _c
Inner-face density	Trichoma/mm ²	40	100	159	147	159 _a	190 _c	197 _c
Leaf surface	m m ²	30	350 _a	470 _{b,c}	316 _{b,c}	380 _b	371 _{a,b,c}	348 _{a,c}
Leaf thickness	μ m	23	456 ¹ _a	550	680	407 _b	396 _b	442 _a
Palisade tissue thickness	μ m	24	180 _a	339 _b	340 _b	194 _a	194 _a	218 _a
Ames/A Aa/A		18	41.6	94.9	83.1	48.1 _a	47.2 _a	53.5
Palisade cell cross-section area	μ m ²	20	396	149	291 _a	291 _a	258 _b	269 _b

¹Numbers followed by the same letters are not significantly different from each other at 5% level.

Besides, trichoma reflect radiation that promotes the warming up of the leaf (Eller, 1977), and influence photosynthesis as well as transpiration (Lüttge et al., 1986). This is how the elevated values of this parameter are favourable for the resistance to drought. For this reason, the Chemlali of Souassi comes to the first rank, followed by the Chemlali of Gafsa, and the Chemchali as such. The Chemlali of Enfidha and the Oueslati follow. The Chetoui has the weakest trichoma density.

The thick leaves with well-developed palisade tissue characterize dry-area plants (Shulds, 1950; Nobel, 1980). This structure influences the journey through which the steam of water circulates after having left the interleaf evaporating surfaces from the leaves through stomates (Kramer, 1983; Jarvis and Slatyer, 1970). For these characters, the most elevated numbers are considered as characters permitting a good behavior in conditions with water deficit.

The Chemlali and the Oueslati distinguish themselves from the other cultivars by thick leaves. The Chemchali precedes the Oueslati by its higher proportion of palisade tissue. The Chemlali of Gafsa comes next. For the Chemlali of Enfidha and the Chemlali of Souassi, the thickness of leaves and palisade tissue are at the same level and classified before the Chetoui, in spite of its thick leaves, which presents the weakest percentage of palisade tissue.

The ratio of the leaf internal surface to the external one gives indications of the diffusion of the CO₂ toward the chloroplasts (Hamlyn, 1983), the internal surface proportion in contact with intercellular space (Nobel et al., 1975), and the degree of compactness of the mesophyll cells (Bongi et al., 1987). The elevated values of these parameters indicate a big surface of CO₂ exchange, which facilitates its diffusion toward chloroplasts. Small mesophyll cell size increases the internal surface. For the internal mesophyll structure, the Chemchali and the Oueslati cultivars present the best characteristics; the Chemlali of Enfidha and Souassi follow. The Chemlali of Gafsa has an inner structure compact enough which could hamper exchanges of CO₂. The Chetoui is classified in last position for its lowest internal surface.

Average values of stomatal resistance and transpiration show that the daily average values of the weakest stomatal resistance are with the Chetoui olive tree and Chemlali of Enfidha. As far as transpiration is concerned, we note that the daily average is at the same level as the Chemlali and Oueslati varieties. For the Chemlali variety, one notices less important values of the daily middle transpiration to Souassi and Gafsa, than to the Enfidha.

CONCLUSION

The synthesis of the morphological, anatomical and physiological characters observed in natural conditions clearly point out the most interesting characters in order to choose between the six cultivars studied for

drought resistance. The mesophyll internal aspect, leaf thickness, the ratio of the leaf internal surface to the external surface and a ratio of mesophyll cell area in contact with the inter cellular space per unit of total mesophyll cell area are characters that distinguish, by their elevated values, the Oueslati varieties and Chemlali from the other cultivars. These present the best features which permit them to avoid losses of water and to maintain a good level of gas exchange. Criteria such as stomata and trichoma densities showed that these varieties present the best behavior in the least rainy zones, which encourages the Chemlali variety in relation to the Oueslati and place it ahead of this classification. The stomatal resistance, the stomata length and the trichoma density permitted to classify the Chemlali of Souassi after the Oueslati, followed by the Chemlali of Gafsa. The Chemlali of Enfidha comes before the Chetoui because of its weak stomatal resistance and trichoma density.

REFERENCES

- Bongi, G., M. Mencuccini, and G. Fontanazza. 1987. Photosynthesis of olive leaves: effect of light flux density leaf age, temperature, peltates, and H₂O vapour pressure deficit on gas exchange. *J Amer. Soc. Hort. Sci.*, 112 (1): 143-148.
- Eller, B.M., and P. Willi. 1977. The significance of leaf pubescence for the absorption of global radiation by *Tussilago fafara* L. *Oecologia*, 29: 179-187.
- Hamlyn, G.J. 1983. Plants and microclimate. *Cambridge Univ. Press*.
- Henchi, B. 1987. Effets des contraintes hydriques sur l'écologie de *Plantago albicans* L. *Thèse Doc. Etat*. Univ. de Tunis.
- Jarvis, P.G., and R.O. Slatyer. 1970. The role of the mesophyll cell wall in leaf transpiration. *Planta*, 90: 303-322.
- Jones, H.G., and L. Fanjul. 1983. Effects of water stress on CO₂ exchange in apple. p. 75-84. In: Marcelle, R., H. Clijsters, and M. Van Poucke, (Ed.) Effects of stress on photosynthesis. *Proc. "Conference, Limburgs Universitair Centrum"*, Martinus Nijhoff, and Dr. W. Junk Pub. The Hague
- Jurik, T.W., J.H. Chabot, and B. Chabot. 1982. Effect of light and nutrients on leaf size, CO₂ exchange and anatomy in wild strawberry (*Fragaria virginiana*). *Plant Physiol.*, 70: 1044-8.
- Kramer, P.J. 1983. Water relation of plants. Academic Press, Orlando.
- Le Houérou, H.N. 1993. Changements climatiques et désertification. *Sécheresse*, 2 (4): 95-111.
- Levitt, J. 1986. Recovery of turgor by wilted, excised cabbage leaves in the absence of water uptake. *Plant Physiol.*, 82: 147-153.
- Lüttge, U., B. Klauke, H. Griffiths, J.A.C. Smith, and K.H. Stimmel. 1986. Comparative ecophysiology of CAM and C3 Bromeliads. V. Gas exchange and leaf structure of the C3 bromeliad *Pitcairnia integrifolia*. *Plant, Cell and Environ.*, 9: 411-419.

- Nobel, P.S. 1980. Leaf anatomy and water use efficiency. p. 43-45. *In*: N.C. Turner and P.J. Kramer (Ed.) *Adaptation of plants to water and high temperature stress*. Wiley Inter-Science Publ., New York.
- Nobel, P.S., L.G. Zaragoza, and W.K. Smith. 1975. Relation between mesophyll surface area, photosynthetic rate, and illumination level during development for leaves of *Plectranthus parviflorus* Henkel. *Plant. Physiol.*, 55: 1067-1070.
- Roselli, G., and M. Verona. 1990. Relationship between stomatal size and winter hardness in the olive. *Acta hort.*, 286: 89-92.
- Shields, L.M. 1950. Leaf xeromorphy as related to physiological and structural influences. *Bot. Rev.*, 16: 399-447.
- Smith, W.K. 1978. Temperature of desert plants: Another perspective on the adaptability of leaf size. *Science*, 201: 614-616.
- Strobel, D.W., and M.D. Sundberg. 1984. Stomatal density in leaves of various xerophytes, a preliminary study. *J. Minnesota Acad Sci.*, 49: 7-9.
- Spurr, A.R. 1969. A low viscosity epoxy resin-embedding medium for electron microscopy. *J. Ultrastruct. Res.*, 26: 31-43.
- Van Damme, P.L.J. 1991. Adaptations to drought stress in plants. Part II Morphological adaptations. *Mededelingen van de Faculteit van de Landbouwwetenschappen van de RUGent*, 56(1): 1-8.

VII. Expert Systems and Modeling

Expert System Technology Transfer to Agricultural Domain Experts

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ABSTRACT

The expert systems technology is a useful tool for technology transfer. Its use by agriculture and veterinary experts has many benefits. In this paper we present our experience using expert system tools for the transfer of technology to agricultural-domain experts. Three expert systems tools are used. The first tool is based on Hierarchical Classification Generic Task (HGCT), the second is based on Rule Representation (MINIKROL), and the third is based on Case-Based Reasoning (CBR). These tools are used in training courses for agriculture and veterinary experts. The use of these tools in training has proved to be *applicable, reliable, and can be used easily* by non-professionals to develop their expert system.

INTRODUCTION

Production of food and other agricultural products in the third millennium will rely more than ever on innovative new technology and novel "high-tech" systems. One of these high-tech systems is the "Expert System Technology". The use of expert system technology will not only help in bridging the gap between theory and practice and methods designed to meet the specific needs of agro-industry, but also will help in meeting the demands of *quality, scale, economy, and ecology*. The economic, environmental, and human resource development impact of the expert systems indicate that the expert systems technology as a useful tool for agricultural technology transfer in Egypt (Rafea, 1998).

The expert system consists of two main parts: the knowledge part that includes the *domain expertise*, and the software part that includes the *user interface* and the *inference engine*. The knowledge engineer is responsible for handling the knowledge. The handling of knowledge includes *acquiring* the knowledge, *analyzing* and *modeling* the acquired knowledge, and *verifying* the modeled knowledge. The software engineer is responsible for the software development of the expert system. The software development includes determining the system requirement specifications, designing the system architecture and modules, and implementing and testing the system.

In Egypt, the Central Laboratory for Agriculture Expert Systems (CLAES) has been established to conduct research in the area of expert systems in agriculture. The achievements and results of 8 years experience (1991-'99) are a structured methodology for developing expert systems, a large number of high-quality expert systems, and a number of expert system

development tools. The structured methodology produced for developing expert systems is divided into two main parts, *knowledge engineering* and *software engineering*. The two parts of the methodology interact through a spiral model. This methodology (Rafea et al., 1994) has been based on a KADS (Wielinga, 1994), which has been used in building the expert systems developed at CLAES. Some of the developed expert systems are deployed in real-life environments. The developed tools have been used to implement some of those expert systems and have been also used in training agricultural and veterinary domain experts.

During these years of experience, one of the difficulties that have been encountered is the gap between the domain expert and expert system technology. To overcome this problem, many lectures and seminars were held to introduce this technology, but this was insufficient. Consequently, we used three-part expert system shells to transfer the expert system technology to the domain experts. In the meantime, we oriented the CLAES expert systems development tools to be used by non-computer professionals so that it can be used in domain experts training.

In Section 2, we briefly present the tools developed in CLAES that are used in training of domain experts. In Section 3, the expected impact of expert system technology transfer is described. In Section 4, the training courses are described together with the trainees' achievements.

DEVELOPMENT OF EXPERT SYSTEM TOOLS

The proposed tools have been implemented in SICStus Prolog (I.S.L., 1995). Those tools support the encoding of knowledge. The generated knowledge-base code is based on KROL, which is a knowledge-representation language that combines logic and object-oriented and rule-based programming paradigm (Shalaan et al., 1998). The main facilities provided by KROL are the expressive power to represent complex knowledge, the multi-paradigm knowledge representation, modularizing a knowledge base, and controlling inheritance of properties through a concept. KROL also facilitates the integration of many problem-solvers and knowledge representation scheme in one application.

Although each of the developed tools contains a powerful problem-solving approach with great potential, no one tool is expected to solve all real-life problems, i.e., the solution to "all evils, weaknesses and loopholes". Consequently, three tools have been developed until now. The first tool is based on Hierarchical

Classification Generic Task, and is called HCGT tool. The second tool is based on Rule Representation, and is called MINIKROL. The third tool is based on case Based Reasoning, and is called CBR tool.

HCGT Tool

The HCGT tool is used for acquiring knowledge for the Hierarchical Classification Generic Task. The mechanism of this tool is to acquire cases from domain experts and generate a causal model that is used to create the hierarchically organized knowledge base of the HCGT. The knowledge base is represented as SICStus Prolog Objects. The generated knowledge base can be integrated into a multi-functional ES. The tool also assists the expert system developer in building a user-communication model that is the line of questioning which will be pursued with the end-user. The communication model code is either represented as SICStus Prolog objects or as Java. Furthermore, a design document is generated automatically for documentation purposes. The tool is implemented in SICStus Prolog. The tool aims at enhancing knowledge acquisition, and knowledge/software engineering for the class of diagnostic expert systems.

MINIKROL

The MINIKROL tool consists of a group of editors integrated in one development environment. These editors are the *concept editor*, the *relation editor*, the *table editor*, the *function editor*, the *database editor*, the *dialogue editor*, and the *project editor*. The mechanism of this tool is based on acquiring the knowledge as rules, which represent the domain expert's heuristic knowledge. Other supportive representations are tables to acquire tabular knowledge, functions to acquire mathematical knowledge, and concepts to acquire the domain ontology. The database editor is used to interface the expert system with information needed that is stored in a database, e.g., weather data. The dialogue editor helps the developer to create a customized user interface. The project editor is used to package the developed expert system application.

Case-Based Reasoning (CBR) Editor

CBR use past experiences (cases) to solve current problems. Given an input specification of a problem, the system will search its case memory for an existing case

that matches the input specification. It may find an exact match and immediately go to a solution. Even if an exact match cannot be found, the system applies a matching algorithm in order to find a case that is most similar to the input specification. A CBR tool is being a good choice if a large set of examples exists and being applicable for a problem where no real expert exists. A case-based system can also be quickly built and easily maintained by adding new cases. The CBR editor represents a tool that supports knowledge encoding of cases.

TRAINING COURSES

The goal of most of the courses is to introduce the expert system technology to senior and mid-level management, in both the Arab region and locally in Egypt, in the field of agriculture and veterinary medicine. This helps the domain experts in assessing the value of expert systems' applications in their working environment. The expert system technology is transferred through these courses to the domain experts. Expert system theory is first introduced to the domain experts. Second, they are trained on using an existing expert system. Third, domain experts are trained on one of the expert systems building tools developed in CLAES. Fourth, a small knowledge base is provided to the trainees to build an expert system using one of the developed tools. Finally, the domain experts build, from scratch, an expert system in the areas of expertise using CLAES expert system tools. At the end of the course, the trainees are able to:

- Recognize the basic components of an expert system and its characteristics.
- Differentiate between expert systems and other computer software.
- Identify the development life cycle of an expert system.
- Use one agriculture or veterinary expert system developed at CLAES.
- Develop an experimental prototype expert system using our expert system tools.

Table 1 shows information about the tools that are used in the courses. The main outcome of these courses is building a number of prototype expert systems in different domains with different knowledge representation. The number of developed prototype expert

Table 1. Information about the tools that are used CLAES the courses.

<u>Tool Name</u>	<u>Number of Courses</u>	<u>Locations</u>	<u>Days</u>	<u>Total Hours</u>	<u>Number of Trainees</u>
HCGT	2	CLAES, Muscat, Dubai, Damascus	3	15	6 11 4 15
MINIKROL	5	CLAES	8	32	42
CBR	4	CLAES	3	15	24

systems is cotton, 2; bean, 1; fish, 1; calf, 1; chicken, 2; maize, 2; and non-related commodities, 3. These systems were developed for diagnosis, 6; irrigation, 2; fertilization, 1; plant caring, 1; mechanization, 1; and extension method selection, 1. Those prototype expert systems are listed below:

- *"Expert system for methods of controlling cotton insect pests"*. In this system, the control agent for controlling cotton insect pests, which attack plants at different development stages, are encoded. The development stages are divided into three categories, i.e., seedling, vegetative, and fruit stages. The system diagnoses five insects that are the cause of serious damage to cotton. These insects are cut-worm, aphids, cotton-leaf worm, pink bollworm, and spiny bollworm.
- *"Expert system for extension method selection"*. This system puts together all possible criteria needed to maximize the characteristics of selected extension method. These methods are categorized into individual methods, group methods, and mass communication methods.
- *"Expert system for diagnosis of drip irrigation problems"*. This system concentrates on the activities of drip irrigation, especially hydraulic network functioning, and reasons for these activities, namely: water distribution, materials, impact of soil nature on water distribution, and plant performance when irrigation starts. The system deals with drip irrigation problems and gives its solutions. The system contains two knowledge bases. The first one gives diagnosis of drip irrigation problems and the second one-give solutions to the diagnosed drip irrigation problem.
- *"Expert system for bean disorder diagnosis"*. This system diagnoses and treats 18 bean disorders. The system uses leaf observations, roots observations, stem observations, plant observations, flowers observations, seed observations, pods observations, and grown tops observations
- *"Plant caring expert system for maize crop"*. The system contains two main functions, land preparation, and plant care. The system gives advice in the following agricultural operations: planting, irrigation, fertilization, pesticide, production, and harvest.
- *"Expert system for determining fish farm fertilization"*. The system determines the quantity of mineral fertilizer and quantity of organic fertilizer. The systems also provide advice as to when to stop fertilizer, the timing of first fertilization, and operational methods of mineral and organic fertilizer.
- *"Expert system for management of chick production"*. The system determines the causative organism of the disorders based on the findings. The system includes six of the causative organisms.
- *"Expert system for calf disease diagnosis"*. In this system, there are nine disorders. The system uses ten sign and symptoms to reach to a diagnosis.
- *"Expert system for poultry diagnosis"*. The goal of this system is to diagnosis bacterial diseases in broiler, layer, and baby chicks. In this system, there are 11 disorders. The system uses 16 sign and symptoms to reach to a diagnosis.
- *"Expert system for scheduling irrigation of maize crop"*. This system handles the scheduling of irrigation of maize crop in Middle Egypt in order to save water for use in reclamation of new lands.
- *"Expert system for drip irrigation of cotton crop"*. This system handles the drip irrigation of cotton crop for three soil types: sands, loam, and clay.
- *"Expert system for selecting the suitable machine for harvesting and threshing different crops for different size holding"*. The objective of this system is to improve the mechanization service for different holding size to help farmer to choose the suitable harvesting or threshing tools. Building a suggested harvesting and threshing system is included in this objective.

The list of the expert systems shows that the domains of these systems are varied. Some of these expert systems are new for CLAES. These expert systems can be used in the future as a starting point in building "real" expert systems.

IMPACT OF TOOLS ON TECHNOLOGY TRANSFER

The feedback comments of the trainees of the expert system tools courses held in CLAES prove that the expert system tools are useful to transfer such technology to agricultural domain experts. Expert system tools helped in the understanding and using of the expert system technology by the domain experts. This has led to many highly positive impacts on the domain expert themselves. The most important one is the better understanding and the better shaping of their knowledge. This, of course, will be reflected in the quality of knowledge of the developed expert system packages and applications.

In effect, expert system tools link agricultural technology, human domain experts, expert systems applications, and the end-users in a cyclic manner. These links will eventually, through transfer of technology and feedback, improve the quality of the entities in this linkage and maximize the net gain, the human resources utilization, and environmental protection.

It is ensured that the domain experts trained in CLAES understand the expert system technology through building their own expert systems from scratch. As building an expert system from scratch means that the trainee has the ability to do knowledge acquisition, which is the bottleneck in building the expert system, and to organize the different activities essential to get the expert system running.

CONCLUSIONS

The CLAES expert systems development tools have been oriented to be used by non-computer professionals so that they can be used in domain experts' training and ultimately to be used by the domain experts themselves to build their own expert systems. The goal of this training is to introduce the expert system technology to senior and mid-level management, in both the Arab region and locally in Egypt, in the field of agriculture and veterinary medicine. The feedback comments of the trainees and the prototype systems built by them prove that the expert system tools are useful in transferring the expert system technology to agricultural and veterinary domain experts.

REFERENCES

- Rafea, A. 1998. Agriculture. In: J. Liebowitz (Ed.) *The handbook of applied expert systems*, CRC Press.
- Rafea, A., S. Edrees, S. El-Azhari, and M. Mahmoud. 1994. A development methodology for agricultural expert systems based on KADS. *Proc. "Second World Congress on Expert Systems"*.
- Wielinga, B.J. 1994. Expertise model definition document. ESPRIT Project P5248, *KADS Document*.
- Intelligent Systems Laboratory (ISL), 1995. SICStus prolog user's manual. *Swedish Instit. Computer Sci., Stockholm*.
- Shalaan, K., M. Rafea, and A. Rafea. 1998. KROL: A knowledge representation object language on top of Prolog, *J. Expert Systems with Applications*, 15: 33-45.

Remote Sensing and Computer-Supervised Digital Classification for Monitoring Desertification in Western Sudan

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ABSTRACT

The Sahel zone in El-Fasher region of the Western Sudan is the traditional home of nomadic animal husbandry system. Recently, the increase of population has led to transition of the traditional nomadic system to a sedentary life. The new system practised many activities such as *intensive, traditional rainfed agriculture, overgrazing, felling of trees for many purposes, and pressure on water resources*. These activities, accompanied by droughts in 1970-'73 and 1983-'84, have triggered desertification of the El-Fasher region.

The main objective of this study was to demonstrate a quick and efficient quantitative methodology to monitor desertification, instead of the qualitative conventional method. The latter method is based mainly on census, interviews, and field observations. The quantitative method used is supervised digital classification of a thematic mapper (TM) using computer compatible tapes (CCTs) assisted by visual interpretation of multi-spectral scanner (MSS) and fieldwork.

The results of the study showed that digital classification by computer with different bands (spectral resolution) combined together gave more information on the indicators of desertification. The higher spatial resolution of TM pixels gave a good separation of individual units of the surface objects. The outcome was supervised digital soil classification map for monitoring desertification.

INTRODUCTION

Desertification has been defined as "land degradation in the arid, semi-arid and dry sub-humid areas, resulting from various factors including climatic variation and human activities" (UNEP, 1994). The dryland environment of Africa poses formidable problems for sustainable development; among these are the unpredictable and severe droughts, desiccation, and land degradation or desertification (Darkoh, 1998). Kelly and Hulme (1993) stated that desertification is the outcome of resource management failure. Thus, the leading cause of desertification is human and animal pressure, which leads to over-exploitation and intensified stresses on the natural environment.

Sudan is one of the Sahelian African countries that is seriously affected by *drought, desertification, and famine*. In the western states of the Sudan, desertification has been accelerating at a faster rate in the last

three decades and has led to loss of arable land (Laki, 1994). The fieldwork and the interpretation of LANDSAT image (MSS, TM, and aerial photographs) revealed the main factors contributing to desertification. They include droughts, population growth, and the spread of extensive cultivation, overgrazing, deforestation, rapid urbanization, the dissolution of local administration, and the lack of suitable economic and social institutions. The combination of these factors has produced a fragile ecosystem. The study area, which is severely affected by desertification, lies in the zone of the Seneb savannah ranging between 200-600 mm isohyets in undulating stabilized sand dunes (Ibrahim, 1984).

The ever-increasing rate with which people are destroying their resources has become alarming and, especially when the destruction is accelerating by drought and land degradation, *the alarm becomes a real nightmare*. The aim of this paper is to monitor desertification by recording the climatic variations, mapping soils, land-use patterns, and settlements. Visual interpretation of LANDSAT images, assisted by fieldwork and computer digital classification, was used to achieve this objective.

MATERIALS AND METHODS

Study Area

The study was conducted in North Darfur State in the vicinity of El-Fasher town, the capital of the state, and south of Wadi El-Ku. It is confined between latitudes 13° 35' and 13° 40' N and longitude 25° 13' and 25° 30' E. The climate is arid to semi-arid, with summer rainfall ranging between 200-400 mm, mainly in July and August (Van der Kevie, 1973). The prevailing winds are southwesterly, bringing rains and the dry northeasterly wind, which causes wind erosion. The dominant soils are sandy, developed on stabilized undulating dunes, and *wadi* alluvial soils. The soils of the pediplain and pediments of the hilly lands are of minor extent. The main crops are *penistum tyfodium* (millet), which is grown in the sandy soils, and *sorghum vulgare* (dura) and snaf tobacco are grown in the alluvial soils of the *wadi*. *Acacia senegal* (Arabic gum) is the dominant natural tree.

Methods

To achieve the objective of the present study, various activities were conducted. Remote sensing data from aerial photographs and LANDSAT images (MSS and TM) were obtained from visual interpretation and supervised digital classification. The other activities included fieldwork to check the validity of the preliminary interpretation, identify soils, select representative training areas, and to collect samples for physical and chemical analysis.

Materials

Remote Sensing

The study area was covered by a part of a scene of multispectral scanner CMSS, (scale, 1:100,000, dated 1973 of band 3). Two sets of panchromatic aerial photographs (scale 1:40,000 dated, 1974, and scale 1:45,000 dated 1956), were available from the Land Survey Department, Khartoum. A visual interpretation colored soil map was produced at a scale of 1:100,000. This map was based on *physiography*, *grey tone*, *drainage pattern*, and *landuse*. The delineation of the mapping units and the identification of the soils were verified in the field in 1990 and 1991. Two topographic maps of scale 1:250,000 of El-Fasher (Sheet No. 541, produced by Land Survey Department in 1920), and El-Fasher No.351, (TFH-Berlin, 1990) were used to compare the expansion of settlements and for orientation as well.

During the field investigation, 84 training sites were selected from the different landforms. The positions of the training sites were determined using Global Positioning Satellite System (GPS). Computer compatible tapes (CCTs) of Thematic Mapper (TM) 178-51 (11th, Jan., 1986) were obtained from TFH-Berlin, Germany. The CCTs were digitally processed with five combined bands: (2, 3, 4, 5, and 7) using Earth Resource Data Analysis (ERDAS) software at the TFH-Berlin. The radiometric intensities of unprocessed channels of the CCTs were processed according to the mean of the digital counts of the training sites.

Soil Investigation

Soils samples were collected from the topsoil to analyze the particle size distribution, organic carbon, pH, and CaCO₃. The surface soil color was recorded from a Munsel Color Chart as well as soil moisture. These determinations are very important in the reflectance of the sun's rays. The samples were dried, crushed, and sieved by 2-mm sieve. The particle size was determined by pipette method (Day, 1965), organic carbon was determined using the Walkely-Black (Jackson, 1965), calcium carbonate (CaCO₃) equivalent values were obtained by using the acid neutralization method (Richard, 1954), and soil pH was measured on 1:1 soil-water suspension (McLean, 1982).

RESULTS AND DISCUSSION

Desertification is a problem of ecological imbalance caused by natural factors and mismanagement by man, (Ibrahim, 1984). The major variable factors studied to monitor the ecological imbalance of the ecosystems of El-Fasher region were climate, geomorphology, soil properties, vegetation cover, and forms of landuse and settlements.

Climate

Average annual rainfall of El-Fasher Meteorological Station declined from a wet (1946-'55) to dry (1976-'85) 10-year period. The average annual rainfall decreased by 52.3%, i.e., 340 mm in 1946-'55 to 161 mm in 1976-'85. This decline in rainfall in the last three decades since 1965 over extensive areas of the Sahel zone is well documented (e.g., Goudie, 1977; Nicholson, 1979; 1985; Farmer and Wigley, 1985). Ibrahim (1984) stated that the area of North Darfur experienced the occurrence of many droughts in different periods during the 20th Century, but the droughts of 1970-'73 and 1984-'85 had great impact on the ecological balance because they were accompanied by mismanagement of man to his material resources.

The variation of annual rainfall for central Sudan for 1902-'86 was large; with wide fluctuations in rainfall until 1920, good rainfall above-normal in 1920 to 1965, and a marked decrease in 1965-'88. Kass (1974) stated that in the Sahel the ecological balance among climatic conditions, soil, vegetation cover, animal life, and soil biota is *unstable* and any incidental change may upset it.

Geomorphology and Soils

A soil map of 22 classes was produced from the visual interpretation of the MSS band 32 and aerial photographs, assisted with the studies of GTZ (1989) and fieldwork. The relief is generally lowland east of Jebel Marra, consisting mainly of sandy soils developed on fixed undulating old dunes, alluvial deposits of Wadi El-ku and its tributaries, and hilly land of basement complex with its pediments and peneplain.

Landuse

The sandy soils were developed on stabilized dunes known as "Goz" land. The stability of the Goz land is due to the vegetation covers, mainly *Acacia senegal* (Arabic gum) trees and natural grasses. The main landuse was nomadic grazing with very limited traditional rainfed agriculture. This land-use pattern favored the development of an A horizon with appreciable amounts of organic matter, which led to the stability of the Goz land. This situation still persists in remote areas south of Wadi El-ku, despite droughts and aridity. This indicates that dryness alone will not activate the instability of the Goz.

The alluvial soils are very fertile and very productive, and their use depends on the annual floods. The low topographic position of these soils between the

higher Goz lands favors the addition of materials more than erosion. The extent of these soils is very limited; thus the holdings are small, fenced, and well conserved. The alluvial sand sheets have a good surface cover of vegetation, and thus are less affected by wind erosion.

The hilly lands with its pediment and the pediplain are not attractive to cultivators because of the steep slope, having shallow soils with a sealed surface. Thus, they are left as natural grazing land, less affected by misuse of the cultivators.

The old form of rational exploitation of natural resources has been gradually abandoned because of the rapid population growth. This change has been witnessed by the increase of settlements by comparing the topographic maps of 1920 and 1990. This increase of settlements in the Goz land has changed the nomadic style to a sedentary life. Thus, the new life led to excessive felling of trees for building materials, energy, and fencing for animals and fields. They cleared the land from bushes, grass, and herbs for extensive and intensive rain cultivation of *Pennisetum typhoides* (millet) without fallow.

This land-use pattern is very clear in the LANDSAT images as white parceling devoid of any vegetation. Goats overgraze the surroundings of the settlement and the unpalatable bushes increase to be known as "green desert". These changes of land-use without proper management, coupled with the droughts, have caused the reactivation of the sandy soils of the fixed dunes. The intensive cultivation has changed the characters of the top fixed A horizon of the sandy soils of the Goz from well-aggregated structure to a loose surface. This exposed surface, coupled with dryness, enhanced wind erosion, which led to deflation of the fine fertile particles of the top fixed-dune. This process resulted in loose coarse sand, low in organic matter, excessively drained with low water-holding capacity and low fertility, as an unproductive soil. The deflated material was transported with northeasterly wind as fresh dunes on the crest and along the side of old fixed dunes in NE-SW directions.

Other evidence of desertification in the region is the recent loose accumulation resulting of wind-blown materials on the slope of mountains as "luft", or in the lee sides, as longitudinal dunes along the corridors in the direction of the wind or as sand sheets in the pediplain. The blown materials lack a developed topsoil, possess high permeability, and are devoid of any vegetation, i.e., loose sand material. Another indicator of desertification is the overgrazed area around El-Fasher town and villages, where the dominant unpalatable species like *calatropis procera* (Usher) and *Cassia tora* (Kawal) are spreading.

Digital Classification

The physical and chemical properties of the main training areas from different landforms show that. In fact, these selected properties (clay, organic carbon, CaCO_3 , moisture, and soil color) greatly affect the reflected

energy of the surface soil. These properties are also considered as cementing agents that determine the structure, consistency, and fertility. The low values of these properties are indicators of soil degradation and desertification.

The digital classification depends mainly on the reflectance of surfaces of the landscape. A digital classification map of 13 classes was produced from five combined bands of TM (Jan. 1986). It was found to be useful in monitoring the desertified areas, but not for differentiating the forms of the same reflectance. The transported sands, as hummocks, small dunes, longitudinal dunes, and sand sheets, are monitored as one class. Their shape and topographic positions can recognize these forms. Another indicator of desertification is the overgrazed areas around El-Fasher town and villages, although they lie in desertified areas, but reflect differently because of the spread of the unpalatable species like *Calatropis procera* and *Cassia tora*.

CONCLUSIONS

Some conclusions from this investigation are summarized below:

1. Supervised digital classification by computer is very useful in monitoring desertification if assisted by ground-truth data and visual interpretation of LANDSAT imagery to select representative training areas.
2. It is a very quick method to monitor vast areas.
3. In digital classification by computer, different bands (spectral resolution) can be combined to give information and can be compared to select the best results.
4. The overgrazed areas around the villages are clearly shown within the deflated areas because of the different reflectance due to the unpalatable vegetation, mainly *Calatropis procera* and *Cassia tora*.
5. Different features (fresh dunes on the crest, sand sheets, lee or "luft" of the hills) have the same reflectance and are mapped the same, but they can be differentiated by their shape and topography.
6. Thematic mapper is more effective and useful for monitoring desertification than a multi-spectral scanner due to its higher geometric and radiometric resolution.
7. The higher spatial resolution of TM systems ($30 \times 30 \text{ m}^2$ pixels) enables a good separation of individual units, while in MSS ($79 \times 56 \text{ m}^2$ pixels) the surface objects constitute mixed pixels, so that the units are mingled and an unambiguous allocation during the classification proves difficult.

REFERENCES

- Darkoh, M.B.K. 1998. The nature, causes, and consequences of desertification in the dry lands of Africa. *Land Degradation Devel.*, 9: 1-20.

- Day, P.R. 1965. Particle fractionation and particle size analysis. p. 545-567. *In*: C.A. Black (Ed.) *Methods of Soil Analysis*, Part 1, Agron. 9, Amer. Soc. Agron. Madison, WI.
- Farmer, G., and T.M.I. Wigley. 1985. Climatic trends for the tropical Africa. *Research Report* for Overseas Dev. Admin. Climatic Res. Land Unit, School of Environ. Sci., Univ. East Anglia, Norwich.
- Goudie, A.S. 1977. *Environmental change*. Oxford. Clarendon Press.
- Ibrahim, N.F. 1984. Ecological imbalance in the Republic of the Sudan, with reference to desertification in Darfur, *Vol. 6*.
- Jackson, M.L. 1965. *Soil chemical analysis*. Prentice Hall, Inc., Englewood Cliffs, N.J., USA.
- Kass, M.A. 1974. *The problems of arid lands. A report to United Nations Development Programme* Nairobi, Kenya.
- Kelly, M., and M. Hulme. 1993. Desertification and climate change. *Tiampo*, 8: 1-7.
- Laki, S.L. 1994. Desertification in Sudan, causes, effects, and policy options. *Intern. J. Sustainable Devel. World Ecol.*, 1: 198-205.
- McLean, E.O. 1982. Soil pH and lime requirements. p. 199-224. *In*: A.L. Page, R.H. Miller, and D.R. Keeney (Ed.) *Methods of soil analysis*, Agron. 9, Part 2, Amer. Soc. Agron. Madison, WI.
- Nichoalson, S.E. 1979. Revised rainfall series for the West African subtropics. *Man-Weather Rev.* 107: 620-623.
- Richards, J.D. 1954. *Diagnosis and improvement of saline and alkaline soils*. U.S. Dept. Agric. *Handbook No. 60*, Washington, D.C. U.S. Gov. Printing Office.
- UNEP, 1994. *United Nations convention to combat desertification*, Nairobi, Kenya.
- Van der Kevie, W. 1973. *Climatic zones of the Sudan. Tech. Bull.* Soil Survey Administration SSA, Wad Medani, Sudan.

Using Generic Agricultural Expertise Models for Technology Transfer

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ABSTRACT

Production management of agricultural products is one of the complex problems that involves many parameters and requires very complicated modeling steps. The complete set of crop management activities could be classified into evaluation, variety selection, diagnosis of possible plant problem, and agricultural practice activities such as irrigation, fertilization, and pest control. In this research, a typology of those agricultural activities is presented and expert models for those activities are identified. These expert models are utilized in developing many expert systems for different crops such as cucumber, citrus, tomato, and lime. In addition, these models can be re-used easily to build expert systems for other crops.

INTRODUCTION

The Central Laboratory for Agricultural Expert System (CLAES) has been gaining considerable experience in developing knowledge-based systems in the agricultural domain. These knowledge-based systems cover different agricultural production management problems and are applied for different crops i.e., cucumber, citrus, tomato, wheat, and lime (Rafea, 1994). The overall production management problems involve, among other aspects, *water and fertilizer requirements, pest control, farm evaluation, and variety selection*. The crop production management problem also includes the lack of experts to support the agricultural growers and the heavy dependence upon the experiences of these experts. This makes the choice of the knowledge-based approach for the solution of this problem a suitable one.

Agricultural problems can be classified into two major tasks, namely, *strategic* and *tactical*. Each of these is subsequently divided into further sub-classes. Strategic problems are concerned with those agricultural practices that are known for each crop beforehand. They include three main domain problems, namely, *farm assessment, plant care, and irrigation and fertilization scheduling*.

Farm assessment contains two types of problems, farm evaluation, and variety selection. Farm evaluation assesses certain farm practices against some parameters for advising the user about the feasibility of cultivating a certain crop. The variety selection is concerned with identifying the most suitable varieties based on the surrounding environment. Irrigation and fertilization scheduling propose the suitable scheduling of applying

both water and fertilizers according to plantation characteristics. The plant care sub-task specifies the most appropriate agricultural operations for a certain plantation, taking into consideration all the factors that affect the way these operations are performed.

The tactical problem class is concerned with how to identify and deal with the non-expected events that might occur in the farm. It includes a complex component called *integrated pest management*. Pest control is an approach to manage pests (e.g., diseases, insects, nematode, weeds, etc.) by combining biological, physical, and chemical control in a way that minimizes economic, health, and environmental risks.

The objective of this paper is to identify and demonstrate an expert model for each problem type (i.e., irrigation, fertilization, diagnosis, treatment, etc.) in the agricultural domain. Section 2 of this paper gives a brief description of the expertise model. Section 3 describes the expertise models for strategic problems. Section 4 describes the expertise models for tactical problems. Section 5 concludes with outcomes and the results of this work.

EXPERTISE MODEL

An expertise model is a model that describes the problem-solving behavior of an expert (Wielinga, 1994). In this paper, the expertise model is represented as a graph structure. The graph has two types of node, *task node* and *data node*. In the models, the *oval shape* represents tasks, while the *rectangular shape* represents data nodes that are consumed and/or produced by the tasks.

The task in the expertise model represents a primitive function (e.g., abstract, match, etc) that uses part of knowledge base in order to transform the input data to output data. For instance, suppose the input data contains soil texture of a certain farm as "sand", the abstract task uses those relations in knowledge base that relate soil texture to their corresponding type to transform soil texture into type "light".

The data nodes include three types, namely, *input data, intermediate data, and output data*. The input data are those data that could be provided by an external agent (user, database, external program, etc.) for describing the underlying problem. The intermediate data are generated by executing a task which is needed for subsequent computations. The output data are produced by executing a task and contains the final solution of the underlying problem.

STRATEGIC MODELS

As mentioned above, the strategic models include three main expertise models, namely, *assessment expertise model*, *plant care expertise model*, and *irrigation and fertilization expertise model*. The following sub-sections describe in detail these expertise models.

Assessment Expertise Model

In the agriculture, the domain assessment system may take many forms, either as in-farm evaluation system, or other problem as in variety selection problem in which we grade all the available varieties against specific farm characteristics. The following sub-sections describe in details these two expertise models.

Farm Evaluation

The objective of farm evaluation system is to assess the feasibility of growing a specific crop type in a specific location (Salah, 1992). The outcome of such a system would be that the conditions of a given location are suitable or unsuitable to cultivate the underlying crop. Also, another assessment outcome may be to perform some agricultural operations prior to cultivating such a crop. If the given location already exists (i.e., the crop is already cultivated), the suitability of that location is assumed and only the recommended actions are proposed.

The expertise model of assessment contains three tasks, namely, *Abstract*, *Match*, and *Recommend*. The *Abstract* task takes the real-farm description related to soil, water, climate, and plant variety as inputs, and transforms these descriptions into comparable parameters to those existing in the farm standard. The *Match* task compares and extracts the deviations from the standards. The *Recommend* task produces the required recommendation based on the output of the previous task.

Variety Selection

The objective of variety selection system is to advise the user about the most suitable varieties of the underlying crop (El-Azhary, 1998a; El-Azhary, 1998b). Also, the system could provide information related to their expected yield, growth-period, and disorders resistance according to the given site-specific environment, such as soil features, water features, climate conditions, market requirements, etc.

The expertise model of variety selection contains three tasks, namely, *Abstract*, *Propose*, and *Revise Variety*. The *Abstract* task takes the real-farm description related to soil, water, climate, and plant variety as inputs and transforms these descriptions into an abstracted farm features, which is used then by the *Propose* task to suggest a list of proposed Varieties. The *Revise* task generates the most suitable varieties from the proposed varieties list, taking into consideration the available information related to the market requirements.

Plant Care Expertise Model

The objective of plant care system is to identify and specify the proper agricultural operations to be done in order to obtain normal growth of the plant and the target yield (Abdelhamid et al., 1999). These decisions are hard to take since the identification and specification of agricultural operations during the plant's lifetime (plant growth stages) should take into consideration many inter-related factors.

The inter-related factors could be categorized into *farm factors*, *plant factors*, and *environmental factors*. The farm factors include parameters related to soil, water, location, irrigation, and drainage systems. The plant factors include parameters such as plant variety, sowing date, and plant conditions. The environmental factors are parameters related to weather and market.

The expertise model of plant care selection contains three tasks, namely, *Abstract*, *Suggest*, and *Assign*. The *Abstract* task takes the real-farm description related to soil, water, climate, and plant variety as inputs and transforms these descriptions into abstracted farm features. These abstracted farm features with the market requirements are used by the *Suggest* task to propose a list of agricultural operations to be done in order to compensate the given farm situation. The *Assign* task specifies, for each agricultural operation, the most suitable values of operation properties, such as material name, material quantity, tool, method, etc.

Irrigation and Fertilization Expertise Model

The main function of the irrigation system is to give a recommendation to the user about the optimum irrigation water quantity and frequency that fits the farmer's situation at any cultivation stage (Edrees et al., 1997). This model takes a number of inputs representing the current situation of the surrounding environment, including plant age, plant growth stages, soil type, water salinity, irrigation system, climate, and some other factors related to the plantation itself such as the drainage quality, water-table level, weed populations, and planting date.

The main function of the fertilization system is to give a recommendation to the user about the optimum quantity of different fertilizers that fits the farmer situation at any cultivation stage. This model takes number of inputs representing the current farm situation, such as water quantity, plant age, growth stage, plant yield, soil type, fertilizers, irrigation system, and water salinity (Edrees et al., 1997).

The expertise models of both irrigation and fertilization system are based on a computational model and contain three tasks, namely, *Abstract*, *Generate Schedule*, and *Revise Schedule* tasks. The *Abstract* task takes farm description parameters such as planting date, plant variety, soil features, climate data, and water properties as inputs and generates specific parameters that are used in the computational model (e.g., plant: KC, root depth, irrigation efficiency, fertilizer factor, etc.).

In irrigation systems, the *Generate Schedule* task computes the suggested irrigation operations (quantity and interval), while the *Fertilization System* generates the fertilization schedule using the outputs that are generated from the previous task. The *Revise Schedule* task adapts the suggested irrigation or fertilization schedules according to some given constraints (e.g., plant vigor).

TACTICAL MODELS

The tactical models include two main expertise models, namely, *diagnosis expertise model* and *treatment expertise model*. The following sub-sections describe in detail these two expertise models.

Diagnosis Expertise Model

The diagnosis system finds out the causes of the user complaints (Rafea, 1995; El-Desouki, 1993). The expertise model consists of three tasks, *Predict*, *Confirm*, and *Verify*. The function of *Predict* task is to predict the possible disorders that cause the user complaint. The *Confirm* task differentiates between the plausible disorders by obtaining additional observations from the user. The *Verify* task verifies the existence of the confirmed disorders by asking about some environmental parameters such as the air humidity, air temperature, soil type, etc.

In some situations, the user may know the causes of the abnormal observations and wants to verify his/her assumption. In this case, the system verifies the user assumption by executing the *Confirm* and *Verify* tasks.

Treatment Expertise Model

The treatment system provides the user with the remedy of identified disorders, either by the user or by the diagnosis system (Rafea, 1995; El-Desouki, 1993). The expertise model consists of four tasks, *Determine Pesticides*, *Select Pesticide*, *Suggest Treatment Plan*, and *Order Treatment Activities*. The function of *Determine Pesticides* task is to determine the suitable pesticides for the current disorder(s), taking into consideration the farm description, such as plant growth stage, the plantation type, soil features, etc.

The function of the *Select Pesticide* task is to interact with the user to select the available pesticide from among the alternative pesticides, if any. The *Suggest Treatment Plan* task proposes detailed treatment operation(s), including pesticide concentration, application type, and tools used in applying the pesticides, etc. The *Order Treatment Activities* task sorts the suggested treatment operations based on the disorder severity.

CONCLUSIONS

This paper proposed the generic conceptual expertise model of the most common agricultural problems. These models have gained from the expertise of CLAES in developing so many expert systems (CUP-TEX, CITEX, LIME, NEPER-WHEAT). They can be re-used and help any researcher to develop any expert system related to the predefined agriculture problems (i.e., irrigation, fertilization, assessment, diagnosis, etc.) for other crops.

REFERENCES

- Abdelhamid, Y., H. Hassan, S. Edrees, S. El-Azhari, M. Mahmoud, and A. Rafea. 1999. Knowledge-sharing approach for a multi-crop plant care expert system. *In: Proc. 7th Intern. Conf. "Artificial Intelligence Application"*, Egypt, Feb. 1999.
- El-Azhary, E. 1998a. Faba bean variety selection design. TR/CLAES/51/98.12, CLAES, ARC, Giza, Egypt, Dec. 1998.
- El-Azhary, E. 1998b. Rice variety selection design. TR/CLAES/44/98.10, CLAES, ARC, Giza, Egypt, Oct. 1998.
- El-Desouki, A., S. Edrees, and S. El-Azhary. 1993. CUPTEX: an integrated expert system for crop management of cucumber. *Proc. "Second National Expert Systems and Development Workshop"* ESADW, May, 1993, MOALR, Cairo, Egypt.
- Edrees, S., S. Al-Azhari, K. Tawfik, and A. Rafea. 1997. Citex: an expert system for citrus production management. *In: Proc. 5th Intern. Conf. "Artificial Intelligence"*, Cairo, Egypt, Feb 27 - Mar. 3, 1997.
- Rafea, A., S. El-Azhary, I. Ibrahim, S. Edrees, and M. Mahmoud. 1995. Experience with the development and deployment of expert systems in agriculture. *Proc. Conf. "Innovative Applications of Artificial Intelligence"* IAAI, Aug. 21-23, Montreal, Quebec, Canada.
- Rafea, A. 1994. Agricultural expert systems development in Egypt. *Proc. Intern. Conf. on "Expert Systems for Development"* ICES - 94, Bangkok, Thailand.
- Salah, A., A. Rafea, and E. Mahmoud. 1992. An expert system for citrus cultivation feasibility. *Proc. 2nd Intern. Conf. "Expert Systems and Development"* ICESD - 92, April 19-23, Cairo, Egypt.
- Wielinga, B. 1994. Expertise model definition document. Univ. Amsterdam, July. Deliverable DM 2.1c, ESPRIT Project P - 5248, /KADS - II/ M2/ UvA/ 026/ 5.0.

Evaluation and Impact of Expert Systems on the Agricultural Sector in Egypt

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ABSTRACT

Although there are many developed expert systems in the world, little consideration has been given to the impacts resulting from their use. There is a difference between the developed expert systems (ES) in the laboratories for research and demonstration and the expert systems that can be applied in the field. The applied expert systems must cover the end-users' requirements and meet some other evaluation criteria. In the Central Laboratory for Agricultural Expert Systems (CLAES), expert Systems are evaluated both in the laboratory and in the fields. In the laboratory evaluation there is a methodology to guarantee that the ES can be used in the field. The field evaluation is achieved by applying field experiments. Those field experiments showed that fields managed by the ES are better than the control fields.

In this paper, the evaluation criteria that guarantee the success of ES deployed in the fields are presented. These evaluation criteria have been applied on three ES applications, namely: CITEX for citrus cultivation, CUPTEX for cucumber cultivation under plastic tunnels, and NEPER for wheat cultivation. Expert systems potentially have several different types or categories of impact relative to the applied domain. Field experiments are used to evaluate the *economical, social, and environmental impacts* of the ES. The economical impact includes the cost, profit, and yield. The social impact includes the effect of the ES on improving the efficiency of the extension workers through improving their general decision-making skills in their jobs. The environmental impact includes the effect of using the ES on water and soil conservation, and also on decreasing the amount of pesticides used in the field.

INTRODUCTION

A lot of expert systems are developed in laboratories for research and demonstration, but little of those systems have been applied in the field. Expert systems potentially have several different types or categories of impact relative to the applied domain. Field experiments are used to evaluate the economical, social, and environmental impacts of the ES. The economical impact includes the cost, profit, and yield. The social impact includes the effect of the ES on improving the efficiency of the extension workers through improving their general decision-making skills in their jobs. The

environmental impact includes the effect of using the ES on water and soil conservation, and also on decreasing the amount of pesticides used in the field.

In the Central Laboratory for Agricultural Expert Systems (CLAES), expert systems are evaluated both in the laboratory and in the field. In the laboratory evaluation, there is a methodology to guarantee that the ES can be used in the field. These evaluation methodologies have been applied on three ES applications, namely: CITEX for citrus cultivation, CUPTEX for cucumber cultivation under plastic tunnels, and NEPER for wheat cultivation. Section 2 describes the laboratory evaluation. In Section 3 the impact on human resource development is discussed. The field evaluation is achieved by applying field experiments to measure the economic and environmental impacts are described in Section 4. The social impacts of using ES in the fields are discussed in Section 5.

LABORATORY EVALUATION

In the laboratory evaluation, there is a methodology to guarantee that ES can be used in the field. This methodology consists of three main procedures. Each procedure is a step in the evaluation methodology. Those procedures or steps are *Verification, Validation, and Evaluation*. Notice that those procedures evolve through a cycle.

Verification is defined as the demonstration of *consistency, completeness, and correctness* of software (Adrion et al., 1982). O'Keefe et al., (1987; 1989; 1990) have defined verification as "Building the system right", that is making sure that the implemented system is functionally matching the proposed design and free of semantic and syntactic errors. Validation is the process whereby the system is tested to show that its performance matches the original requirements of the proposed system. It is defined as the determination of the correctness of the final program or software produced from a development project with respect to the user's needs and requirements (Adrion et al., 1998). As noted by O'Keefe et al., "Validation means building the right system". Evaluation is the process whereby we ensure the *usability, quality, and utility* of the expert system. A complete testing cycle is performed in iterations through which the expert system is updated and refined.

The verification process evolves through two main stages during the development of the expert system: the *development stage* and the *examination stage*. In the

development stage, the developer practised different functions of the implemented systems, looking for potential errors that may exist. This can be accomplished using different techniques. Generally, these techniques fall into two broad categories: *non-case-based* and *case-based*. Non-case-based techniques include tracing, *spying*, and other *traditional debugging* techniques.

Case-based verification techniques are applied by preparing "Typical Cases". These cases should be selected to serve requirements' satisfaction as spelled out in the requirement specification. In the examination stage, the expert system is tested to make sure that it is running properly by testing all the functions of the system trying to examine the performance of the system in different situations. The output of this stage is the *verification report*, which is a document of differences between system design and implementation.

This report serves two aspects. First, undocumented modifications applied to the system during development can be addressed. Second, further errors in implementation can be discovered. As a direct consequence of this report, the design document can be updated to reflect undocumented modifications in the implementation, and implementation can be revised to match design specifications.

specific sub-system. If one sub-system includes more than one specialty, cases are distributed to all experts in different specialties. For example, in the remediation sub-system, we have three specialties: plant pathology, entomology, and nutrition. Therefore, nine experts have participated in the validation of this sub-system. For each specialty, an evaluator is selected to blindly assess the responses of the three human experts and the expert system.

After the evaluation took place, the domain expert participated in the development, the evaluator, and the domain experts participated in the evaluation meet together with the knowledge engineer to discuss the evaluation results till they reach to a consensus. The experiment scores of CUPTEX and CITEX are shown in Figures 1 and 2, respectively (Rafea et al., 1995; Salah et al., 1993). CUPTEX and CITEX are not single expert systems; they are, in effect, a group of systems. Notice that CITEX over-performs human experts in the three sub-systems, while CUPTEX over-performs human experts in two sub-systems, and its score in the third one is 0.75 of the best expert-group. After this experiment, CUPTEX has been developed to reach excellency.

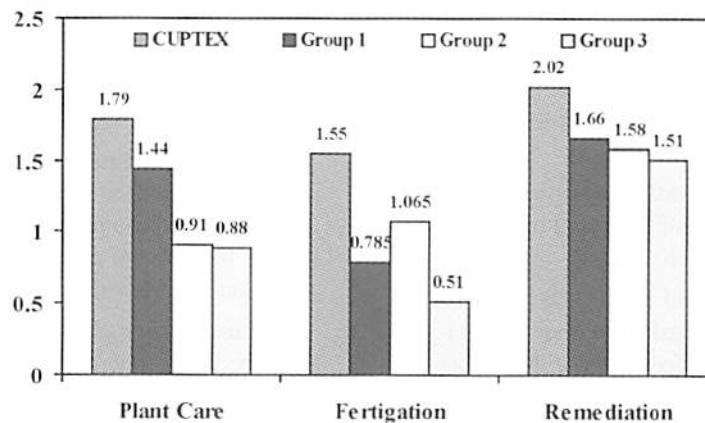


Fig. 1. Expert system evaluation (CUPTEX).

Generating a set of test cases to be solved by both the expert system and the domain expert performs the validation process. Test cases can be generated using the "White-box" testing method (O'Keefe et al., 1987; 1989; 1990). In this method, cases are selected according to different situations of the expert system. The developer compares the results, and a validation report that identifies the differences between the expert system solutions and the domain expert solutions is prepared. According to this report, the developer modifies the expert system.

The evaluation step is to assess the quality, usability, and utility of the expert system from the point of view of human experts other than the domain experts who participate in the system development. The evaluation methodology is to create typical cases and distribute them to three domain experts in the specialty of a

IMPACT ON HUMAN RESOURCE DEVELOPMENT

Before disseminating the expert systems to the end-users, a program is developed to train them on using the system. This training program includes: an introduction to computers, commonly used ready-made packages such as word processors, spread-sheets, database management, expert-system shells, and, finally, the usage of the developed expert system. The idea is to encourage the extension workers to use computers in other activities in addition to the expert system. The training is very useful in testing the developed expert system and getting some input from the trainees who are used for system enhancement.

In order to measure the impact of using ES on the performance of the extension workers, an experiment was conducted during the training of extension workers

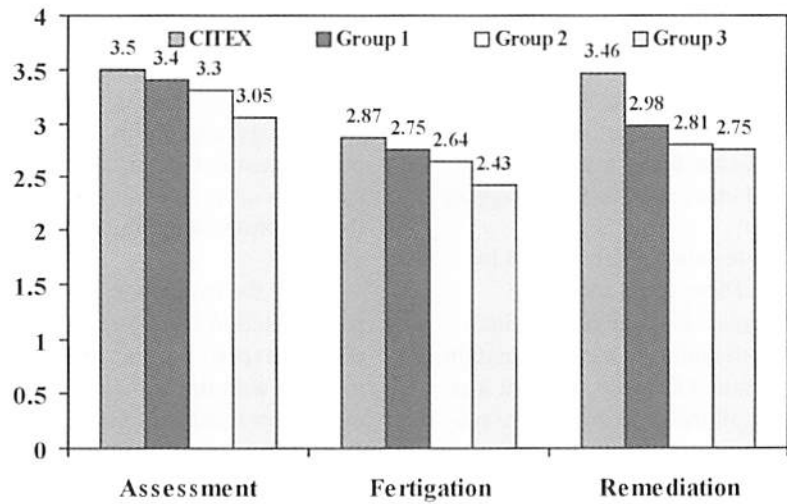


Fig. 2. Expert system evaluation (CITEX).

on CUPTEX and CITEX (ESICM, 1994; Rafea et al., 1996). In this study, 11 extension workers specialized in protected cultivation were involved in the evaluation using CUPTEX and eight extension workers specialized in horticulture were involved in the evaluation using CITEX. The experiment can be summarized in the following steps:

1. Forms are designed for the different sub-systems of CUPTEX and CITEX, namely irrigation, fertilization, verification, and treatment. In effect, the irrigation and fertilization are grouped in one form, whereas the verification and treatment are grouped in another form.
2. Sets of cases covering the different aspects of the developed expert systems are prepared in forms (each set is approximately 20 cases).
3. Each trainee is given around 10 cases before conducting the training and is asked to give his decisions for these cases. The decision is either irrigation schedule, fertilization schedule, symptoms to be observed if a disorder is suspected, or a treatment schedule. It should be noted that some of the trainees have the same cases while some others may have different cases.
4. The training is conducted by letting the trainees run the expert system, providing the inputs in the cases, and observing what the outputs of the expert system

- are. During training, each trainee is given all the cases, and is asked to create some other cases.
5. The same cases (cases before training) are given to each trainee after conducting the training. He is not told that they are the same cases. He also has no access to the forms he filled before training.
6. In all cases, the forms before and after training are analyzed, taking results produced by the expert system as a reference. If the decision given by the trainee matches the expert system, the trainee is given full marks. If the decision given by the trainee mismatches the expert system, the trainee is given zero. In cases where the decision is a quantity or an amount, the trainee is given a score relative to the quantity or amount produced by the expert system. In the other cases, a domain expert who is responsible for this evaluation estimated a score.

Evaluators used all the component of the above-mentioned experiment in their effort to measure the effect of using expert systems on extension personnel performance. The outcome of applying all components of the experiment to both CUPTEX and CITEX are summarized in Table 1. The detailed results are described in the technical report (ESICM, 1994; Rafea et al., 1996).

Table 1. Results summary.

Sub-System	CUPTEX		CITEX		CUPTEX	CITEX
	Before	After	Before	After		
	-----% Score -----				-----% Enhancement----	
Irrigation	40	72	35	64	81	84
Fertilization	25	66	51	67	157	35
Verification	29	52	3	55	80	1464
Treatment	25	48	8	59	90	732
Average	30	59	27	61	102	579

The average score percentages for trainees on the four sub-systems of CUPTEX and CITEX are approximately in the same range (30 and 27). However, if we look at each individual sub-system, we can find a tangible difference in verification and treatment sub-systems in favor of CUPTEX trainees, while there was a tangible difference in the fertilization sub-system in favor of CITEX trainees. This remark was related with the percentage of enhancement.

The best enhancement for CUPTEX is in the fertilization sub-system, whereas the best enhancement for CITEX is in the verification and treatment sub-systems. The average enhancement for CITEX is approximately six times the average enhancement for CUPTEX. This is because the performance of the CITEX trainees in the verification and treatment sub-systems are very low (3 and 8), and consequently their performance has increased dramatically after using the system (percentages of enhancement are 1464 and 732).

The results of this study suggest that expert system can be an effective training tool in agriculture extension programs. The experiment showed that there is an enhancement in a very short time in the performance of extension workers after the usage of the expert systems. Although the expert systems developed are verified with domain experts, there is always room for further improvement. Regardless of the quantitative measures which may be arguable about how these values are calculated, the trend of the trainees is accepting the advice given by the system, and that is why their measured performances are increasing, taking the decisions of the expert system as a reference.

FIELD EVALUATION: ECONOMICAL AND ENVIRONMENTAL IMPACT

Many experiments were conducted in the last few years, especially for CUPTEX (El-Egazy et al., 1996; Wally et al., 1997) and NEPER expert systems (CLAES, 1996; CLAES, 1999). The objectives of those experiments were to validate the system in the field and to measure the impact of using the system. The first experiment was conducted in different locations by selecting two tunnels at the same area and location: one was to be cultivated based on CUPTEX without any interference from the agriculture engineer or any specialist, and the other one was to be cultivated as usual; this is a control tunnel. The second experiment was conducted at different locations by selecting two fields at the same area and location: one was to be cultivated using NEPER Wheat without any interference from the agricultural engineer or any specialist, and the other one was to be cultivated as usual; this is a control field.

In order to get the best results from the experiment, the following issues and activities are considered and followed:

- Data about sites of the experiment, expert systems, and control fields were collected. Data include soil type, irrigation system, area, etc. All data were

recorded in a specially designed form and entered in a PC database.

- Data collected during field visits were recorded in another form and entered in the same PC database. Also, data were collected from the expert system and control fields.
- Formal training in CLAES and in-site training on the usage of the expert system was conducted for the staff of the selected sites that are going to use the system.
- A computer engineer from CLAES was responsible for supporting the site staff on the usage of the system and handling trouble-shooting problems of hardware and software.
- A periodical field visits and on-job extension workers from CLAES conducted training.
- Monthly reports were submitted.

The experiments data, analyses, and results are published in technical reports. The following sub-sections, summarized those results, form two aspects: *economical and environmental impact*.

Expert System Economic Impact

1. CUPTEX System

Two experiments were conducted for CUPTEX expert system (El-Egazy et al., 1996; Wally et al., 1997) in two different seasons and different number of tunnels; the first one consisted of a total of 28 tunnels selected for conducting the experiment. These tunnels were equally divided so that 14 tunnels were assigned to utilize CUPTEX in handling all operations for irrigation, fertilization, plant caring, diagnosis, and treatment of any occurrence of disorders, and the other 14 tunnels were to be managed in the usual practice, and acts as control. The 28 fields were located in seven different geographical areas, namely, Dokki, Haram, Tokh, Mariot, Bostan, Noubaria, and Bosally.

The second experiment consisted of a total of 40 tunnels. These tunnels were equally divided so that 20 tunnels were assigned to utilize CUPTEX in handling all operations for irrigation, fertilization, plant caring, diagnosis, and treatment of any occurrence of disorders, and the other 20 tunnels were to be managed in the usual practice and act as a control.

The result of the first experiment (El-Egazy et al., 1996) showed that the average total cost was decreased, while the yield and net profit were increased in CUPTEX tunnels. The total costs of the CUPTEX tunnels were decreased by 171 Egyptian pounds (L.E.), which represented 6.9% savings. It was found that the average production increase was 1024 kg, which represented 19.8% increase in the production. Consequently, the net profit was increased by 1036 L.E. This represented a 41% increase in net profit.

In the second experiment (Wally et al., 1997), the average total cost decreased, while the yield and net profit increased in CUPTEX tunnels. The total costs of

the CUPTEX tunnels decreased by 161 LE, i.e., 10.9%. It was found that the average production increase was 545 kg, which represents 25.1% increase in the production. Consequently, the net profit increase was 838 LE. This represents a 56.9% increase in net profit.

2. NEPER Wheat

Two experiments were conducted in two different seasons for the NEPER expert system (CLAES, 1996; CLAES, 1999). The two experiments had the same number of fields; both of them consisted of a total number of 32 fields selected for conducting the experiment. These fields were equally divided so that 16 fields were assigned to utilize NEPER and managed by the expert system, and the other 16 fields were to be managed in the usual practice, and act as a control. The 32 fields were located in three different geographical areas, namely: Noubaria, Gemiza, and Sharkia. In Noubaria, two sites were selected to cover the different types of soil at that area. One of those sites was located in Bostan and the other one was in Banger El-Sokar.

The first experiment covered only the diagnosis and treatment part of the NEPER Wheat Expert System, including Weed Identification. The second one included the strategic part and tactical part. Strategic part includes six sub-systems called: *Variety Selection*, *Pre-cultivation*, *Pest Control*, *Tillage*, *Planting*, *Irrigation and Fertilization*, and *Harvest*. The tactical part includes two sub-systems called *Diagnosis* and *Weed Identification*; each of them includes the treatment function.

In the first experiment (CLAES, 1996), the averages of treatment costs, yields, and straw per feddan was calculated for both NEPER and the control fields. By taking the averages of treatment cost, yield, and straw per feddan, it was found that the net production increase was 449 LE. This represents a 26% increase in production.

In the second experiment (CLAES, 1999), which included *Variety Selection*, *Pre-cultivation Pest Control*, *Tillage*, *Planting*, *Irrigation and Fertilization*, and *Harvest*, in addition to the *Diagnosis* and *Treatment*, the averages of total costs, yields, and straw per feddan was calculated for both the expert system and the control fields. The average yield of the expert system fields was 235 LE, more than the average yield of the control fields, which represents about 14% increase in production. The average cost of cultivating the ES fields was less than the control fields by LE 60, which represents a 7% decrease in costs. Consequently, the net profit of the ES fields was more than the profit gained by the control fields by 295 LE, which represents a 34% increase in net profit.

Environmental Impact

The conservation of natural resources has two aspects. The first is pertinent to the management of these resources on the macro-level, such as controlling the expansion of urban development in order not to lose

agricultural land. The second is concerned with the management of these resources on the micro-level, such as adding chemical fertilizers to the soil. In this paper, the focus is on the status of the water and land resources because they are the two main resources related to our work on crop management expert systems.

Water is the most scarce resource in Egypt, since its supply is nearly fixed and water demand for different sectors is continuously increasing. The water supply can be classified into three categories: *surface water*, *groundwater*, and *water reuse after treatment*, either from agricultural drainage or domestic usage. The decision-makers concerned with water resource management in Egypt are challenged by how to balance the limited water supply with an increasing water demand for the future, since water is the major constraint for land expansion to satisfy food self-sufficiency. Another challenge is how to reduce the water pollution resulting from using chemical fertilizers and pesticides. After water, land is the major limiting factor for sustainable agricultural development (Rafea, 1996).

There are two problems facing decision-makers to conserve water resources, namely, the efficient utilization of water resources, and pollution resulting from the usage of chemical fertilizers and pesticides. Regarding soil conservation, there are two main problems, namely, the urban expansion, and the soil degradation resulting from excessive use of fertilizers and other bad agricultural practices. Therefore, the main contribution of expert systems for soil and water conservation is to transfer the agricultural practices according to certain strategy or a combination of strategies, namely, *environmental sustainability*, *economical sustainability*, and/or *social sustainability*.

In the expert systems that have been built so far, we are concerned with economic sustainability, taking into consideration the environmental sustainability in the second place. In other words, we are trying to acquire the recommendations that optimize the output relative to agricultural inputs. As a consequence, environmental conservation is achieved, because no extra inputs, such as water, fertilizers, and pesticides are provided without a return in the yield.

The results of experiments conducted for the two expert systems agree with the goals of environmental conservation. Note that all fields managed by the expert system have used fewer resources in terms of fertilizers and pesticides than the control fields, and hence conserve the environment. The cost is an indicator of the increase or decrease of using chemicals in general. Hence, we have used the cost as a factor in determining the quantity of fertilizers and pesticides used.

The average cost of fertilizers and pesticides used by CUPTEX tunnels was less than the control tunnels in the first experiment by 171 LE/tunnel (El-Egazy et al., 1996) and by 161.6 LE /tunnel, in the second experiment (Wally et al., 1997). This reduction in using chemicals did not affect the yield but, on the contrary,

yields were increased by 1024 and 545 LE /tunnel, respectively.

The average cost of pesticides used by NEPER wheat fields in the first experiment (CLAES, 1996) was more than the control fields by 15 LE /Feddan, but the production increased by 465 LE /feddan. Notice that the increase of cost in this experiment was negligible. In the second experiment (CLAES, 1999), the average cost of fertilizers and pesticides used by NEPER Wheat fields was less than the control fields by 61 LE /feddan and the production increased by 494 LE /feddan. In fact, this indicates that changes to the NEPER Wheat system have made it more compliant to the goals of resource management and environmental conservation.

In the experiment of NEPER Wheat expert system, the average water quantity used to produce one ardeb of wheat in the expert system fields was 112.74 m³ water, while in the control fields the farmers used 152.58 m³ water on average to produce the same quantity of wheat. This represents a 35% decrease in the use of irrigation water (CLAES 1999).

We also found that the average water quantity needed to produce one ton of cucumber, using CUPTEX expert system, during an early summer season experiment, was 45.28 m³, while 46 m³ was used to produce the same quantity of cucumber in control fields (El-Egazy et al., 1996). In a second experiment conducted during the spring season, the average water quantity needed to produce one ton of cucumber using the expert system was 37.1 m³, while 37.1 m³ was used to produce the same quantity of cucumber in control fields (Wally et al., 1997). This represents a decrease of 3% and 11%, respectively, in use of irrigation water.

SOCIAL IMPACT

The objectives of social impact was to assess the reliability of expert systems in field application, and to include the practical and users' suggestions for enhancement of expert system capabilities and efficiency to satisfy most of the users' needs.

To achieve the above objectives, field experiments were conducted at a wide range of geographical areas in Egypt. It was decided to represent all stations where there is an expert system in operation in this study (Nawar et al., 1997). The unit of study was the operator of expert system station who is assigned one unit of the expert system for at least six months. All operators were from among those who were exposed to a previous training on computer application and developed expert system. Classification of operators was based on both the number of training courses they were exposed to and the period of their practical experience working with expert system.

According to the specific objectives of this study, a special questionnaire was designed, pre-tested, and applied at the operators' level. The survey was undertaken after meeting with all operators during their periodical meetings with the CLAES staff to clarify all aspects and objectives of this survey.

In the study, the following aspects were considered:

1. The number of courses attended by the operators.
2. The operating period of the expert system.
3. The involvement of operators in training others on using expert system.
4. The number of other persons trained by the operator.
5. The number of others sharing the trained operator in operating the system.
6. The frequency of operating the system during the production season.
7. The frequency of maintenance of the computer and the system.

A significant relationship was found between the number of training courses attended and the operating period of the system. It was found that the more training courses the operators attended the more skills and positive attitudes they acquire. It was found that 83% of those who were exposed to more courses respond positively. This motivates them to train others on the use of expert system as a source of self-assertion. This trend of relationship should be supported by periodic refresher training courses for the existing operators and new ones.

The extension officers' training and frequency of operating the system were 56% of the group used the system at least once daily, while 16% used it several times daily. This means that about two thirds of the group studied had intensive use of the system during the production season. Those intensive users represented 66.7% of those who attended four or more courses, while they represented 72.7% of those who attended two to three courses.

CONCLUSIONS

In this paper we have shown that not only is good laboratory evaluation is essential for preparing ES for field-testing, but it also increases the benefits gained from the field-testing. We have also shown that training has many benefits, both on the trainees and on the use of ES in the field. Field experiments have shown that fields managed by the ES are better than the control fields; the experiments proved that ES are very useful in reducing costs, and increasing yield. Regarding the field test for CUPTEX and NEPER, we have seen that ES have out-performed the human experts. The dissemination of that ES nationwide will be very effective. The second outcome of those experiments is that less pesticide can be used, and hence better environment conservation. As our initial strategy was to optimize the economic aspect of the agricultural process, we get an agricultural practice which is less harmful to the environment.

REFERENCES

- Adrion, W., M. Branstad, and J. Cherniovsky. 1982. Validation, verification, and testing of computer software. *ACM Computing Surveys*, Vol. 14, No. 2.
- CLAES, 1996. Validating NEPER wheat expert system and CERES wheat simulation model. *Tech. Report*, No. TR/CLAES/ATUT (1)/3/96. 12.
- CLAES, 1999. Validating NEPER wheat expert system field-testing for season. 97/ 98, *Tech. Report*, No. TR/ CLAES/ ATUT(w4)/ 5/ 99. 2, 1996.
- El-Desouki, A., A. Rafea, and M. Youssef. 1992. Verification and validation in knowledge based systems. *Proc. "First International Conference on Expert Systems and Development" (ICESD - 92)*, MOALR, Cairo, Egypt.
- El-Desouki, A., S. Edrees, and S. El-Azhari. 1993. CUPTEX: An integrated expert system for crop management of cucumber. *Proc. "Second National Expert Systems and Development Workshop" (ESADW - 93)*, MOALR, Cairo, Egypt.
- El-Egazy, M., M. Mahmoud, and N. Galal. 1996. A comparison study for cultivating cucumber under plastic tunnels using expert system (CUPTEX) compared with control tunnels for spring season 1995 *Tech. Report*. (TR/CLAES/12/97. 5). CLAES, ARC. Min. Agric. & Land Reclamation, Egypt.
- ESICM, 1994. A study of the needs assessment for expert systems in the agricultural sector in Egypt. *Tech. Report* (TR - 88 - 024 - 33). "Expert Systems for Improved Crop Management Project". Min. Agric. & Land Reclamation, Egypt.
- Benbasat, I., and J.S. Dhaliwal. 1989. A framework for validation of knowledge acquisition. *Knowledge Acquisition*, 1(2): 215-233.
- Nazareth, D. 1989. Issues in the verification of knowledge in rule- based system; *Intern. J. Man-Machine Studies*, 30: 255-271.
- O' Keefe, R.M. 1990. Consultant Report, Report No. CR - 88 - 024 - 08 "Expert Systems for Improved Crop Management Project". Project No. EGY/88/024, Aug. 1990.
- O' Keefe, R.M., O. Balci, and E.P. Smith. 1987. Validating expert system performance. *IEEE Expert*, 2(4): 81-90.
- O' Leary, D., and R. O'Keefe. 1989. Verifying and validating expert systems. *Tutorial: MP4, IJCAI*.
- Rafea, A. 1996. Natural resources conservation and crop management expert systems, *Workshop on "Decision Support Systems for Sustainable Development"*, UNU/IIST, Macau. 26 Feb. - 8 Mar.
- Rafea, A., S. El-Azhari, I. Ibrahim, S. Edrees, and M. Mahmoud. 1995. Experience with the development and deployment of expert systems in agriculture. *Proc. "IAAI - 95 Conference"*, Montreal, Canada.
- Rafea, A., and K. Shaalan. 1996. Using expert systems as a training tool in the agriculture sector in Egypt. *Expert Systems with Applications - An International Journal*, Pergamon.
- Rafea, A., M. Warkentin, and S. Ruth. 1991. An expert system for cucumber production in plastic tunnel. *Proc. "World Congress on Expert Systems"*, Florida, USA
- Salah, A., A. Rafea, and E. Mohamed. 1992. An expert system for citrus cultivation feasibility. *Proc. "First International Conference on Expert Systems and Development" (ICESD - 92)*, MOALR, Cairo, Egypt.
- Salah, A., H. Hassan, K. Tawfik, I. Ibrahim, and H. Farhat. 1993. CITEC: An expert system for citrus crop management. *Proc. "Second National Expert Systems and Development Workshop" (ESADW - 93)*, MOALR, Cairo, Egypt.
- Wally N., M. Mahmoud, N. Galal, and E. Mohamed. 1997. A comparison study for cultivating cucumber under plastic tunnels using expert system (CUPTEX) compared with control tunnels for summer season 1995. *Tech Report* No. (TR/CLAES/12/97.5). CLAES, ARC. Min. Agric. & Land Reclamation, Egypt.

VIII. Biotechnology

Modified Procedure for Rapid Recovery of Transgenic Wheat Plants

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ABSTRACT

Five-day-old calli derived from immature embryos of wheat (*T. aestivum*), cultivar "Hiline", were bombarded with the plasmid pAB₅ containing *bar* (phosphinothricin acetyl transferase, PAT) gene, as a selectable marker for resistance to the herbicide Bialaphos, driven by CaMV 35S promoter and *uidA* (β -glucuronidase, GUS) gene, as a reporter gene, driven by rice actin-1 promoter. Selection pressures of 0 and 5 mg/L Bialaphos were only carried out during the callus induction period of 4 weeks. Regenerable calli from both categories were transferred to 1 mg/L Bialaphos for regeneration, and to 2 mg/L Bialaphos for rooting. The performance of roots under selection was the first reliable criterion we used to identify the putative transgenic plants, which was confirmed by *bar* gene expression assays, e.g., leaf painting (200 mg/L Basta) and PAT. Three transformants were obtained, but from the no-selection category during callus induction.

In general, we found that Bialaphos selection during callus induction markedly reduced the regenerability of wheat calli. Besides, Bialaphos selection takes 6-8 weeks to likely identify Bialaphos-resistant calli. PCR, followed by southern blotting, indicated the presence of the introduced foreign full-length genes in the genomic DNA background of the three transgenic plants. The histochemical GUS assay was negative in transformed shoots and roots, while strongly positive in pollen grains (1:1 segregation). Therefore, GUS expression in shoots and roots of our three transgenic plants was proven by using dot blot and quantitatively by using ELISA. Since actin-1 promoter was frequently reported as a strong promoter to induce expression in different plant systems, we think that histochemical assay is not sufficient to identify GUS expression in transgenic wheat plants.

INTRODUCTION

Establishment of transformation protocol in hexaploid wheat, as the largest crop in total production and cultivation area, has gained a worldwide attention and encouragement. Many recent attempts have been made to increase both regeneration and stable transformation efficiencies with some limitations (Redway et al., 1990; Vasil et al., 1992). The most successful protocol in

wheat transformation was developed by Weeks et al. (1993), where they used young immature embryo as the target tissue and micro-projectile bombardment as the DNA delivery system. This protocol was considered as the shortest in producing fertile transgenic wheat plants. The wheat cultivar "Bobwhite" was the most widely used in transformation attempts.

In the present study, we report the use of even shorter protocol than that developed by Weeks et al. (1993). Besides, we have used no selection pressure during callus induction as an easy way in maintaining regenerability of transformed cells. Our protocol has exclusively optimized for Hiline cultivar. We also report the disadvantage of using the histochemical GUS assay in scoring transformed wheat shoots and roots.

MATERIALS AND METHODS

Plant Expression Vectors

The plasmid expression vector pAB₅ (10.01 kb) was constructed to use in transforming wheat immature embryos. A 2.65 KB *EcoRI/PstI* fragment derived from pTAB₁₀ [which contains the *bar* gene (De Block et al., 1987) driven by the *CaMV 35S* promoter and the *OCS* terminator] was ligated into pBluescript II SK +/- to obtain pAB₂. A 4.4 KB *XbaI/PstI* fragment containing the GUS cassette derived from pAct1D (McElroy et al., 1991) was inserted into pAB₂ to obtain pAB₅.

Wheat Transformation

Immature embryos were isolated from greenhouse grown wheat cv "Hi-Line", an elite Montana spring wheat variety (Lanning et al., 1992), and pre-cultured for 5 d in the dark on modified MS medium as reported by Weeks et al. (1993) before bombardment. Preparation of gold particles and coating with plasmid DNA was as described by the manufacturer (Bio-Rad, Hercules, CA, USA). One bombardment was done for each scutellar tissue, while maintaining the shortest distance between the stopping screen and the targeted tissue and a gas pressure of 1550 psi. Osmotic treatment before and after bombardment was performed according to Vain et al. (1993).

Bombarded tissues were then placed on the same culture medium supplemented with either 0 or 5 mg/L Bialaphos (a gift from Dr. Hiroyuki Anzai, Meiji Seika Kaisha, LTD, Japan) for 4 weeks at 25°C in the dark.

Bialaphos-resistant calli, as well as those under no selection, were transferred to regeneration medium (MS medium containing 2% sucrose, 0.15 mg/L thidiazuron and 1 mg/L bialaphos) for about 2 weeks at 25°C under a 16-h photoperiod (66 $\mu\text{mol m}^{-2}\text{s}^{-1}$). Regenerated shoots were transferred to rooting medium (half-strength MS medium and 2 mg/L Bialaphos) for 2-3 weeks at 25°C under the above light conditions.

Plantlets were transferred from rooting medium to greenhouse potting mix Sunshine mix #1 (Fisons, Canada). Greenhouse day/night temperatures were 25 $\pm$ 2 C/19°C under a 16-h photoperiod with supplemental lights to provide 150 $\mu\text{mol m}^{-2}\text{s}^{-1}$ PPFD. Primary transformants were tested using a leaf-painting assay with a 0.1% aqueous solution of Glufosinate 200™ (AgrEvo USA Company, NJ, USA) containing 20% ammonium glufosinate.

PCR-Southern Blot Hybridization

Genomic DNA was extracted from the three putative transgenic as well as control plants as described by Dellaporta et al. (1983). PCR was performed to amplify partial-length *bar* (400 bp) and *uidA* (1200 bp) genes using specific primers (~30 mer), which were designed and synthesized at AGERI, then electrophoresed in 1% agarose gels, and the DNA was transferred onto Hybond N⁺ nylon membrane (Amersham, Arlington Heights, ILL, USA). Further processing, pre-hybridization, hybridization (against probes of either gene) and washings were performed according to the manufacturer's protocols.

Enzyme Assays for *bar* and *uidA* Genes

GUS activity was performed in leaves, roots and pollen of the three transgenics as well as the non-transgenics according to Jefferson et al. (1987), while PAT (phosphinothricin acetyl transferase) acetylation assay was performed only in leaves according to Spencer et al. (1990), with minor modifications.

ELISA and Dot Blot of β -glucuronidase

Total leaf and root protein extracts were prepared and analyzed for β -glucuronidase content using ELISA and dot-blot techniques. ELISA was performed according to Edwards and Gooper (1985). Dot-blotting was performed using the BIO-RAD Mini Trans-Blot apparatus according to the manufacturer's instructions. Processing of the dot-blots was performed following the instructions in Promega Protocols and Applications Guide (1991). Nitrocellulose membranes were incubated in anti-GUS antibody (1 $\mu\text{g/ml}$) developed at AGERI for 30 min followed by incubation in goat anti-rabbit IgG alkaline phosphatase conjugate (Promega, Madison, WI, USA). β -glucuronidase enzyme was detected using 4-nitroblue-tetrazolium (NBT) and 5-bromo-4-chloro-3-indolyl-phosphate (BCIP) substrates (Promega, Madison, WI, USA).

RESULTS

Transformation Protocol

Five-day-old wheat immature embryos were shown to be active in cell division. Embryos that recovered no cell cluster at that age were excluded from bombardment. If embryos of "Hiline" cultivar were excised and placed with the scutellum side exposed, they are not able to perform cell division. We also report that the callus-induction period of 4 weeks is ideal for maintaining the regenerability of transformed cells. Bialaphos selection during callus induction markedly reduced the regenerability of wheat calli, which might explain the recovery of transgenic plants only after no selection pressure. Bialaphos selection needs 6-8 weeks to likely identify bialaphos-resistant calli. In addition, shortening callus induction period (in the present findings) to 4 weeks was shown to result in higher rate of callus regeneration. In the rooting medium, the performance of roots under 2-mg/L-selection level was the first reliable criterion we used to identify the putative transgenic plants. This criterion was confirmed, later, by *bar* as well as *uidA* gene integration and expression assays. In general, three transgenic lines, i.e., 290, 306, and 314 were developed in the present study.

Analyses of Transgenic Wheat Plants

Leaf Painting

This procedure reflects the expression of *bar* gene in the genomic background of wheat. At least, two leaves were painted for each plant, which indicated a total of three independent transgenic T₀ plants (lines 290, 306, and 314). These three plants were generated from three transformation experiments (600 immature embryos each for no selection) for *bar* gene, while the parental plant of Hi-Line cultivar was used as non-transgenic control.

PCR-Southern Analysis

This analysis reflects the integration of either gene in the wheat genome. The three transgenic plant lines expressing *bar* gene were tested for the integration of *bar* and *uidA* genes using PCR. Expected sizes of 400 and 1200 bp were recovered as PCR products for both *bar* (2a) and *uidA* genes, respectively. As a control, pAB₅ plasmid was used and gave positive results. The results of southern analysis for each gene were shown to be highly positive. It was intended to use each gene as a probe for hybridization with its subsequent PCR product to ensure the identity of the integrated transgenes in the resulted transgenic wheat plants. However, the results of the non-transgenic control were negative.

Enzyme Assays for *bar* and *uidA* Genes

The level of PAT enzyme activity as measured by the production of acetylated form of phosphinothricin in leaf tips of the three transgenic plants (indicated by the

arrow) was high, but non-detectable in the negative control of "Hiline" cultivar. Leaves and roots of the three transgenic plants GUS negative in the histochemical assay, although mature pollen grains of the three transformants were stained. An expected ratio of 1:1 (GUS⁺: GUS⁻) was given at T₀. No explanation is given for this conflicting GUS expression in the different tissues. Other publications in wheat transformation indicated that GUS activity was potent in leaves of transgenic plants of "Bobwhite" cultivar. We think that GUS expression in leaves and roots might be genotype specific.

ELISA and Dot Blot Analyses

The results of ELISA and dot blot, which were done to test the expression of GUS gene in the roots and shoots of the transgenic plants, were negative when assayed for GUS activity. It was clear that GUS gene is expressed in the three transgenic plants giving rise to the advantage of using these analyses over the histochemical GUS assay.

DISCUSSION

Several features of the transformation procedure described in this report will facilitate its adoption by other laboratories. Our results demonstrate that micro-projectile bombardment can be efficiently used to obtain fertile transgenic wheat plants from scutellar tissue. The procedure uses standardized conditions for DNA delivery and the commercially available Biolistics device.

The procedure we used to obtain transformants has the advantages over that previously published in wheat: a) reproducible, giving one transgenic plant lines per 600 embryos bombarded, the three transgenic lines were fertile, b) high callus regenerability, c) no selection pressure is needed at the callus-induction period, and d) rapid, where less than 5 months elapsed between excision of embryos for bombardment and anthesis of the transformed T₀ plants. As a general comment, the ability of explants to root in the presence of Bialaphos was a reliable indicator of stable integration of the *bar* transgene. In addition, results of the PAT assay were indicative of transformation, in disagreement with Weeks et al. (1993).

Leaf painting of plantlets with Basta is a fast and highly efficient method to identify transformed plants. PCR followed by southern blot analysis showed that the three plants which were positive for the integration of *bar* and *uidA* genes. The integration of only one copy is desirable for practical genetic engineering to avoid potential problems of co-suppression of expression caused by multiple gene integration (Napoli et al., 1990).

It is not known whether plants originate from a single cell or from multicellular structures within the scutellum. There are some indications that primary transformants were not chimeric and were probably of

single-cell origin. In our experiments the *uidA* marker gene had a 1:1 ratio in pollen grains of all plants tested and progeny from these plants showed a 3:1 Mendelian segregation for both genes (tested by leaf painting). This indicated that enzyme activity of either gene was encoded and transmitted as a single dominant allele.

The relatively low transformation frequency obtained in this work makes further improvement of the transformation conditions desirable. However, the fact that a high number of explants can be treated in a quick and easy manner, now opens the way for embryos bombarded during the first few days after culture were more prone to bombardment damage than embryos, which had been in culture for longer periods of time (2-3 weeks). Transformation methodology will also allow a biotechnological approach to modification of important traits of wheat, including environmental stress tolerance, pathogen resistance and bread-making quality.

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REFERENCES

- Dellaporta, S.L., J. Wood, and J.B. Hicks. 1983. A plant DNA miniprep: Version II. *Plant Mol. Biol. Rep.* 4: 19-21.
- De Block, M., J. Botterman, M. Vandewiele, J. Dockx, C. Thoen, V. Gossele, N.R. Movva, C. Thompson, M. Van-Montague, and J. Leemans. 1987. Engineering herbicide resistance in plants by expression of a detoxifying enzyme. *EMBO J.* 6: 2513-2518.
- Edwards, M.L., and J.I. Gooper. 1985. Plant virus detection using a new form of indirect ELISA. *J. Virol. Methods.* 11: 309-319.
- Jefferson, R.A., T.A. Kavanagh, and M.W. Bevan. 1987. GUS fusions: β -glucuronidase as a sensitive and versatile gene fusion marker in higher plants. *EMBO J.* 6: 3901-3907.
- Lanning, S.P., L.E. Talbert, F.H. McNeal, W.L. Alexander, C.F. McGuire, H. Bowman, G. Carlson, G. Jackson, J. Eckhoff, G. Kushnak, V. Stewart, and G. Stallknecht. 1992. Registration of "Hi-Line" wheat. *Crop Sci.* 32: 283-284.
- McElroy, D., A.D. Blowers, B. Jenes, and R. Wu. 1991. Construction of expression vector based on the rice actin 1 (*Act 1*) 5' region for use in monocot transformation. *Mol. Gen. Genet.* 231: 150-160.
- Napoli, C., C. Lemicux, and R. Jorgensen. 1990. Introduction of a chimeric chalcone synthase gene into petunia results in reversible co-suppression of homologous genes in trans. *Plant Cell.* 2: 279-289.

- Redway, F.A., V. Vasil, D. Lu, and I.K. Vasil. 1990. Identification of callus types for long-term maintenance and regeneration from commercial cultivars of wheat (*Triticum aestivum* L.). *Theor. Appl. Genet.* 79: 609-617.
- Spencer, T.M., W.J. Gordon-Kamm, R.J. Daines, W.G. Start, and P.G. Lemaux. 1990. Bialaphos selection of stable transformation from maize cell culture. *Theor. Appl. Genet.* 179: 625-631.
- Vain, P., M.D. McMullen, and J.J. Finer. 1993. Osmotic treatment enhances particle bombardment-mediated transient and stable transformation of maize. *Plant Cell Rep.* 12: 84-88.
- Vasil, V, A. Castillo, M. Fromm, and I. Vasil. 1992. Herbicide resistant fertile transgenic wheat plants obtained by microprojectile bombardment of regenerable embryogenic callus. *Bio Technology* 10: 667-674.
- Weeks, J.T., O.D. Anderson, and A.E. Blechl. 1993. Rapid production of multiple independent lines of fertile transgenic wheat (*Triticum aestivum* L.). *Plant Physiol.* 102: 1077-1084.

Construction of a Genebank for an Extremely Halophilic Bacterium (*Halo bacterium halobium*) in *E. coli*.

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ABSTRACT

Soil salinity is becoming a major threat to agriculture, especially in the arid and semi-arid regions of the world. A long-term project was developed at IPA with the aim of studying the molecular basis of salinity tolerance in both plants and microorganisms. This study forms one part of the project investigating an extremely halophilic bacterium (*Halobacterium halobium*) isolated from highly salt-affected soils in the southern parts of Iraq. For this purpose, an efficient genebank was constructed using the replacement bacteriophage, lambda EMBL₃ vector. This was done by the isolation of bacterial chromosomal DNA, which was then partially digested with *Sau3a* restriction enzyme. DNA fragments ranging between 10-20 KB were ligated to the double-digested vector arms. The *in vitro* packaged recombinant phages were plated on genetically selective strains of *E. coli* (NM539). Recombinant plaques in the order of 1.2×10^3 were obtained representing over 90% of bacterial genes.

INTRODUCTION

Saline soils cover a substantial portion of Iraq's land surface, a fact that is common in most of the arid and semi-arid regions in the world (Shannon, 1984). Plants vary in their tolerance to salinity, which affects seed germination and substantially reduces both yield quantity and quality (Rush and Epstein, 1976; Al-Shamma, 1982). Salinity tolerance is considered as one of the complex characters and is controlled by a group of genes (Moshe, 1985). Despite the fact that conventional breeding methods have been able to release a number of plant cultivars that tolerate salinity, these methods are somewhat slow and generally are limited only to individuals within same species, due to the genetic barrier.

Since the advent of genetic engineering, techniques have raised the possibility to isolate and transfer individual gene regulating different characters, i.e., crossing genetic barrier, increasing attention is being paid to developing transgenic plants through transfer of bacterial and/or wild plant genes into cultivated plant cells (Valentine, 1984). One of the bacterial strains that may be considered as a potential candidate for such studies is the extremely halophile *Halobacterium halobium*. This bacterium is an obligate halophile and can grow in high levels of salinity media with a NaCl concentration ranging between 15-30% (Kushner, 1978). It was

isolated worldwide from different salty environments, e.g., from the Dead Sea (Nissenbaum, 1975) and the Nijeran Valley in Egypt (Lomhoof et al., 1978). In Iraq, it was isolated by Al-Doori et al (1993a) from southern salty parts of the country.

Many molecular biology studies on the halophilic bacterium have been reported regarding its genome organization and plasmid content (Pfeifer, 1981). The isolation of bacteriorhodopsin gene from a genebank prepared using pBR322 plasmid was reported by Vogelsang et al. (1983). Bacterioopsin gene was also isolated from a genebank prepared using the cosmid pJB8 (Belatch et al. 1983). A physical map of Hb *halobium* strain DS2 was reported by Charlibois et al. (1991) using six different restriction enzymes. In Iraq, only a few such investigations were reported, e.g., attempts to transform salt-sensitive mutant of this bacteria into salt tolerant ones (Abraham and Ammash, 1993).

In this work, we describe the construction of an efficient genebank for the *Hb. Halobium*. The bacteriophage Lambda EMBL₃ (Fig.1) was used as a cloning vector. To achieve this, chromosomal DNA was isolated and partially digested with *Sau 3a* restriction enzyme. Vectors arms were prepared by double digestion with *Bam*HI and *Eco*RI, were ligated to target DNA fragments. The recombinant DNA molecules were *in vitro* packaged, and plated on a genetically selective strain of *E. coli* (NM539). Recombinant plaques in the order of 1.2×10^3 were obtained representing over 90% of chromosomal DNA.

MATERIALS AND METHODS

Isolation and RepARATION of Target DNA

Chromosomal DNA of *Hb. Halobium* was isolated according to a method described by Marmur (1961), with a few modifications. This mainly involved the harvesting of bacterial culture by centrifugation. After suspending of bacterial cells in a total volume of 25 mL of 1M NaCl and 100 mM EDTA, they were lysed by the addition of 2 ml of 25% SDS. The suspension was incubated at 60°C for 10 min followed by addition of sodium perchlorate at room temperature to a final concentration of 1 M. Nucleic acid was then extracted using chloroform isoamyl alcohol according to Maniatis et al. (1982). The solution was treated with RNase and Proteinase K at room temperature, followed by a phenol and chloroform extraction, and then DNA was atonal precipitated and redissolved in TE buffer.

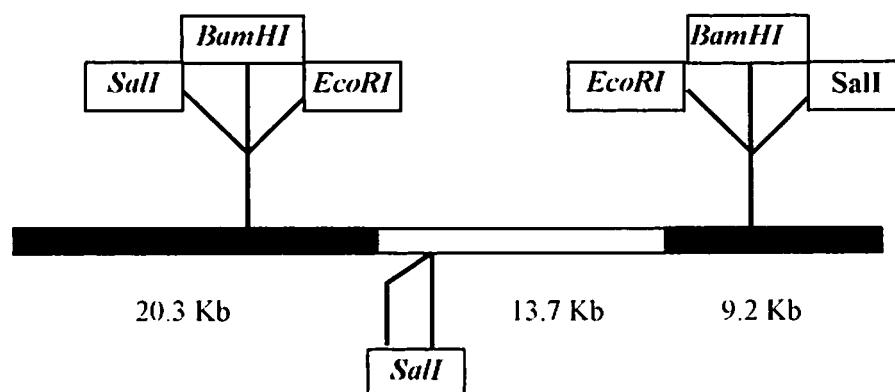


Fig. 1. Physical maps of the replacement EMBL₃ cloning vector.

To obtain maximum number of *Hb. Halobium* DNA fragments ranging between 10-2 Kb suitable for cloning into lambda EMBL₃ vector, the chromosomal DNA was enzymatically fragmented using a defined concentration of *Sau3a* restriction enzyme (0.015 u/μg) determined previously using a serial dilution (0.0-0.015 u/μg) method in a pilot experiment according to Maniatis et al. (1982). After this, the chromosomal DNA (50 μg) was randomly digested with *Sau3a* using concentration of 0.015 u/μg DNA. Digested DNA was treated with CIP alkaline phosphates to avoid re-circulation, and then followed by purification and re-suspending in TE buffer in a final concentration of 0.5 μg/μl.

Isolation and RepARATION of EMBL₃ Arms

Bacteriophage DNA was isolated using a large-scale method described originally by Frischuaf et al. (1983) and modified by Jubrael (1987). One litre of *E. coli* (strain MN538) culture, grown on LB media, was inoculated with 5-ml of phage stock solution prepared previously. The culture was incubated at 37 °C until lyses was complete. To the clear phage solution 2% NaCl and 8% PEG 6000 were added and incubated overnight at 4 °C. Phage particles were collected from a CsCl density gradient centrifugation. Bacteriophage DNA was then isolated using a phenol chloroform method described by Maniatis et al. (1982).

To prepare EMBL₃ arms, 20 μg of DNA were digested with *Bam*HI (2f enzyme/μg DNA) to remove stuffer (middle) fragment. To remove *Bam*HI sites from stuffer fragments, this was digested with *Eco*RI restriction enzyme. The phage arms were then purified by phenol/chloroform method and recovered by isopropanol according to Lehrach et al. (1982), and re-suspended in TE to a final concentration of 0.5 μg/μl

Ligation Platins *in vitro* Packaging

Ligation experiments between EMBL₃ vector arms and *Hb. Halobium* DNA partially digested were performed using a pre-determined ratio of 4:1, respectively. T4 DNA ligase was used in a final reaction volume of 20

ul. The reaction consisted 2 mL of target DNA (1 μg), 8 mL vector arms (4 μg), 2 μL of 10 × ligation to buffer 2 μL 0.1M ATP, 5 ml distilled water and 1μL T4 DNA ligase (1 Weiss unit). The reaction was incubated at 4 °C for 24 h.

The recommitment DNA molecules obtained were *in vitro*-packaged using Life Technologies *in vitro* package system. The reaction was set up by addition of 10 ml of ligation mixture to 10 μl of Freeze thawed Tysate of *E. coli* (Strain BHB 2688). To this, 15 μL of sonication extract of *E. coli* (Strain BHB 2690) was added. The reaction was incubated at 20 °C for 3 h according to supplier recommendations. To this, 0.5 mL of lambda diluent (10 mM Tris-HCL pH 7.5, 100 mM NaCl and 10 MM MgSO₄) was added. To plate the genebank, serial dilutions of the *in vitro* packaging solution were plated on Top Agar LB plates to containing P2 lysogene *E. coli* strain MN 539 (Lindahl et al., 1970). Control plates contained intact EMBL3 plated on MN 538 and MN 539.

RESULTS AND DISCUSSION

Employing the method described by Marmur (1961) with a few modifications for *Hb. halobinn* DNA isolation was found to be successful compared to other methods tested (Cline et al., 1989). The average yields of chromosomal DNA obtained from repeated experiments were in the range of 2.0-2.5 μg/mL of bacterial culture (based on absorbency A₂₆₀).

The molecular weight of DNA obtained was found be over 50 Kb, which makes it suitable for cloning into bacteriophage vectors (Maniatis et al., 1982). The modification used, such as including Proteinase K, EDTA and SDS, etc., may contribute to enhance the extraction efficiency.

The quality of DNA samples were further tested in the sequential cloning steps. The particle digestion of chromosomal DNA with *Sal* enzyme in the pilot experiment proved to be successful. This may be observed by the appearance of a typical ladder of DNA smears due to the serial concentration of the enzyme. The concentration of 0.015 U enzyme/μg DNA was found to be

optimum concentration that P-generates maximum number of *Hb. Halobium* chromosomal DNA ranging between 10-20 Kb suitable for cloning into EMBL₃ vector.

EMBL₃ DNA preparation results showed an intact single main band of 43.8 Kb when it was run on 0.7% agarose gel electrophoresis. Double digestion with *Bam*HI and *Eco*RI produced three bands representing the left (20.3 Kb) and right arms joined at *cos* sites, followed by the middle fragment (stuffer 13.7 Kb), then the right arm (9.2).

Ligation experiments between the EMBL₃ arms and *Hb. Halobium* DNA partially digested with *Sau*3a. The absence of EMBL₃ bands and most of target DNA smear, reveals a good degree of ligation. The ratio of 4 arms: 1 d⁺ inserts was found as an optimum ratio for ligation compared to other ratios (results not shown). This ratio was also reported in another experiment (Aeid, 1995). Ligation results in these experiments were further tested in the *in vitro* packaging step.

To complete genebank preparation requirements, successful results were also obtained from the *in vitro* packaging steps using the Life Technologies Packaging System. The results of these experiments were demonstrated by plating a serial dilution of the *in vitro* packaged reaction on the P2 lysogenic *E. coli* strain NM539. The efficiency of about 1.3×10^3 recombinant plaques were obtained per one microgram of recombinant phage DNA.

The reason for plating on this strain is that normal lambda is inhibited by P2 prophage, which is integrated in this strain and this phenotype is described as Sp⁺. Insertion of DNA in the cloning site causes a change from Sp⁺ to Sp⁻ (no longer inhibited by the P2 lysogenic), thus only recombinant bacteriophages can infect cells that carry P2 prophages. This was depicted by no appearance of any plaque of intact EMBL₃ (control) on strain NM 539, whereas high number of plaques were found on the strain NM 538.

The efficiency of a genebank is defined as it should represent most or entire target genome (Brown, 1986). The genome size of *Hb. Halobium* is 3.7×10^6 (Charlebois et al., 1991; Lopez Garcia et al., 1992). Therefore, efficiency of the genebank constructed in this work was determined using Clarke and Carbon (1976) formula. If an average size of cloned DNA fragment is about 12 Kb, then 907 recombinant plaques are required. However, the number of obtained in this work was in the order 1300.

These results may be attributed to several reasons, the most important being the successful ligation between the target and vector DNA due to the fact that, since EMBL₃ is a replacement, it has a non-essential middle fragment that can be replaced by a target DNA fragment of different sizes ranging between 10-2 Kb, which would not exceed the limit of 75-105% of intact lambda DNA site that could be packaged and produce viable phage. To this end, the concentration of this

genebank may pave the way for further and more detailed molecular biology investigations in Iraq towards a better understanding of salinity tolerance mechanisms in this bacterium.

REFERENCES

- Aeid, S. 1995. Molecular cloning of phage DNA fragments of the salt-tolerant wild tetraploid bermudagrass *Cynodon dactylon* L. using a bacteriophage, cloning vector. *Ibn Al-Haitham J. Theor. Appl. Sci.*, 2.
- Al-Doori, S.H., N.A. Ali, H.S. Ammash. 1993. Partial characterization of chromosomal and extrachromosomal DNA of halobacteria isolated from local salinity soils. *Arch. Biotech.* Jordan: 35-44.
- Ammash, H.S., and S. Abraham. 1993. Molecular biological study and the isolation and transformation of nonrevertant salt-sensitive purple membrane-deficient mutants of *Hb. Halobium* by spheroplast method: Amman, Jordan. Second Arab Conference of Biotechnology 23 (4).
- Al-Shamma, A.M. 1982. Breeding for salt tolerance in *Hordeum vulgare* L. *Ph. D. Thesis*, Michigan State Univ., East Lansing, MI USA.
- Beltach, M., F. Pfeifer, J. Friedman, and H.W. Boyer. 1983. Bacterio-opsin mutants of *Halobacterium halobium*. *Proc. Natl. Acad. Sci.* 80: 1416-1420.
- Brown, T.A. 1986. Gene cloning. Van Nostrand Reinhold Co. Ltd., Berkshire, England.
- Charlebois, R.L., J.D. Hofman, L.C. Schalkwyk, and A.W.F. Doolittle. 1991. Detailed physical map and set of overlapping clones covering the genome of the *Archaeobacterium Haloferax volcanii* DS2. *J. Mol. Biol.* 229: 509-524.
- Clark, L., and J. Carbon. 1976. A colony bank containing synthetic col E1 hybrid plasmids representative of the entire *E. coli* genome. *Cell* 9: 91-99.
- Frischauf, A.M., H. Lehrach, A. Poustka, and N. Murray. 1983. Lambda replacement vectors carrying polylinker sequences. *J. Col. Biol.* 170: 827-842.
- Imhoof, J., F.F. Hashwa, and I.G. Trupez. 1978. Isolation of extremely halophilic phototrophic bacteria from the alkaline Wadi Natrun, Egypt. *Arch. Hydrobiol.* 84: 381-385.
- Jubrael, J.M. 1987. Preparation of a partial gene library detection of DNA polymorphism and chromosome studies in the fern *petridium*. *Ph. D. Thesis*, University of Manchester, UK.
- Kushner, D.J. 1978. Life in high salt and solute concentration: halophilic bacteria. In D.J. Kushner, (Ed.) *Microbial life in extreme environments*. Academic Press New York. 317-320.
- Lopez-Garcia, P., J.P. Abad, C. Smith, and R. Amils. 1992. Genomic organization of the halophilic archaeon *Haloferax mediterraneus*: Physical map of the chromosome. *Nucl. Acids. Res.* 20: 2459-2464.
- Maniatis, T., E.F. Fritsch, and J. Sambrook. 1982. Molecular cloning: A laboratory manual. Cold

- Spring Harbor Laboratory, New York, N.Y.
- Marmur, J. 1961. A procedure for the isolation of deoxyribonucleic acid from micro-organisms. *J. Mol. Biol.* 3: 208-218.
- Moshe, T.A. 1985. Genetics of salt tolerance in higher plants: Theoretical and practical considerations. *Plant and Soil*, 89: 199-236.
- Nissenbaum, A. 1975. The microbiology and bio-geochemistry of the Dead Sea. *Microb. Ecol.* 2: 139-161.
- Pfeifer, F., G. Weidinger, and W. Goebel. 1981. Genetic variability in *Halobacterium halobium*. *J. Bacteriol.* 145: 375-181.
- Rush, D.W., and E. Epstein. 1976. Genotypic response to salinity *Plant Physiol.* 57: 162-166.
- Shannon, M.C. 1984. Breeding, selection and genetics of salt tolerance. p. 231-254. *In: Salinity tolerance in plants*. Wiley Inter. Science Publ. New York. N.Y.
- Valentine, R.C. 1984. Genetic engineering of salinity tolerant plants. *Calif. Agric.* 38: 36-37.
- Vogelsang, N., W. Oertel, and D. Oesterhelt. 1983. Isolation of bacteria-opsin gene by colony hybridization. *Methods in Enzymol.* 97: 226-240.

Construction of a PCR-Based Linkage Map in Tomato

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ABSTRACT

This work was carried out to provide a low-density genetic map of *Lycopersicon* using random amplified polymorphic DNA (RAPD) markers and to develop sequence-tagged sites (STS) around genes of agronomic importance. The basic mapping population used in this study was an F₂ derived from an inter-specific cross between *L. esculentum* × *L. pennellii*. Fifty random primers were used to screen the parents, 22 of which were further used in screening the above-mentioned F₂ population. These 22 random primers generated 105 RAPD markers (with an average of 4.8 markers per primer) and were used to construct a linkage map covering a distance of 1481.1 cM using the MAPMAKER Version 2.0 software.

Ten pairs of specific primers, each primer about 25 base-pairs long, were designed from the published tomato nucleotide database sequences. Each primer set was used to amplify STS from the total DNA of *L. esculentum*, and *L. pennellii*. Informative primers were then used to screen for polymorphisms in the F₂ progeny of the same cross.

Segregation data based on PCR amplification from STSs were analyzed for linkage with the data for RAPD markers.

The availability of a low-density genetic map of tomato will be the foundation towards achieving a more detailed saturated map, which will provide markers as starting points for map-based cloning and/or for marker-assisted selection of agriculturally important genes, such as disease, insect or a biotic-stress resistance genes.

INTRODUCTION

Three types of genetic markers have been generally used in genetic analysis, i.e., morphological markers, protein-based markers, and DNA-based markers. Variation among genotypes within a species is the raw material for genomic analysis. This variation can be considered at different biological levels, from the simple heritable phenotype to detection of variation at the single nucleotide. Once the variation is identified and the genotypes of all individuals in the segregating test population are known, the frequency of recombination events between loci is used to estimate linkage distances between markers.

A DNA marker is typically a small region of DNA showing sequence polymorphism in different individuals within a species. Among molecular markers, the

most widely used by geneticists and breeders are: Restriction Fragment Length Polymorphism (RFLP) (Botstein et al. 1980), Random Amplified Polymorphic DNA (RAPD) (Williams et al. 1990), and Sequence Tagged Sites (STS) (Olson et al. 1989). More recently, (AFLP) defined as Amplified Fragment Length Polymorphism (AFLP), as described by Vos et al. (1995), and simple sequence repeats (SSR), also known as micro-satellites (Morgante and Olivieri, 1993), have been characterized by their high levels of polymorphism, and proven to be very useful tools in genomic analysis.

Tomato (*L. esculentum* L. Mill) is one of the most important vegetable crops in Egypt, with an average of 412,103 feddans devoted to the production of fresh tomato, and limited but increasing processing production. It is grown on extensive monoculture acreage, often with several crops per year and repeated use of the same ground over many years, which makes it susceptible to major epidemics.

The tomato map developed by Tanksley et al. (1992) comprises over 1030 markers, mainly RFLPs, a limited number of allozymic markers and RAPD markers distributed over the 12 chromosomes. The ultimate objective of this research is to molecularly locate and manipulate single genes and quantitative trait loci (QTL) that govern tolerance or resistance to biotic and abiotic stresses in tomato. Therefore, the aim of this work was to identify DNA sequence polymorphisms between the parents used in this study (*L. esculentum* × *L. pennellii*), to detect molecular markers, to try and develop STS around gene(s) of agronomic importance and to develop a linkage map of tomato, based on RAPD markers.

MATERIALS AND METHODS

Plant Material and Mapping Population

Seeds from cultivated tomato, *Lycopersicon esculentum* and wild species *L. pennellii* (LA 716) were obtained from Professor C.M. Rick, Tomato Genetics Resource Center, Department of Vegetable Crops, University of California, Davis. The tomato map was and is still derived largely from an interspecific cross between *L. esculentum* and *L. pennellii* (Bernatzky and Tanksley, 1986). Therefore, the same inter-specific cross was used in this study and the segregation of RAPD and STS markers was examined and scored in 63 F₂ individuals resulting from this cross.

Extraction and Purification of Genomic DNA

DNA was isolated from leaf tissues using the CTAB (*hexadecyltrimethylammonium bromide*) procedure based on the protocols of Saghai-Marooft et al. (1984), and Porebski et al. (1997).

RAPD Analysis

A total of 50 random 10-mer primers were synthesized at the Agricultural Genetic Engineering Research Institute, ARC, Giza, Egypt, on an ABI 392 DNA/RNA synthesizer (Applied Biosystems). These primers were used to screen for polymorphism between the two parental species *L. esculentum* and *L. pennellii*. Twenty-two of these primers that had generated RAPD markers were selected to analyze the segregation of RAPDs among individuals of the F₂ mapping population (*L. esculentum* × *L. pennellii*).

Preparation of PCR Reactions

Reactions were carried out in a volume of 50 µl containing 25-50 ng of genomic DNA template, 2 µM primer, 200 µM each of dATP, dGTP, dTTP, and dCTP, 50 mM KCl, 10 mM Tris-HCl (pH 8.3), 1.5-2.5 mM MgCl₂, 0.001% gelatin and 2 to 3 units of Taq polymerase enzyme (Promega or Appligene). Amplification was carried out in a DNA thermal cycler with an initial cycle of 94°C for 5 minutes, 45 cycles of 94°C for 1 minute, 36°C for 1 minute, and 72°C for 2 minutes, and a final cycle of 72°C for 7 minutes. The PCR products were then analyzed by electrophoretic separation in a 1.4% agarose gel. After electrophoresis the RAPD patterns were visualized with an UV transilluminator. RAPD markers were scored from the gels as DNA fragments present or absent in the individual samples. Gels were photographed using a Polaroid camera (MP4 Land Camera) and Polaroid film type 57(ASA 3000).

Sequence-Tagged Sites

A computer search was conducted to search for all the published tomato STSs from which ten sequences were chosen that have been previously located on specific chromosomes. From these sequences, PCR primers were designed by the Oligo 4.1 primer analysis software (National Biosciences Inc., Plymouth, MN, USA) to be about 25 bases long, to contain 50% GC, and to harbor no inverted repeat sequences. Each primer set was used to amplify sequences from total DNA extracted from *L. esculentum* and *L. pennellii*. PCR amplification was performed in a 50 µl reaction containing 2-3 units Taq polymerase (Promega), 10X buffer (50 mM KCl, 10 mM Tris-HCl pH 8.3, and 1.5 mM MgCl₂), 200 µM of each dNTP, 0.25 µM primers and 25-60 ng of genomic template. The reactions were subjected to one cycle at 95°C for 5 minutes, followed by 35 cycles at 96°C for 30 seconds, 55°C for 30 seconds, and 72°C for 30 seconds, then a final cycle of 72°C for 5 minutes.

Genetic Map Construction

The linkage map was constructed based on segregation data scored for 105 RAPD markers and one STS in 63 F₂ individuals using MAPMAKER Version 2.0 software (Lander et al., 1987; Botstein et al., 1980; Lincoln and Lander, 1992; Tanksley et al., 1992). Ambiguous genotypes were treated as missing data for map construction. All pairs of linked markers were first identified using the {group} command with a LOD of 3.0, and a maximum recombination frequency (RF) of 0.32. Map units in centiMorgan (cM) between markers were calculated using the Kosambi (1944) function.

RESULTS AND DISCUSSION

Identification of RAPD Markers

A random selection of 10-mer primers was surveyed to detect polymorphic bands specific to either parent. A set of 50 RAPD primers was screened against *L. esculentum* and *L. pennellii* (LA 716). All of the 50 RAPD primers successfully amplified bands in both parents, and all of them generated polymorphic bands between *L. esculentum* and *L. pennellii* (LA 716).

The fifty primers produced multiple band profiles with a number of amplified DNA fragments ranging from 2-14 and 1-11 in *L. pennellii* and *L. esculentum* respectively, while the number of polymorphic fragments ranged from 1-10 and 0-6 in *L. pennellii* and *L. esculentum*, respectively. Therefore, the total number of reproducible fragments amplified by the 50 primers reached 589, including 118 non-polymorphic fragments. This represents a level of polymorphism of 80%, an average of 9.42 markers per primer. The number and size of amplified fragments also varied with different primers.

A maximum of 22 fragments was amplified with primer D6, and a minimum of 5 fragments was amplified with primers D8, D16, D41 and D47. The size of amplified fragments ranged from 23130 bp to less than 200 bp. Klein-Lankhorst et al. (1991); Foolad et al. (1993); Martin et al. (1993); Williamson et al. (1994); Ohmori et al. (1995); McNally and Mutschler (1997) and Kawchuk et al. (1998) demonstrated that the number and size of amplified DNA fragments differed with the different primers tested, and that the amplified DNA fragments ranged from 200-2500 bp. Only the primers that generated repeatable and easy-to-score polymorphic RAPD markers were selected for further analysis.

STS Markers

The specific primer sets were used to amplify STS from total DNA extracted from *L. esculentum* and *L. pennellii*. Nine of the 10 primer sets amplified bands in the two parents, while one primer set (S72) failed to amplify any bands in both parents. The PCR products amplified by 8 primer sets (S70, S71, S73, S75, S76, S77, S78 and S79) did not show size polymorphism

between the two parents, while only the primer set (S74) showed size polymorphism. A 200 bp fragment was amplified from both *L. esculentum* and *L. pennellii*, and an extra fragment of 310 bp was amplified from *L. pennellii* alone. These primers were then used to screen for polymorphisms in the F₂ progeny of *L. esculentum* and *L. pennellii*. The data obtained from (S74) along with the data from the RAPD markers were analyzed together using the MAPMAKER computer program.

In barley, Tragoonrung et al. (1992) used eight primer sets to amplify sequences from two barley lines, six out of these eight sequences did not show size polymorphisms, and no amplification was detected with one of the primers. Similarly, in wheat, Chen et al. (1994) used a total of 38 STS primer sets, all amplified bands in the three accessions used in their study, where 24 of the 38 primer sets (63%) were polymorphic, while the others generated no polymorphisms among the tested accessions.

Segregation Analysis of RAPD and STS Loci

Parents of a mapping population must have sufficient variation for the traits of interest at both the DNA sequence and phenotypic levels. The variation at the DNA level is essential to trace recombination events. The more DNA sequence variation exists, the easier it is to find polymorphic informative markers. All species in the genus *Lycopersicon* have the same chromosome number (2N=24) (Atherton and Rudich, 1986). The cultivated tomato (*L. esculentum* L. Mill) is an inbreeding species, with most cultigens and parental lines being highly inbred, and therefore exhibit extensive genetic homozygosity. Crosses can be readily made, with two to three generations per year, depending on the genotype.

In this study, the mapping population was an F₂ population derived from an interspecific cross of *L. esculentum* and *L. pennellii* (LA 716); this population was selected on the basis of morphological, isozyme and RFLP divergence according to Bernatzky and Tanksley (1986); Young et al. (1988); Klein-Lankhorst et al. (1991); Tanksley et al. (1992); Eshed and Zamir (1995); and McNally and Mutschler (1997).

L. pennellii, a green-fruited species, is commonly used in genetic studies in tomato. The accession (716) which was originally collected from the Peruvian desert, is self-compatible, highly inbred, and can be easily hybridized to *L. esculentum*. The interspecific population was subsequently used for mapping because most markers are polymorphic. This accession of *L. pennellii* also exhibits multiple resistances to serious disease and pests, and abiotic stresses; the majority of these traits have not been genetically mapped.

In the present study, informative primers revealing polymorphic amplification profiles between parental germplasm were identified. The polymorphic loci detected between the two parents were 105 RAPD markers and an STS. Further analysis of the

segregation pattern of these markers in the F₂ population was performed to obtain data, which would permit the arrangement of loci into a linkage map. Data was scored from 63 individual plants of the F₂ population.

The population size was chosen according to Helentjaris et al. (1986) who demonstrated that a population size of 50 individuals is sufficient for the construction of a RFLP linkage map. Similarly, maps constructed by many authors for different plant species were based on the segregation analysis of molecular markers among individuals of a segregating population composed of 45-70 individuals (Bernatzky and Tanksley, 1986; Tanksley et al., 1992).

Construction of a Genomic Linkage Map

As a first step in linkage analysis, Chi-square test of each locus for the F₂ population ($P < 0.05$) was carried out to detect deviation from the expected Mendelian ratio of 3:1. Segregation distortions were observed in the F₂ population. Twenty out of 106 loci revealed a deviated segregation ratio, which represents 18.9% segregation distortion. Segregation distortion can be defined as a deviation from the expected Mendelian proportion of individuals in a given genotypic class within a segregating population.

The genetic basis of segregation distortion may be the abortion of male or female gametes, or the selective fertilization of particular gametic genotypes (Xu et al., 1997). Chetelat and de Verna (1991); de Vincente and Tanksley (1991); Paterson et al. (1991); Foolad et al. (1993) and (1997) reported that segregation distortion is a common feature when analyzing molecular markers such as RFLPs and RAPDs. However, the percentage of loci showing significant segregation distortion might vary depending on the species, population type and specific cross.

In order to organize all of the analyzed loci into their respective linkage groups, all the two loci recombinational values were calculated using the maximum likelihood analysis. Based on the frequency of recombination, these loci were arranged using the MAPMAKER computer program. The linkage criteria employed in this analysis were a LOD threshold of 3.0 and a maximum recombination value of 0.32. The 79 RAPD markers and the one sequence tagged site (STS) marker were arranged into 12 linkage groups (LG) numbered (1-12) in descending order of their lengths in centi-Morgan that cover a genetic distance of 1403 cM. This corresponds to the basic chromosome number of the tomato genome. In addition, there were 8 RAPD loci located on 4 unassigned segments (USA, USB, USC and USD) each comprising two RAPD loci covering an additional 78.1 cM. Therefore, the total genome size reached 1481.1 cM. Eighteen RAPD loci could not be linked to any of the linkage groups and are listed in.

Some of the linkage groups in the present study could be related to their respective chromosomes. The STS marker number 107 is known to be located on

chromosome 10. Therefore, it could be said that LG2 in the present study corresponds to chromosome 10. Moreover, it could be said that the two markers D40 and D45 on LG3 reside on chromosome number 6 in the tomato genetic map based on a study by Kaloshian et al. (1998) and Williamson et al. (1994), which showed that the two RAPD markers OPA 06 and OPB 07 corresponding to markers D40 and D45 respectively, are closely linked to a nematode resistance gene (Mi) in tomato that resides on chromosome 6. Therefore, it could be concluded that the markers on LG3 are located on chromosome number 6.

The present study was a preliminary step towards constructing a genetic map of tomato *L. esculentum* based on RAPD markers. However, additional markers are required to saturate the map completely so that several markers cover every fragment of the genome with a minimum interval between markers. This will lead to increasing the efficiency of the map in marker-assisted selection programs.

REFERENCES

- Atherton, J.G., and J. Rudich. 1986. The tomato crop: A scientific basis for improvement. Chapman and Hall, London, New York.
- Bernatzky, R., and S.D. Tanksley. 1986. Towards a saturated linkage map in tomato based on isozymes and random cDNA sequences. *Genet.* 112: 887-898.
- Botstein, D., R.L. White, M. Skolnick, and W. Davis. 1980. Construction of a genetic linkage map in man using restriction fragment length polymorphisms. *Am. J. Hum. Genet.* 32: 314-331.
- Chen, H. B., J.M. Martin, M. Lavin, and L.E. Talbert. 1994. Genetic diversity in hard red spring wheat based on sequence-tagged-site PCR markers. *Crop Sci.* 34: 1628-1632.
- Chetelat, R.T., and J.W. de Verna. 1991. Expression of unilateral incompatibility in pollen of *Lycopersicon pennellii* is determined by major loci on chromosome 1, 6, and 10. *Theor. Appl. Genet.* 82: 704-712.
- de Vicente, M.C., and S.D. Tanksley. 1991. Genome-wide reduction in recombination of backcross progeny derived from male versus female gametes in an interspecific cross of tomato. *Theor. Appl. Genet.* 83: 173-178.
- Eshed, Y., and D. Zamir. 1995. An introgression line population of *Lycopersicon pennellii* in the cultivated tomato enables the identification and fine mapping of yield-associated QTL's. *Genet.* 141: 1147-1162.
- Foolad, M.R., R.A. Jones, and R.L. Rodriguez. 1993. RAPD markers for constructing intraspecific tomato genetic maps. *Plant Cell Rep.* 12: 293-297.
- Foolad, M.R., T. Stoltz, C. Dervinis, R.L. Rodriguez, and R.A. Jones. 1997. Mapping QTLs conferring salt tolerance during germination in tomato by selective genotyping. *Mol. Breed.* 3: 269-277.
- Helentjaris, T., M. Slocum, S. Wright, A. Schaefer, and J. Nienhuis. 1986. Construction of genetic linkage maps in maize and tomato using restriction fragment length polymorphisms. *Theor. Appl. Genet.* 72: 761-769.
- Kawchuk, I. M., J. Hachey, and D.R. Lynch. 1998. Development of sequence characterized DNA markers linked to a dominant verticillium wilt resistance gene in tomato. *Genome* 41: 91-95.
- Klein-Lankhorst, R.M., A. Vermunt, R. Weide, T. Liharska, and P. Zabel. 1991. Isolation of molecular markers for tomato (*L. esculentum*) using random amplified polymorphic DNA (RAPD). *Theor. Appl. Genet.* 83: 108-114.
- Kosambi, D.D. 1944. The estimation of map distances from recombination values. *Ann. Eugen.* 12: 172-175.
- Lander, E.S., P. Green, J. Abrahamson, J. Barlow, M. Daly, S. Lincoln, and L. Newberg. 1987. MAP-MAKER: An interactive computer package for constructing primary genetic linkage maps of experimental and natural populations. *Genomics.* 1: 174-181.
- Lincoln, S.E., and E.S. Lander. 1992. Systematic detection of errors in genetic linkage data. *Genomics* 14: 604-610.
- Martin, G.B., M.C. de Vicente, and S.D. Tanksley. 1993. High-resolution linkage analysis & physical characterization of the Pto bacterial resistance locus in tomato. *Mol. Plant-Microb. Inter.* 6: 26-34.
- McNally, K.L., and M.A. Mutschler. 1997. Use of introgression lines and zonal mapping to identify RAPD markers linked to QTL. *Mol. Breed.* 3: 203-212.
- Morgante, M., and A.M. Olivieri 1993. PCR-amplified microsatellites as markers in plant genetics. *Plant J.* 3: 175-182.
- Ohmori, T., M. Murata, and F. Motoyoshi. 1995. Identification of RAPD markers linked to the Tm-2 locus in tomato. *Theor. Appl. Genet.* 90: 307-311.
- Olson, M., L. Hood, C. Cantor, and D. Botstein. 1989. A common language for physical mapping of the human genome. *Science.* 254: 1434-1435.
- Paterson, A.H., S. Damon, J.D. Hewitt, D. Zamir, H.D. Rabinowitch, S.E. Lincoln, E. Lander, and S. Tanksley. 1991. Mendelian factors underlying quantitative traits in tomato: comparison across species, generations, and environments. *Genetics.* 127: 181-197.
- Porebski, S., L.G. Bailey, and B.R. Baum. 1997. Modification of a CTAB DNA extraction protocol for plants containing high polysaccharides and polyphenol components. *Plant Mol. Biol. Rep.* 15: 8-15.
- Saghai-Marouf, M.A., K.M. Soliman, R.A. Jorgensen, and R.W. Allard. 1984. Ribosomal DNA spacer length polymorphisms in barley, Mendelian inheritance, chromosomal location, and population dynamics. *Proc. Natl. Acad. Sci. USA.* 81: 8014-8018.
- Tanksley, S.D., M.W. Ganai, J.P. Prince, M.C. de

- Vicente, M.W. Bonierbale, P. Broun, T.M. Fulton, J.J. Giovannoni, S. Grandillo, G.B. Martin, R. Messeguer, J.C. Miller, A.H. Paterson, O. Pineda, M.S. Roder, R.A. Wing, W. Wu, and N.D. Young. 1992. High density molecular linkage maps of the tomato and potato genomes. *Genet.* 132: 1141-1160.
- Tragoonrung, S., V. Kanazin, P.M. Hayes, and T.K. Blake. 1992. Sequence-tagged-site-facilitated PCR for barley genome mapping. *Theor. Appl. Genet.* 84: 1002-1008.
- Vos, P., R. Hogers, M. Bleeker, M. Reijans, T. van der Lee, M. Hornes, A. Frijters, J. Pot, J. Pelman, M. Kuiper, and M. Zabeau. 1995. AFLP: a new technique for DNA fingerprinting. *Nuc. Sci. Res.* 23: 4407-4414.
- Williams, J.G.K., A.R. Kubelik, K.J. Livak, J.A. Rafalski, and S.V. Tingey. 1990. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. *Nuc. Sci. Res.* 18: 6531-6535.
- Williamson, V.M., J.Y. Ho, F.F. Wu, N. Miller, and I. Kaloshian. 1994. A PCR- based marker tightly linked to the nematode resistance gene, Mi, in tomato. *Theor. & Appl. Genet.* 87:757-763.
- Xu, Y. Zhu J.N. Huang, S.R. McCouch 1997. Chromosomal regions associated with segregation distortion of molecular markers in F₂, backcross, doubled haploid, and recombinant inbred populations in rice (*Oryza sativa* L.). *Mol. Gen. Genet.* 253:535-545.
- Young, N.D., D. Zamir, M.W. Ganai, and S.D. Tanksley. 1988. Use of isogenic lines and simultaneous probing to identify DNA markers tightly linked to the Tm-2a gene in tomato. *Genet.* 120: 579-585.

IX. Sustainable Development of Oasis

Moisture Capture by Desert Mountains: Effects on Oasis Environment

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ABSTRACT

In order to utilize the natural environment for human benefit, many efforts have been made through out history. However, we cannot regard the present status as successfully attained. Instead, adverse conditions have resulted. In the arid region, we can count such cases. It has been long since the first attempt was organized for the development of world's deserts: the Arid Zone Program by UNESCO. The Program dealt with coastal deserts in its later stage, but unfortunately, the scheme was terminated.

In the Arabian Peninsular there are three regions where the arid coast is closely walled by high-altitude mountains; the Hejaz in Yemen on the Red Sea coast, the Dhofar Mountains on the Arabian Sea coast, and the Hajar Mountains on the Gulf of Oman coast. Due to the highly heated conditions of the lower atmosphere, these coasts are arid. But in an absolute scale, the local air is one of the most moist ones in the world. The local air is often forced to ascend the walled slopes to more than 1000 m, and even 3000 m. Simple calculation shows 10 to 40 grams of water to be separated as condensate from each one cubic meter air during the ascent.

Such separation is tangible in the field. We recognize that due water resources are dissipated by the destruction of vegetation, which could potentially capture the wind blown droplets i.e., the separated water. Rejuvenated studies of coastal desert and restoration of vegetation on the coastal mountains are required for the drastic improvement of the local hydrological cycle to induce improvement of the oases' environment.

INTRODUCTION

It is a well-known fact that orographical features have tremendous effects over local meteorology. The effect may increase precipitation, particularly on the windward mountainside. In arid regions, some of the oases apparently exploit such conditions, depending on the waters extracted by the effect which is appreciably enhanced in the coastal mountains, as moisture is supplied continuously from the sea surface. Relative humidity can easily be raised to saturation once the air is forced to ascend the mountain and has cooled. This atmospheric procedure has stimulated scientists to bear ideas of artificial structures, i.e., some sort of huge plastic balloons, built on the tropical arid coast, to guide coastal moist air to the high altitudes for

extracting water from it. The acquired water can be used as the resource for a man-made oasis. So far, such an idea has not been implemented yet, but coastal deserts in the tropical and temperate zones are regarded as potential areas for the development.

It was during the Arid Zone Program by UNESCO (conducted from 1949 to 1960s) that coastal deserts were focused on for systematic research (Meigs, 1966). This primary attempt picked up many important aspects, with stresses on its potentiality of development. After a stagnant spell, another research wave recently arrived, assuming fog and fog collection studies (Schemenauer and Bridgman, 1998). Apart from these, ecological and palaeo-environmental studies attracted our attention. The results showed that former destruction of the vegetation may have cause deterioration of the local hydrology, and erased the original state probably at its optimum. Development of an oasis environment should be challenged, keeping the above-mentioned aspects in mind.

SOME FIELD OBSERVATIONS IN THE ARABIAN PENINSULAR

The author once had opportunities to work in the south-eastern part of the Arabian Peninsula. Up there, he found localities of appreciably high altitudes, ranging from 1,000 meters above sea level to such in excess of 3,000 meters. Three remarkable aspects of local hydrometeorology were recognized:

1. Local precipitation is found in proportion to the altitude.
2. Detached seasonal peaks exist for the high altitude precipitation.
3. Conventional rain gauges cannot collect essential but small sized droplets of effective precipitation.

The first aspect is observed widely in arid regions. It is attributed to the orographic effect in which forced air ascent is the major cause. The second one shows a detached wet season at the high altitudes; wet at the high altitude of northern Oman, at Saiq in Jabal Al-Akhdar or Hajar Mountains, but in the identical period, dry at the foot at Al-Rumais on the Batinah Coast. The third one, often termed as *occult precipitation*, is attributed to the small airborne droplets. Small sized droplets, as fog and drizzle, are easily blown away from the gauge, although they are captured by the vegetation as an essential water source. Consequently, conventional rain data do not represent water availed of by the local vegetation.

These three aspects suggest that a better hydrological system proceeds high up in the mountains. But neither vegetation nor water availability appears improved. So presumably, potential water resources just pass through without being captured for the local ecosystem. More efforts should be spent to achieve improvement of the environment as the present paper suggests.

Condensation Procedures

In the preceding section, the local rain-formation process was briefly mentioned. During the southwestern monsoon, a typical process proceeds along the Indian Ocean coast of the Peninsula. In southern Oman, oceanic wind blows up the Dhofar Mountains into the inland plateau, the Nejd. Then the mountains are covered by the clouds for three months. Cloud and fog are formed by the forced airlift caused by the local orography. However, the process is short-lived. The air mass is blown at 6 to 10 m/sec along the slope of less than 15 km distance into inland, so it can reside in the adiabatic process (approximately 1,000 m uplift) for around 30 minutes.

In addition, the general atmospheric circulation oppresses the lower atmosphere by the extensive subsiding upper air, and cloud growth is confined within a certain air depth. The vertical air structure is clearly shown at the nearby windward station, at Salalah Airport; moist air is just bounded by the relatively dry subsiding one from the top. As a result, the air mass quickly passes through the mountains without satisfactory growth of clouds. This is the reason why available condensation is not as of large droplets but small drizzle size. According to a simple calculation, even the short adiabatic process separates a large amount of water condensate, equivalent to 90 mm/day precipitation.

Based on seasonal change of precipitation in Salalah, there are two peaks of relatively high precipitation, i.e., winter and summer. The number of rainy days is more in summer than in winter, but summer precipitation is not proportionate to the rainy days. This simply implies that the rain droplets are blown away due to their immature size, explained above. A similar process is probable in other desert mountains, where the orography facilitates cloud or fog condensation, but cannot proceed to a further stage to form rain. This barrier could be broken artificially; some methods could be devised to capture the smaller droplets.

Pioneer studies on drizzle and fog capturing were done in the Dhofar Mountains using fine plastic netting (Stanley-Price et al., 1988), and simulative ground vegetation was devised to estimate actual input of water from the atmosphere (Salem, 1998). The latter work reported almost four times larger precipitation input than the conventional rain-gauge.

There is a dispute whether artificial structures are to be built at the expense of natural landscape. If artificial structures are not preferred by the local people, substitutions can be sought among the vegetation

improvement and afforestation methods, examining the applicability of the on-going natural capturing process.

Although the summer condensation process does not reach the optimal level of precipitation in the Dhofar Mountains, the stability of the process is great, where the plots of isotopic composition of local rain swarm in a narrow spot (Wushiki, 1991; Public Authority for Water Resources, Oman, 1986). Stability of phenomena is an essential condition for the feasible application of an exploitation scheme. So this result again suggests potential feasibility of water exploitation from the process.

Geomorphological and Hydrogeological Relics of the Past

In arid regions, many geomorphological sites indicate climatic amelioration in the past. In the Peninsula, they were mainly formed during the pluvial times, as specified by radioactive dating in the deposits, e.g., lacustrine deposits (McClure, 1976).

Karstic relics are the remarkable sites of better hydrological periods in the past. Tufa deposits are found at the dried-up water springs and in the abandoned water conduits due to the lowering of the water source level. Those relics are related to the human works, so the change happened during the progress of human activity. In the present sense, it resulted from the nature destruction. Denser vegetation and an intenser hydrological cycle are presumably from the past. However, both the amelioratory past contrasts with the present desertic environment in the localities concerned.

From among the causes of the hydrological deterioration, vegetation decline may be counted as primary. Vegetation exercises two important functions in maintaining groundwater systems and karstic action. Firstly, it can intercept the air-borne droplets; the richer it grows the more it captures droplets. Eventually, groundwater recharge increases. Vegetation roots can improve the infiltration, and intensify the recharge, too. Secondly, rich vegetation produces rich organic material in the topsoil, which when decomposed, is the source of bicarbonate in the groundwater. Bicarbonate in water dissolves limestones along the passage, and the solutes precipitate where the carbonates are released as carbon dioxide gas, the karstic action proceeds this way.

Karstic geomorphology in northern Oman and Dhofar indicates richer vegetation in the past. Some specialists says that aged trees, rarely found on the limestone plateau, may represent indigenous tree biota, describing the plateau covered by forests with a canopy height of 5 to 6 m. Most of the accessible areas there are now barren and have no appreciable soil depth. The major cause can be ascribed to the long sustained effect of animal husbandry. People felled trees to reclaim large stretch of rangeland, as well as for timber logs and fuel. It may date back hundreds or thousands of years for local cattle to have evolved into a subspecies, as specialists believe.

The nature deterioration, caused by such action, may have resulted in the hydrological decline. Water sources seem to have been lowered by 2 m or more. In northern Oman, on the ground surface of qanat-type water facility, numerous remains of channel work are left. Tufa deposits, found heavily on them, suggest that local groundwater had kept a higher water-table at latest until the advent of qanats to Oman. This may imply that newly arrived civilization may have drastically changed or damaged local vegetation, and eventually the hydrology.

CONCLUSION AND FUTURE PROJECTIONS

In southeastern Arabia and in neighboring the coastal mountains, many geomorphological and archaeological remains indicate better hydrological environments in the past. They show 2 m or more lowering of spring discharge level at the mountain foot. At the same time, there are indications of more active karstic action in the past. These facts suggest that major cause of hydrological decline is probably due to the devastation of mountain vegetation by the human activities.

On the other hand, there proceeds remarkable meteorological process up on the mountains, where atmospheric moisture condenses through adiabatic process by the forced air-ascent along the windward slope. During the southwesterly monsoon, such a process is found quite stable in Dhofar Mountains, as reflected in the isotopic composition of drizzle rain. The process is stable, but due to the small area, it does not allow rain droplets to grow large. Eventually the locality seems to avail of occult precipitation in addition to the ordinary one. Experimental measurement of occult precipitation reported almost three times larger values than the conventional data. However, a tremendous amount of water is to be condensed during the forced air-ascent, and this seems to have large potentiality for further development.

The context stated so far implies that moisture capturing by the mountains in the arid coasts can contribute significantly to the local hydrology. It may improve oasis hydrology and may recover the environment to the level recorded in the relics. And we have to consider how to implement such scheme. Of course, there are two measures, short-term and long-term. We may adopt either of them or even both. Amelioration of the hydrological environment can only be achieved by the long-term measures. It will definitely be achieved by restoring vegetation. But short-term measure, perhaps using artificial devices or structures, may exhibit

remarkable effects to accelerate the long-term scheme. So a well-designed combination of the two should be adopted.

The long-term measure, consisting mostly of afforestation, would induce many benefits: it would increase bio-diversity, raise productivity of the ecosystem, provide useful materials for human life, and so on. These benefits may bring oasis life to the status of small but rich ecology, an ultimate condition of human life.

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REFERENCES

- McClure, H.A. 1976. Radiocarbon chronology of Late Quaternary lakes in the Arabian Desert. *Nature*, 263: 755-756.
- Meigs, P. 1966. Geography of Coastal Deserts. *Arid Zone Research Series*, No. 28. UNESCO, Paris. 140 p.
- Public Authority for Water Resources. 1986. Origin and age of groundwater in Oman: A study of environmental isotopes. Sultanate of Oman. 285 p.
- Salem Ahmad Alesh. 1998. Work done on fog and fog collection (moisture capture) in the Sultanate of Oman. *Proceedings: First International Conference on Fog and Fog Collection*, Vancouver, Canada, July 19-24, 1998, p. 417-420.
- Schemenauer, R.S., and H. Bridgman. 1998. *Proceedings: First International Conference on Fog and Fog Collection*, Vancouver, Canada, July 19-24, 1998.
- Stanley-Price, M.R., A.H. Al-Harthy, and R.P. Whitcombe. 1988. Fog moisture and its ecological effects in Oman. *Proceedings: International Conference on Arid Lands Today and Tomorrow*, Tucson, Arizona, Oct. 1985, 69-88.
- Wushiki, H. 1991. $^{18}\text{O}/^{16}\text{O}$ and D/H of the meteoric waters in South Arabia. *Mass Spectroscopy*, 39(5): 239-250.

Oasis Ecology and Desertification Control at Taklimakan Desert's Southern Margin

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ABSTRACT

By analyzing the oasis ecological characteristics of the Southern Margin of Taklimakan Desert, the article uncovers the double characters of the oasis ecology and the inevitability that the oasis ecosystem should be threatened by desertification. Through the analysis, the authors conclude the fundamental courses into two factors, including artificial and natural, and three factors, namely: population, water resources, and plants. Furthermore, the authors provide a good model for desertification control for this area.

INTRODUCTION

The Southern Margin of Taklimakan Desert, stretching from Pisan County to Minfeng County, extends more than 600 km and covers about 245,000 km². This area administratively belongs to Hetian, Xinjiang, China, covering about 14.8% of the whole area of Xinjiang. There are hundreds of dispersed oases, big or small. According to surveys and calculations, the area of the deserts and Gobi around the oases amounts to 1,890 km², and the area of the oases is 92,000 ha, amounting to 3.75% of the general area.

There are 1.5 million people in an area over 16.7 km². The past several years' rapid increase of the population has intensified the conflicts between social development and local resource, environment, and ecology. Meanwhile, desertification occurs in this area and is attributed much to conflicts. Relative to a long period of peace and order of the oases, how to mediate the conflicts has arisen as a point at issue.

Oasis Formation and Ecological Characteristics

An oasis is a special kind of natural geographic landscape which is widespread in arid and semi-arid regions, and is characterized by abundant and diverse plant life that provide a basic condition for the life of the local people. The fundamental conditions of the oases include adequate water, plain terrain, and enough sunlight and heat. The area of the places that can meet all these conditions is very limited. From distribution of the river system and the oases in this region, we can easily find the space distribution of the main oases and rivers in the region, which are highly related. This indicates the most important condition of the form of the oases is the river; these oases are called river oases.

The oases in this region are dispersed along respective river systems. The oasis climate is influenced greatly by the desert arid and hot climate, and forms a warm continental climate. The characteristics of this kind of climate include enough sunlight, less rain and dry, intense evaporation, frequent wind, and small sand particles. Wind and dry conditions can occur in the same season, and rain and hot in the same period.

According to many years' statistics of this region, yearly solar radiation is 132.5-151.5 kilocalorie/cm², annual sunshine time is 2470-2790 hours, yearly average temperature is 10.4 to 12.2°C, average temperature is -5.6 to 9.2°C in January, average temperature in July is 24.8 to 25.6°C, the cumulative temperature that higher than 10°C is 4,065-4,360°C, there are 170-201 days without frost, there are 16.5-34.1 days in one year whose highest temperature is higher than 35°C. The yearly average relative humidity is 40-44%, and annual average precipitation is 30.7-51.3 mm.

There are 30 rivers that can be utilized among all the 36 rivers. The amount of flow that is distributed in different seasons is significantly different. The following tables show the meteorology (Table 1). The water resource of the oases (Table 2) in Southern Margin of Taklimakan Desert.

The average wind velocity in the Southern Margin of Taklimakan Desert is 1.6-2.3 m/s, the number of yearly average strong wind days is 1.9-8, and the peak is 17. There are about 4-64 days that have sandstorms. The number of yearly floating-dust days is 134-304. From March to May the windy days are frequent; there are about 2/3 sandstorm days that occur in this period, so we call this season windy season. The frequency of windy days decreases after May, but the wind is stronger, so we call it "strong-wind" season.

The distribution of all types of soil in southern margin of Taklimakan Desert varies; the main types of soil in the oases are silt, damp soil, and race-soil. The soil in wasteland includes brown desert earth, wind and dust earth, grassy marshland earth, and saline soil. Besides, the main component of the sand in the Southern Margin of Taklimakan Desert is very minute sand that is apt to flow by the act of wind. It is a great threat to the oases in the region where the wind is frequent.

Table 1. Meteorology of oases in Southern Margin of Taklimakan Desert.

<u>Oasis</u>	<u>Annual</u>	<u>Mean</u>	<u>Temperature</u>		<u>Wind</u>
	<u>Precipitation</u>		<u>January</u>	<u>July</u>	
	-----mm-----		-----°C-----		
Pishan	48.2	11.9	- 6.0	25.4	3.3
Hetian	33.4	12.2	- 5.6	25.5	7.3
Cele	34.4	11.9	- 5.8	25.1	4.0
Yu tian	44.1	11.6	- 5.0	25.0	1.9
Minfeng	30.2	11.1	- 6.8	24.8	4.9

¹Number of days that is stronger than 8 band.

Table 2. Seasonal distribution of surface water at the main oases in the southern margin of Taklimakan Desert.

<u>Oasis</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Autumn</u>	<u>Year</u>
			-----10 ⁸ m ³ -----		
Pishan	0.6239	1.1681	4.8933	1.2487	7.934
Hetian	3.352	4.84	34.753	6.765	49.71
Cele	0.4494	0.8323	4.7542	0.9891	6.935
Yutian	1.542	1.861	7.078	2.256	12.737
Minfeng	0.444	1.115	4.568	0.776	6.903
Total	6.4113	9.8164	56.0465	12.0348	84.219

According to all above-mentioned facts, we can generally get some knowledge about the main characteristics of the oasis ecology of southern margin of Taklimakan Desert. As other oases in arid regions, the oasis ecology there shows double characteristic.

1. The main symbol of the combination of the oasis factors is rain and high temperature that occur in the same period; this character is the fundamental base of high productivity.
2. The main character of the unfavorable combination of the oasis factors is that wind and dryness in the same season, which is the material base of the evolving and developing of the oasis desertification.
3. The opposing characters indicate not only the vital role that the oases play in the ecology system of arid regions, but also the inevitability that the oasis ecology system can be threaten by desertification.

Oasis Desertification Trend

The course to oasis and desert in the arid and semi-arid region are two consistent but opposite processes. The development of desertification in arid and semi-arid region in essence is the process of the retreat of the oases and the human living space there. These are the most important ecology forces in arid and semi-arid regions. Viewed from a small scale, the oases in the Southern Margin of Taklimakan Desert have some resource ecology characteristics, such as rich sand material, cell size sand being apt to flow and the same period of wind and aridity. It plays the role to promote the process of desertification.

Viewed at the large scale, desert is the circumstance of oasis existence. It is the possible outer condition for the oases to turn to desert. The process to oasis and

desert are two reversible ecological way-taking places in the arid and semi-arid region. The dislocation of the population and damage to natural resources will promote the ecology process of desertification and strengthen it. Desertification, as a combination of natural and man-made disaster, is more serious than floods or earthquake to some degree. The profundity of its influence lies in destruction of fields and houses upon which people rely, and so it threatens direct the social and economic base and space of human being which can last several generations, being essentially irreversible. Furthermore, desertification is far easier than the process of developing an oasis. The cost to revert desertification is labor, material and funds, and also considerable time.

Currently, there are 4900 km² oases deserted to different extent in the world, in which 1,400 km² have been seriously affected. All these means there is 1/3 of the earth's facing the danger of desertification. Desertification and desert have been the biggest pressure on the natural ecology, especially the oasis ecology. Desertification is an extreme phenomenon of deterioration of oasis ecology, substantially; it is the direct result of an unsustainable oasis.

The general area of oases in China is 95,700 km², i.e., 3.8% of the general area of the arid continental region. There is 95% population of this region. Xinjiang is the largest desert region in China; the area of the desert is 25.4% of the general area of 1.66 million km², and 56.4% of the area of the plain of 746,800 km². There are large deserts in many counties in Xinjiang. According to the report, "The Finished Survey of Desertification in Xinjiang", the deserted area of 79 million (M) ha is 48% of the general area of

Xinjiang, including deserted land 43 M ha and desert 34 M ha, ever there are 8,400 ha added to desert every year. Oasis are surrounded or separated by continuous dunes and endless desolated deserts. In Xinjiang, the ecological environment is weak because the oases, which are 4% of the general area, are surrounded or separated by deserts or Gobi (48% of the general area).

Desertification Control Taklimakan Desert

The Southern Margin of Taklimakan Desert is a region seriously desertified. In the middle of 1950s, there were tree forests and desolate desert poplar forests of 1.8 M ha. We could see oases and shades given by green trees everywhere, it was common to find trees whose trunk girth could only be measured by several people's connected embraces. The desert plant that is conserved well and produces in a natural way play a good role of oasis ecology environmental conservation.

From the late 1950s, regardless of the threshold capacity of the resource in the oasis environment, and against the objective law, people encroached on the desert blindly, destroyed forests and grasslands, and ploughed the land as fields. According to the investigation from 1959 to 1960, there are destroyed forests and opened-up wasteland of 66,667 ha in this area. The natural protective screen of the oases was broken and resulted in grave consequence of the extensive deserts. The consequence that ignores the threshold capacity of the resource in the oasis environment is that new-cultivated wastelands cannot be preserved and turn into a source of sand. It is a vicious circle.

For example, there are only 2,000 ha conserved in the 16,700 ha of opened-up wastelands in Moyu County. To resolve the problem of water source for the opened-up fields of about 1,700 ha in Cele Xiang, Cele County, people changed the river with a bar, which resulted in the plants along the bank being withered. Because of the loss of the protective bar in the western oases, there were fields (1,700 ha) fell to desert and more than 40 houses of the locale peasants were buried by sand, while there were fields (1,670 ha) wasted because of no outlet and were seriously salinized.

In line with the investigation about the ancient oases provided by the earth investigation group in Hetian, there are 10-70 km between the present oases and the Tang city, the Silk Road deviates tens to hundreds of kilometers in the south from that of the Han Dynasty. It reflected in the moving velocity of the dunes; the yearly average velocity of the "new-moon" dune and dune chain is 5.4 m. The northern margin of the oases in Hetian is connected with Taklimakan Desert, so in some areas dunes go close to oases gradually. Within about 1000 years, more than 20 old cities in the Silk Road were buried by desert. Since the 1980s, other several cities are facing this problem, the front of the shifting sands is 1.5 km away from town in 80s Cele County, the dunes are 2-3 km away from Keketiereke Village, Pishan County, it is 3 km from Niya town of Minfeng County, and so on. In fact, there

is no room to retreat except moving to Kunlun Mountain for Minfeng County which has moved three times in its history because of the invasion of the desert.

On the basis of the analysis of the cause of formation of the desert in the Southern Margin of Taklimakan Desert, we can put the causes into two main groups natural and artificial, and three factors, namely *population*, *water resource*, and *plants*. So desert control should begin with these issues. We should take measures to reduce the growth rate of the population, which is the foundation of desert control. Water, whose reasonable distribution is important and complicated and will be discussed in another article, is the foundation of the oasis ecology system and the key for the success of desert control. Plants, which are most sensitive and directly react of changes of the environment, are the basis of the desert control. *Vegetation destruction is the start of desertification.*

With seriously destroyed plants, frequent winds, fine sands, wind and drought in the same season, the Southern Margin of Taklimakan Desert is prone to the erosion of the land surface and formation of the quick-sands, the work of desert control should begin on the restoration, reconstruction and protection on vegetation, and establish protective system of the oases, combine trees, shrubs and grass, add the roughness of the land surface to drop the velocity of the wind of 7-8 bands in the oases through the protective system to 4 m/s, which is less than the velocity to raise the sands.

On the basis of analysis and investigation of the natural conditions, resource characteristics, and desert control methods in the Southern Margin of the Taklimakan Desert, we can put the desert control methods into four parts, *distribute sequentially with sand-screen river, grass-bush belt, sand-fixation forest, sand-fixing bush forest* not with narrow multi-belts. The major part of this system combines biological with engineering measures. Depending on the functions of each component, this system can prevent the extent of the desert.

Sand-screen River, set on the border of this system, is a kind of engineering measure. Generally, there are floods in summer in the Southern Margin of Taklimakan Desert, so Sand-screen River can utilize the drive and water of the floods to maintain its function. Its function lies in cutting the space between desert and oasis, and detaining much sand when the saturated or almost-saturated wind-sand flux comes from desert go across the weak-wind area in the bank to reduce sand brought to grass-bush belt.

After Sand-screen River, the *grass-shrub belt* is the first biology bar on the border of the oasis. In line with the need, we can plant some species of grass or shrub to add to the species diversity and the stability of the shelterbelt in the course of irrigation with flood to enhance the restoration of the natural plants. Meanwhile, it will meet ends such as adding density, bio-diversity of the plant population, improve the

construction of the community, enforce the stability of the community and provide of shelter continuously.

In the light of the fact that the sand flux is occurs within 30-cm height from the soil surface, sand-screen river utilizes the characteristic of grass-bush belt and its relative height can form high density population on a large scale to *increase the roughness of the soil surface, lower wind velocity, weaken the intensity of wind-sand flux, prevent soil surface sand rising in the wind.* It intercepts a large quantity of sand through Sand-screen River and into shelter system and lowers it in belt, reduces the quantity of the sand that the wind-sand flux carries obviously. Grass-bush belt is relatively lower, so its function of wind-shelter is limited; its main function is a sand bar and the shelter to rising sand on the spot. This requires certain coverage. According to some research carried out by related specialists and our survey, it will be more affective when the coverage is more than 60%.

Sand-fixation shrub forest is the second biology barrier in the system; its function is to add the height of the plant population, strengthen the effect of the wind shelter, and intercept sand that comes through the grass-shrub belt and into the system. Its main function is to prevent wind damage, and strengthen the ability of the system to resist the harm caused by wind and sand. Sand-fixation bush forest, meanwhile, is fuel forest, which provides some fuel every year and alleviates the local energy suppliers.

Shallow belt, sand-shelter forest lies in the connecting region between system and oasis is the last barrier

of the outer shelter system. Its main function is to improve the ability of the system to resist gale with forests composed of some taller trees. When the forward air-flux is blocked by the tall trees, a part of air is raised and cannot descend because the multi-band, sand-shelter forest net is connected with the inner farmland shelter forest net. The wind that goes through multi-belt forest has its motion energy consumed by continuous friction. The sequence of barriers described above provides a comprehensive strategy to wing erosion control.

REFERENCES

- Jiuwen, Wang. 1995. The oasis, the form and construct of the oasis. *J. Arid Land Resources & Environ.* 9 (3): 1-12.
- Zili, Fan. 1993. The development and evolve of the oasis in Tarim Basin. *Acta Geography Sinica.* 43 (5): 421-427.
- Xuncheng, Xia. 1991. Desertification and control of blown sand disasters in Xinjiang, *Science Publishing House.*
- Xiaoming, Li, and Zhang Ximing. 1995. Oasis ecosystem of Southern Margin of Taklimakan Desert. *Arid Zone Research.* 12 (4): 10-16.
- Ximing, Zhang, Li Xiaoming, and Zhang Helian. 1998. Desertification and desert control pattern in Southern Margin of Taklimakan Desert. The learning thesis about preventing the degeneration of earth and reconstruct of the beautiful mountain. *Urumqi.* 3: 17-18.

Date Palm Insect Control for of Sustainable Development of El-Bahria Oasis, Egypt

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ABSTRACT

In El-Bahria Oasis (Giza Governorate), date palm plantations suffer heavy infestation by *Arenipyes sabella*, *Batrachydra amydraula*, *Coccotrypes dactyliperda*, *Ephestia calidella*, *Deudoris livia*, and *Carpophilus spp.* These insect pests cause 20-73.3% loss of tamr annually, and may reduce palm propagation, date production and income of date producers. Such a problem, in turn, may influence sustainable development of the Oasis.

An integrated control program including mechanical, chemical, agricultural practices, and biological treatments was evaluated against insect pests of date palms under a field environment. Orchard sanitation and pruning of palms were highly effective in protecting palms and dates against *B. amydraula* infestation, while using date-bunch isolators significantly limited date infection by *A. sabella* and *E. calidella*. Delfin (bacteria biocide) gave better results than Nemazal (5%). On the other hand, Basodin (60% EC) was superior in controlling *B. amydraula* and *E. calidella*, while Sevin 85% WP + macronized sulfur effectively controlled *A. sabella* and *C. hemipterous*. Sumethion (50%) gave the best results for controlling *C. dactyliperda*.

Yield assessment of dates showed significant increases of treated palms compared with untreated ones. Field sanitation, palm pruning, and employment of date-bunch isolators resulted in 31.9-58.6% yield increment. The highest rate of yield increment (49.5%) was achieved by spraying date palms with Malathion and the least (19.4%) was obtained when date- bunches were dusted with Sevin (10%).

INTRODUCTION

Date palm is considered among the most important horticultural crops, providing a primary item of food and commerce in the great desert areas from western North Africa to India. Dates, however, occupy fourth position among tropical and subtropical fruit production after citrus, banana, and pineapple.

Numerous investigations on insect species that attack date palms and dates, their population dynamics, and seasonality have been made (Stickney, 1950; Elmer, 1968; Villardeho, 1973; Hussein, 1974; Carpenter and Elmer, 1978; Hammad, 1981; Al-Azawi, 1986; Ali and Hussein, 1995). Population dynamics, seasonal abundance, and rate of date infestation of

Batrachydra amydraula (Myrick), *Ephestia calidella* (Guen.), *Virachola livia* Klug, and *Carpophilus spp.* were studied by Saleh (1974) in the New Valley (Egypt). Ali and Hussein (1995) carried out the first survey of insects prevailing in the date palm agro-ecosystem in El-Bahria Oasis and reported 22 insect species, 14 species of them being serious pests attacking palms and dates.

El-Bahria Oasis lies in the western desert, 360 km from Giza. This area is widely populated with about 500000 palm trees, producing 43945 tons of *tamr*. Such a figure may reflect the importance of palm trees and dates for the inhabitants. Consequently, the date palm is still almost the universal producer, not only supplying food, but also for numerous domestic requirements.

One of the most serious problems of date palm and date production in El-Bahria Oasis is the consequent annual reduction in date yield due to the great invasion of different insect pests to palm orchards. This occurs in the absence of any knowledge about infestation syndromes, insect behavior, seasonality and control measures. Accordingly, about 25% of the date yield may be lost annually due to insect pests ravage.

The present paper deals with the status of date palm insect in El-Bahria Oasis, infestation rates, and the control program employed to eliminate such insect infestation and yield loss. The aim also extends to solve insect pest problem that oppose palm propagation and date production that directly affects the income of date palm producers

MATERIALS AND METHODS

A field survey of insects prevailing in the agro-ecosystem of date palm plantations as well as field experiments was conducted in date palm groves, 60 palms each, located in five different locations of El-Bahria Oasis during the date palm fruiting seasons of 1993-'96.

Insect Survey

Palm trees were inspected at weekly intervals where trunk, bunches and fruits were carefully examined. At the same time, samples of 100 fallen dates beneath each palm were gathered and examined. Symptoms of infestation and different insect stages present were isolated and identified. The insect survey also involved the use of ultra-violet Robinson's light trap for catching flying insects.

Assessment of Insect Infestation of Dates

Rates of date infestation inflicted by the insect pests *A. sabella* (Hamp.), *B. amydraula* (Myrick.), *E. calidella* (Guen.), *C. dactyliperda* Fab. and *C. hemipterous* L. were estimated in date palm groves during the 1995-'96 seasons. Thirty palm trees (6-8 m high; 8-10 years old) of the most common semi-dry date (Saidi variety) were selected at Beer Abo-Khalifa. Palms received normal agricultural practices and no chemical measures were applied. To determine infestation rates of date bunches, five spathes within fruits/palm were randomly chosen at weekly intervals and 10 stalks/spathe, 10 fruits each, were examined for insect prevalence. Number of infested dates per sample and causal insect species were determined. Meanwhile, 100 fallen dates were collected, examined and dissected. The number of infested dates and insect stages were recorded.

Evaluation of an Integrated Pest Control Program

An integrated pest management program (IPC) against insect pests infesting palms and dates was evaluated in date palm orchards at El-Bahria Oasis during two consecutive seasons (1995-'96). This program involved the following components:

4. Mechanical and cultural practices, including palm sanitation, palm pruning, and employment of date-bunch isolators.
5. The following insecticides were tested: *Malathion* (57% EC) at a rate of 200 ml, *Sevin* (85% WP) at 200g, *Basodin* (60% EC) at 300 ml, *Sumethion* (50% EC) at 250 ml, *Syanox* (50% EC) at 250 ml and *Sevin* (85% WP) + macronized sulfur per 100 L water, and *Sevin* (10%) dust.
6. Biological products including *Nemazal* (5%), (Neem-plant seed extract) at a rate of 200 ml and *Delfin* (Insect bio-bactericide) at a rate of 150g/100L water.

For each treatment, four palm trees were chosen. Application of insecticides and biological products was carried out monthly, commencing in February to the end of September, while setting up of date-bunch isolators started after palm pruning in April. Date infestation was assessed on the inspection of weekly samples of dates of treated palms. At date-harvest time, bunches with dates of each treated palm were weighed and compared with the yield of untreated palms. Date yield in relation to the applied program components was estimated.

RESULTS AND DISCUSSION

The insects found in date palm orchards and in the dates belonged to 25 species within 21 genera of 17 families related to 8 orders (Table 1). Out of 25 species, 20 are serious pests of palms and dates which compose 63.6% of the total insect species, 7 species are predators and one species is a parasite. Insect species

Arenipses sabella, *Batrachydra amydraula*, *Ephestia calidella*, *Coccotrypes dactyliperda* and *Carpophilus hemipterous* were the most serious pests threatening palms and date production. It is worth noting here that Dubas bug, *Ommatissus binotatus lybicus* De Berg, and the date bug, *Asarcopus palmarum* Horvath, were first recorded as date palm pests in Egypt (Ali and Hussein, 1996; Hussein and Ali, 1996). Insect diversion prevailing in palm-agrosystem could be regarded to the complex relationships between palms (food), cultural systems and surrounding hosts, weather factors and insect species.

Insect Infestation Patterns

The Greater Date Moth

The greater date moth, *Arenipses sabella*, is considered as one of the major insect pests threatening date palms in El-Bahria Oasis and Giza Governorate in general. Insect larvae are very active and bore holes in leaf base, bunches, spathes, and in green and ripe dates. Infested bunches ranged from 8.8 to 51.5%, and the maximum infestation occurred in April (Table 2). Date bunches also showed also conspicuous infection by *A. sabella* throughout June - October. A second peak of infested dates (15.1%) was recorded in September. The lowest infestation rate (4.8%) occurred in August and the seasonal infestation averaged 13.9%.

The Lesser Date Moth

The first sign of infestation by *B. amydraula* larva was observed in small green dates in March. Infestation rate averaged 9.7% during March and gradually increased to show the first peak in May, where infested green dates amounted to 28.5%. The second peak occurred in July, though it was less than the first one (19%). Infestation by this insect pest disappeared completely during September and October before date harvesting. Seasonal average of infested dates amounted to 13.9%. These results demonstrate that the lesser date moth, *B. amydraula*, had two annual generations, and larvae of the first generation may spend the winter as diapaused larvae.

The Oasis Date Moth

Inspection of date bunches through March to June revealed the complete absence of the insect infestation. The Oasis date moth, *E. calidella*, infested unripe dates throughout July - October. Infestation rate was very low in July (1.8%) and increased gradually towards the end of the fruiting season and before harvesting. The maximum infestation of date bunches averaged 40%. These results are conforming to those obtained by Hussein (1987), who reported that neither infested date bunches nor larvae occur before July. Saleh (1974) obtained similar results on date infestation by *E. calidella* in the New Valley.

The Stone-Date Beetle

Inspection of date bunches and fallen date samples showed that *Coccotrypes dactyliperda* infests date bunches from May to September. Infestation rates of dates during this period ranged between 12.5 and 33.8%. The highest rate of infested date bunches occurred in July (33.8%), and the lowest (12.5%) in October. There were two distinct peaks of infestation, the first in July (33.8%), and the second (28.2%) in September.

Nitridulid Beetle

The nitridulid beetle, *Carpophilus hemipterous*, was found in fallen dates during July, August, and September when humidity is high enough. The first signs of infestation were shown in green dates in June (21.9%) and rate of infestation proportionally increased to reach 48.1% in fallen dates at August, and then it drastically dropped to 9.5% in October.

Table 1. Insect species found in Bahria Oasis date palm groves, 1993-'95.

Order	Family	Species	Stage	Status	Frequency
Coleoptera	Bostrichidae	phonapathe frontalis F.		P	2
	Scolytidae	coccotrypes dactyliperda fab.	L&A	P	3
	Nitidulidae	carpophilus hemipterus L.	L&A	P	3
	Cerambycidae	pseudophilus testaceus gahan	A	P	3
	Scarabaeidae	oryctes elegans fell	A	P	3
Dermaptera	Labiduridae	labidura riparia	A	PR	1
Dictyoptera	Mantidae	sphodromantis bimaculata (burn.)	A	PR	2
Dipetra	Drosophilidae	drosophila melanogaster	L&A	P	2
	Tephritidae	ceratitis capitata wics	L&A	P	1
Homoptera	Diaspididae	parlatoria blanchardi	L&A	P	2
	Margarodidae	icerya aegyptiaca	L&A	P	1
	Tropiduchidae	ommatissus binotatus	L&A	P	2
Hymeptera	Brachonidae	bracon hepetor	L&A	PA	2
	Vespidae	vespa orientalis	A	PR	1
	Vespidae	polistes gallica	A	PR	2
Hemiptera	Issidae	asarcopus palmarum horvath	L&A	P	2
Lepidoptera	Lycaenidae	deudoris (=virachola) livia	L&A	P	1
	Momphidae	batrachydra amydraula	L	P	3
	Phycitidae	ephestia calidella (guen.)	L	P	3
	Phycitidae	ephestia cautella (walk.)	L	P	3
	Pyralidae	arenipses sabella (hamp.)	L	P	2
	Pyralidae	myelois ceratoniae	L	P	1
Neuroptera	Chrysopidae	chrysoperla carnea	A	PR	2
	Murmeleontidae	ceuta varigata	L	PR	1
	Murmeleontidae	palpares cephalotes	L	PR	1

A: Adult; L: Larva = Nymph; P: Pest; PR: Predator; PA: Parasite. (1): Low density; (2): Moderate density; (3): High density.

Table 2. Infested date bunches with insects species during the 1996 fruiting season at El-Bahria Oasis.

Month	A. Sabella	B. Amydraula	E. Calidella	D. Livia	C. Dactyliperda	C. Hemipterus	P. Gallica	Average
	-----%							
March	8.8	9.7	0.0	0.0	0.0	0.0	0.0	2.3 d
April	51.1	19.7	0.0	0.0	0.0	0.0	0.0	8.9 c
May	32.5	28.5	0.0	0.0	20.8	0.0	0.0	10.2 b
June	11.4	19.8	0.0	0.0	27.0	21.9	0.0	9.9 bc
July	9.8	19.0	1.8	1.8	33.8	18.3	3.8	11.0 b
August	4.8	14.8	16.7	15.6	27.8	48.1	3.2	16.3 a
September	15.1	0.0	32.5	7.5	28.2	34.8	2.1	15.0 a
October	13.0	0.0	40.1	0.0	12.5	9.5	0.3	9.4 bc
Average	18.4	13.9	11.4	3.1	18.8	16.5	1.2	

Means followed by the same letter in a column are not significantly different (P = 0.05; Duncan's Multiple Range Test).

Polistes Gallica

Adults of *P. gallica* appeared and fed on date bunches from July to early October. Infested green and ripe dates ranged between 0.3 to 3.8%. The highest infestation (3.8%) was recorded during July and gradually decreased to a minimum (0.3%) in October.

Deudoris Livia

First sign of date infestation by *D. livia* occurred on July with a rate of 1.8% and sharply increased to 15.6% in August. In September and just before date harvest, date infestation dropped to 7.5% after which no infection existed in October.

The rate of date infestation greatly varied according to local environment and insect species concerned. Infestation with *A. sabella* was superior in El-Bawietti and El-Harra, while *C. dactyliperda* was the dominant species in El-Zabou and El-Agouz. Based on the total infestation rates of the different insect species per location, El-Harra was first (30.7%) followed by El-Zabou (29.8%), while El-Bawietti was the least populated with date insect pests (17.9%).

Program against Insect Pests

The integrated pest control program against insect pests attacking date palms and dates was applied for two consecutive seasons, 1995 and 1996, through fruiting period (March - October).

Mechanical and Agricultural Treatments

In the first season (1995), sanitation of date palm fields, pruning of palm trees, and isolating date bunches by muslin bags significantly lowered date infestation

(Table 3). An infestation rate of date bunches averaged 1.8, 4.6, 3.0, 7.5 and 5.5% for *A. sabella*, *B. amydracula*, *E. calidella*, *C. dactyliperda* and *C. hemipterous*, respectively, while infestation rate of check palm dates ranged from 9 to 25%. Consequently, the application of this method could reduce date infestation by 70 to 97.4%, and the highest efficiency of such treatment was shown by *B. amydracula* (97%).

In the next season (1996), since isolation of date bunches by muslin bags gave about 83.7% protection of dates against insect attack, we used different materials for isolating date bunches including muslin, plastic net and polyethylene sheets. Muslin bags was the most efficient against *C. dactyliperda* while plastic net reduced the date infestation of *B. amydracula* by 60.2%. On the other hand, plastic bags significantly reduced date infestation by 92.3, 80.4, and 93.4% for *A. sabella*, *E. calidella* and *C. hemipterous*, respectively. It could be concluded that sanitation of date palm fields, pruning of palms, and caging of date bunches by plastic nets or plastic sheet bags significantly protected date bunches against insect attack by 60-93%.

Pesticide Treatment

Application of the insecticides markedly reduced date bunch infestation and the rates of infestation reduction greatly varied according the pesticide applied and insect species concerned. Results of the first season's application showed a great effect of Malathion (57% EC) on *A. sabella* and *E. calidella* where infestation rates averaged 5.2 and 2.0%, while they were 18 and 25% for untreated palm trees. This means that Malathion could reduce the former insect's infestation

Table 3. Integrated control of date infestation rate and percentage reduction (in parenthesis) with different insect pests in Bahria Oasis in 1995.

Control Measures	Treatments	<i>A. Sabella</i>	<i>B. Amydracula</i>	<i>E. Calidella</i>	<i>C. Dactyliperda</i>	<i>C. Hemipterus</i>
Mechanical	Cleaned and pruned Palms	7.8 (16)	4.6 (71)	7.0 (30)	9.0 (65)	5.9 (69)
	Cleaned and isolated bunches	1.8 (79)	8.4 (97)	3.0 (70)	7.5 (70)	5.5 (71)
	Non-cleaned and isolated bunches	5.9 (36)	9.7 (39)	5.0 (50)	12.1 (52)	9.1 (52)
	Normal palms	9.3 (-)	16.1 (-)	10.0 (-)	25.4 (-)	19.1 (-)
Chemical	Malathion 57% EC	5.2 (70)	8.5 (55)	1.9 (92)	13.4 (49)	13.5 (59)
	Basodin 60% EC	5.4 (69)	8.1 (57)	5.0 (80)	10.6 (59)	12.7 (61)
	Sevin 25% W.P	8.9 (50)	11.3 (40)	10.0 (60)	6.9 (74)	12.0 (64)
	Sevin 10% Dust	8.8 (46)	10.3 (49)	10.0 (50)	5.9 (31)	8.4 (56)
	Sumethion 50% EC	5.5 (51)	9.2 (46)	7.0 (80)	7.4 (77)	12.2 (74)
	Syanox 50% EC	9.6 (69)	9.7 (51)	12.0 (70)	18.2 (72)	14.6 (63)
	Sevin 85% + Sulfur	8.5 (52)	6.0 (68)	13.0 (44)	4.3 (83)	6.5 (80)
Biological	Nemazal 5%	7.4 (58)	10.1 (46)	15.1 (39)	8.7 (70)	18.5 (44)
	Delfin (Bactericide)	5.2 (70)	10.1 (46)	7.5 (70)	5.3 (79)	5.2 (84)
Check	Untreated palms	18.0 (-)	19.1 (-)	25.0 (-)	26.5 (-)	33.3 (-)

by 70.5 and 92.1%, respectively. Infestation rates by *B. amydracula*, *C. dactyliperda* and *C. hemipterous* were greatly affected and were lowest when date bunches was treated by Sevin 85% PW + sulphur. This treatment reduced insect infestation by 68.45, 83.5 and 80.53%, respectively (Table 3).

Results obtained in the second season application were quite different. Infestation of date bunches by *A. sabella* and *C. hemipterous* were more markedly influenced by Sevin (85% PW + sulphur) application than other pesticides, and date infestation was reduced by 78.0% and 70.5%. On the other hand, Basodin (60% EC) was superior against *B. amydracula* and *E. calidella*, reducing their infestation by 63.1 and 78.5%, respectively. Sumethion (50% EC) gave the best results against *C. dactyliperda*.

Biological Products

Application of biological products, Nemazal 5% and Delfin, against insect pests infesting date bunches was different from one year to another. In 1995, Delfin treatment successfully affected insect infestation induced by all insect species and reduced infestation rates by 46.5 (*B. amydracula*) and 84.3% (*C. hemipterous*). Nemazal showed lower effects. In the second season, Delfin had a pronounced effect on date infestation caused by *A. sabella*, *E. calidella* and *C. hemipterous*. Percentages of infestation reduction averaged 81.68, 83.76 and 56.14, respectively. Dates infested by *B. amydracula* and *C. dactyliperda* were markedly influenced by Nemazal treatment. Date bunches sprayed by Nemazal showed 7.2 and 10.5% infested dates by the former species, while these rates averaged 18.6 and 27.5% for untreated palms.

Control Program - Date Yield

The employment of proposed IPC program against date pests induced a significant increase of date bunch weight both in 1995 or 1996. In 1995, weight of date bunches of treated palms ranged between 10.6 and 15.6 kg, averaging 9 kg for untreated palms. Similar trends were shown in the 1996 season. Results also revealed that an increase rate of date-bunch yield ranged between 19.4 and 50.5% due to the control program applied.

The total annual production of date palms in El-Bahria Oasis (0.5 million palm trees) averaged 43954 metric tons of *tamr*. Total price value of this production amounts 26.4 million Egyptian pounds (LE) approximately. Insect pests attacking date palms cause 20-25% crop loss, which reaches 659310 LE.

Application of the proposed integrated pest control program in this study resulted in 26.5-49.5% (average 38%) crop increase. Consequently, the expected increase of 24614 tons of *tamr* could be gained, its price value amounting 11.2 million LE. This obvious increase of income covers the costs of control program application and the remainder goes to date palm growers as money benefit. This is a rough economic evaluation of the expected economic impact of this

integrated program; however, more detailed economic evaluation is required to determine the exact expected economic income which plays a great role in the development of El-Bahria Oasis and the palm grower's life.

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REFERENCES

- Al-Azawi, A.F. 1986. A survey of insect pests of date palms in Qatar. *Date Palm J.* 4 (2): 247-266.
- Ali, M.A.M., and A.E. Hussein. 1995. Survey and distribution of date palm insects in Bahria Oasis, Egypt. *Al-Azhar J. Agric. Res.* 22: 165-177.
- Ali, M.A.M., and A.E. Hussein. 1996. First record of date bug, *Asarcopus palmarum* Horvath (Hemiptera: Issidae) in Egypt. *Bull. Ent. Soc. Egypt.* 74: 137-138.
- Carpenter, J.B., and H.S. Elmer. 1978. Pests and diseases of date palm. *USDA Agric. Handbook* No. 527.
- Elmer, H.S., J.B. Carpenter, and L.J. Kolts. 1986. Pests and diseases of the date palm. Part 1: Mites, insects and nematodes. *FAO Plant Protection Bull.* 16 (5): 77-91.
- Hammad, S.M., A.A. Kadous, and M.M. Ramadan. 1981. Studies on insects and mites attacking date palm in the eastern province of Saudi Arabia. *Proc. Saudi Arabian Biol. Soc.* 5: 251-268.
- Hussein, A.E. 1974. Date palms and their pests in Iraq. Baghdad Univ. Press (In Arabic), pp. 140.
- Hussein, A.E. 1987. Ecological studies on certain lepidopterous insect pests infesting date palms in Bahria Oasis, Egypt. *Ph. D. Thesis*, Fac. Agric., Al-Azhar University, Cairo, Egypt.
- Hussein, A.E., and M.A.M. Ali. 1996. New record of the Dubas bug, *Ommatissus binotatus lybicus* De Berg., a threat to date palms in Bahria Oasis, Egypt. *Bull. Ent. Soc. Egypt* 74: 1-8.
- Saleh, M.R.A. 1974. Ecological and control studies on pests infesting date bunches in the New Valley, U.A.R. *Ph. D. Thesis*, Fac. Agric., Ain Shams Univ., Cairo.
- Stickney, F.A., Parnes, D.F., and P. Simmons 1950. Date palm insects in the United States. *USDA Circ.* No. 846, 52 p.
- Villardeho, A. 1973. Prince pax de la datte ext dattier. p. 67-95. In Mumier (Ed.), *Le Palmier-Dattier*, G.P. Maisonneure and La Rose, Paris, 221p.

Ecological Environment Strategy and Construction in China's Hexi Corridor

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ABSTRACT

Hexi Corridor is one of the major economic development regions in Gansu Province of China. It is also an important base for large-scale development in northwest China at the beginning of the 21st Century. This paper analyzes the region's ecological environment status and economic features, and puts forward an ecological strategy "formulating rational exploitation involving planning of water and land resources, rehabilitating the environment while developing the economy, and practising resource-saving development", and suggests some concrete measures to construct the ecological environment.

INTRODUCTION

Hexi Corridor in the northwestern part of Gansu Province of China refers to the vast region west of the Wushoaling Mountain, with a land area of 215,000 km² or 50% of the province's total area. The region is a multi-national area dominated by the Han people, with a population of 4.41 million (M). It is also an important base for large-scale development of northwest China at the beginning of the 21st Century. Based on the ecological environmental status and regional economic features, this paper puts forward the ecological strategy and measures to construct ecological environment in the region.

Hexi Corridor, in the transitional zone between Qinghai-Tibet plateaus, is located in the inland desert region and has an arid desert climate. Annual precipitation decreases from 150-250 mm in the eastern part to less than 50 mm in the western part, annual evaporation increases from 2000 mm to 3500 mm or more, annual mean air temperature increases from 6.6 to 8.9°C, and accumulated temperature increases from 20 to 36°C. The Corridor is long and narrow in shape and adjoins the Qilian Mountain and Alun Mountain to the south, and borders the Heli Mountain and Longshou Mountain to the north. With oases scattered in the interior of Gobi and Sandy Desert, the Corridor has abundant light, heat, land and mineral resources and diverse ecotypes, but its ecosystem is fragile, and water resource are meager, thus hampering economic development.

Owing to the unbalanced natural pattern, resource development and human-induced environment issues are regional and diverse. As a whole, the region's ecological environment is unbalanced, environmental pollution and human disturbance are serious, which are mainly manifested in serious soil salinization in

midstream oases of inland river basin; land densification and desiccation of downstream region; forest destruction and grassland degradation in upstream region; serious soil erosion and mineral loss in mountain regions; and serious air and water pollution in several cities.

DESTRUCTION AND DEGRADATION OF LAND RESOURCES

Soil Salinization

Hexi Corridor has 8347.66 km² of alkali-saline wasteland and 70,400 km² of alkali-saline cultivated land, of which 13,200 km² are slightly salinized, 20,200 km² are moderately salinized, 37,000 km² are seriously salinized, and thus results in an annual grain output loss of 2000 tons. *Soil salinization results from over-irrigation, poor drainage, and groundwater table rise.* Salt accumulation in surface soil layer results from saline groundwater irrigation. Such phenomena mainly occur in the downstream region, especially in the Mingin Lake region of the lower Shiyang River. According to investigations, salinized soil area in the Mingin Lake region was 105 km² in 1958; 122 km² in 1963; 220 km² in 1978; 255 km² in 1981; and 408 km² in 1992, of which 252 km² are seriously salinized, 84 km² are moderately salinized, and 72 km² are lightly salinized.

Land Degradation

Owing to overuse of water resources, runoff flowing into the downstream region has decreased greatly. Taking Minqin region in the lower Shiyang River as an example, the runoff was 546 M m³ in the 1950s; 322 M m³ in 1960s; 221 M m³ in 1980s; and 148 M m³ in 1990s; the runoff reduction was 2%, or reduced by 108 M m³ every 10 years. Surface water shortage leads to over-pumping of groundwater. Over last 20 years, over-pumping of groundwater in the Shiyang River Basin has resulted in soil desiccation and vegetation degradation or even death due to lowering of the watertable.

According to the report of Minqin Forestry Bureau, there were 724 km² of natural shrub forest consisting of *Tamarix chinensis*, *Nitraria tangutorum* and *Elaeagnus angustifolia* in the Mingin Basin in 1950s, until 1991 cumulatively planted *Elaeagnus angustifolia* forest 172.5 km², and other shrub forest 274.2 km² but now some 360 km² of shrub forest have dried up and another 58 km² of shrubs are suffering from "stag headedness". In addition, some 75 km² of artificial shrub

forest are in the danger of drying up, and, out of 10233 km² available grassland in the basin, 4463 km² have desertified or degraded, accounting for 44%.

Hexi Corridor, as a seriously desertified region, has 18772 km² of sandy desert or 8.8% of its total area; 67699 km² of Gobi, or 31%; and 10947 km² of artificial oasis, or 5%. Around the oases in the Corridor, there are 560 km² of on-going desertified land, 2272 km² of moderately desertified land, and 1824 km² of seriously desertified land (Zhu, 1989).

Strong winds in spring often cause sand encroachment on farmlands, villages and roads. According to a report, on May 18-21, 1986 a strong east wind of over gale-force 9 and a dust storm swept over Anxi, Dunhuang, Yumen, Jinta and Jiuquan regions. Some 29,300 km² of farmland was affected, causing a direct economic loss of 64 M Yuan. On May 5, 1993, another strong dust storm hit Jinchang, Wuwei, Minqin, and Gulang regions; its instantaneous velocity reached 20 m/s, maximum 34 m/s, with a visibility ranging from 0-100 m, causing a direct economic loss of 236 M Yuan.

Rangeland Degradation

Hexi Corridor has 8.7 M km² of rangeland with a carrying capacity of 6 M sheep unit, while its actual stocking density is 8 M heads, or exceeds the carrying capacity by 2 M heads. Furthermore, the use of rangeland is seasonally unbalanced. Summer rangeland area is large, but winter rangeland area is small; grazing rangeland area is large, but the cutting grassland area is small. This has resulted in a vicious cycle whereby "animals are fat in summer and autumn, lean in winter and die in spring". According to investigation, Wuwei has 685,300 km² of degraded natural rangeland, or occupying 40% of the region's total available rangeland area; Zhangye has 1.1 M km² of degraded natural rangeland, or 42.7% of the region's total available rangeland area; Jiuquan has 400,800 km² of degraded rangeland, mainly distributed in Subei and Aksay counties, occupying 5% and 22% of the region's total available rangeland area, respectively.

Forest and Grassland Destruction and Mountain Region Soil Erosion

Prior to 1980s, forest and grassland destruction in Qilian Mountain region was serious. In Tianzhu forest region, some 4700 km² of trees were felled, occupying 11% of its total area, and 5600 km² of shrub were destroyed, occupying 3.8% of its total; in the mountain region of Wuwei county some 53,300 km² of grassland were cultivated; in Shandan horse ranch, some 33,000 km² of grassland were cultivated, including 7600 km² in Huangcheng region; in Zhangye some 1600 km² of forest were destroyed, and this caused serious soil erosion and reservoir siltation.

Atmospheric Pollution in Urban Regions

Environment monitoring shows that among five cities in Hexi Corridor, Jinchang and Zhangye suffer from

moderate degrees of air pollution, Wuwei suffers from a slight degree of air pollution, and Jiyuguan and Jiuguan have somewhat clear atmosphere. With atmospheric suspended particles as the indicator, the daily mean concentration in Zhangye city is 0.52 mg/m³, exceeding the standard index by 85%; the corresponding figure in Jinchang city is 0.25 mg/m³, exceeding the standard index by 31.7%; and the figure in Jiuquan city is 0.19 mg/m³, exceeding the standard index by 15%.

Water Pollution

The most seriously polluted river system is the Shule River, followed by the Shiyang River system. Oil pollutant content in the tributary, Shiyou River, of the Shule River exceeds the standard index by 66%. These include volatile phenols, oil, ammonium nitrogen, copper and potassium permanganate contents and exceed the standard indexes by 65, 24, 3, 2, and 0.5 fold, respectively. The *colibacillus* number, potassium permanganate and volatile phenol contents and biological oxygen demand in the Wuwei section of the Shiyang River exceed the standard indexes by 19.3, 189, 0.40, and 0.07 fold, respectively.

Regional Economic Features and Industrial Structure

The region, as an unique oasis-farming economic zone, has abundant agricultural natural resources. According to 1995 statistical data, the total agricultural output in Hexi Corridor was 94 M Yuan, or 32% of the province's total agricultural output, of which agriculture accounted for 71%, forestry 0.88%, animal husbandry 27%, and fishery 0.27%. The region has 633,900 km² of cultivated land, occupying 18% of the province's total cultivated land area, annual grain output is 2.25 M tons, or occupying 36% of the province's total grain output. The region is a major commodity grain production base. Water shortage is the largest constraint for economic development of the region.

The region is rich in mineral resources; except a few of minerals, the ore abundance are low. According to statistical data, some 500 ore fields and 61 kinds of minerals have been found; mining fields number 267, and ore reserve occupies 46% of the province's total reserve. Nickel reserve in Jinchuan's copper-nickel deposit occupies 70% of China's total reserve, ranking second in that country. Tungsten reserve in Subei Taergou ranks first in north China; chromite in Dadaoerji, barium reserve in Fangshankou rank fourth and sixth in China, respectively. In addition, iron ore reserve occupies 26% of the province's total reserve. However, rich ores are lacking. Coal reserve in Hexi Corridor region is less, and occupies only 12% of the province's total reserve.

Although several mining industries in the region have achieved certain benefits, local economic development is backward, and large backbone enterprises fail

to push forward regional economic development. Advanced industry and traditional agriculture, as well as advanced cities and backward rural areas, form a sharp contrast and city - countryside integration level is rather low.

The industrial structure is unbalanced: light industry output, with agricultural products as raw material, occupies 82%, while that with non-agricultural products as raw material occupies only 17%. This shows that raw materials from heavy industry have not been used fully. As for heavy industry of the region, mining industry occupies 24%, raw material industry 64% and machine-building industry 11%, thus forming an industrial structure with mineral and raw material as the pillar.

Industrial structure needs to be readjusted and tertiary industry needs to be strengthened. According to statistical data, gross national product in Hexi Corridor in 1995 was 16 billion (B) Yuan, of which first industry was 5 B Yuan, or occupied 32%; second industry was 7 B Yuan, or occupied 43%; and tertiary industry was 4 B Yuan, or occupied 24%. The emphasis needed to be laid on the development of special agricultural products, strengthening of agricultural comprehensive use, and speeding up of tourism. In the meanwhile, the infrastructure needs to be further perfected, including the construction of highways, railways, and airports, otherwise the economic development of the region will be affected.

Ecological Environment Strategy

As described above, industrial structure in Hexi Corridor is dominated by oasis agriculture and raw material industry. Owing to overuse of water resources in oasis agriculture in upstream and midstream regions, the ecological environment of downstream region is getting worse. This not only affects the agricultural production in the downstream region, but also results in the shift of the oases towards upstream region. On the other hand, because the raw material industries are highly energy-consuming and heavy polluting, special attention must be given to environmental protection and rehabilitation during the industrial development processes. As the region is still a economically underdeveloped zone, it is impossible to raise enough funds to solve the problems of environment pollution and ecological destruction, and considerable attention should be given to the issues of economic development and environment rehabilitation at the initial stage and use limited funds to solve these problems.

At present, the central issue of the region is how to step up a new stage in the economic development or realize economic takeoff. Economic development should not be at the expense of resources and ecological destruction and environmental pollution. Ecological environment strategy should be "with the river basin as an unit, rational use of water and land resources, develop economy and rehabilitate environment at same time, and practice resource-saving development". Desert

development must be combined with ecological environment protection.

ECOLOGICAL ENVIRONMENT CONSTRUCTION

Basin Planning and Rational Use of Water and Land Resources

Hexi Corridor consists of three inland river basins, namely those of Shiyang River, Heihe River, and Shule River. Each inland river basin is an overall ecosystem unit, hence it is necessary to formulate the planning with the basin as an unit and work out economic development scale in accordance with water and land conditions. The distribution of water resources in upper, middle and lower reaches should be based on the overall planning and should take all factors into consideration. It is necessary to establish authoritative water management institutions and adopt some engineering measures to realize the water-allocation scheme.

The possibility of inter-basin transfer of water in water-deficient regions such as Minqin and Jinchuan should be taken into consideration under the prerequisite conditions of water-saving and scientific use of water. According to the regional differences between upper, middle and lower reaches, a rehabilitation direction has been suggested, namely "taking upper reach as water conservation forest construction region, middle reach as stable and high-benefit oasis agricultural region, and lower reach as desert agricultural and animal husbandry construction region".

Water-Saving and Resource -Saving Economic System

Water resources in Hexi Corridor are unevenly distributed. The Shiyang River basin is a serious water-deficient region, while the Heihe and Shule River basins have adequate water resources and great development potential. In addition, water-saving potential in the agricultural irrigation is large. At present the net duty of water in the Shiyang River basin is $6060 \text{ m}^3/\text{km}^2$, the corresponding figure in the Heihe River basin and Shule River basin are $6405 \text{ m}^3/\text{km}^2$ and $14,895 \text{ m}^3/\text{km}^2$ respectively. If some water-saving irrigation techniques are adopted, the net duty of water is expected to reach $5460 \text{ m}^3/\text{km}^2$ in the Shiyang River basin, $5865 \text{ m}^3/\text{km}^2$ in the Heihe River basin and $6315 \text{ m}^3/\text{km}^2$ in the Shule River basin in the near future.

In the meanwhile, great efforts are being made to establish water-saving and land-saving agricultural system; high-benefit, energy-saving and raw material-saving industrial system; and transport-saving common traffic system. All these will contribute to the development of national economy in the Hexi Corridor towards high benefit, low energy and raw material consumption direction.

Oases in the Hexi Corridor are the economic developmental basis. Efforts are being made to readjust land

use structure in the light of local conditions. In the meanwhile, a three-in-one protective system "protect south mountain (Qilian Mountain) forest, middle oases and north desert" is under construction.

Environment Planning Pollution Control

Formulating environment planning, rational use of resources, enhancing environment-carrying capacity, coordinating the relations between population, resources and economic development are the basic ways to coordinate environment and development in the whole region. With the transformation of industries in coastal regions, some high energy consuming and heavy polluting industries may be transferred to the inland region. Therefore, consideration must be given to the layout of key and large-size projects and to the natural environment function and carrying capacity.

In view of serious shortage of water resources in Hexi Corridor, it is not suitable for constructing large water-consuming industries. In addition, it is necessary to readjust energy source structure, improve atmospheric environment and control water pollution. Environment improvement should be based on the environment laws, "those who pollute the environment should be responsible for the improvement of the polluted environment".

On the one hand, attention should be paid to the comprehensive exploitation of resources so as to reduce waste. Resource development and construction should have full preparation, give overall evaluation to the

projects, predict environmental changes, and put forward preventive measure in advance. Already polluted areas must be rehabilitated without delay and every effort should be made to improve the ecological environment.

REFERENCES

- Zhu, Zhenda, and Lis Shu. 1981. Desertification processes and control regionalization in the north China, Beijing. *China Forestry Publ. House*, 74-76.
- Zhu, Zhenda. 1989. Desertification and its control in China, Beijing. *Science Press*, 9-12.
- Li Fuxing, and Gao Qianzhao. 1991. Desertification disastrous situation analysis and counter-measures in the arid Hexi Corridor region of Gansu province *J. Desert Res.*, 11(1): 1-6.
- Meng, Rong. 1994. Comprehensive planning study of water resource and environment economy, Beijing. *Geological Press*, p. 35-42.
- Chen, Longheng, and Qu Yaoguang. 1992. Water and land resources and their rational development and utilization in Hexi Region, Beijing. *Science Press*, p. 36-76, 88-119.
- Zhao, Xingliang. 1993. Strong sandstorm damages and counter-measures in Gansu. *J. Desert Res.*, 13(3): 1-7.
- Fu, Bojie. 1994. Ecological environmental construction in the national economic development region of the upper Yellow River. *Arid Land Resources Environment*, 8(1): 1-9.

Artificial Oasis in Dry Lands: Shimanto Method to Reuse Treated Wastewater

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ABSTRACT

The advance wastewater treatment system, known as *Shimanto* method, has been developed since the end of 1980s, even in poorly financed local governments such as Kochi prefecture in Japan. It aims at: 1) conservation of water resources; 2) zero emission as a preventive measure of environment protection; 3) conservation of energy material resources; 4) educational and institutional initiatives, including public involvement and women in development, for efficient water use; 5) preventive measures to avoid conflict among different sectors; and 6) international cooperation opportunity to apply it in arid countries.

The method intentionally reuses the waste disposal as a biofilter, which results in low capital investment, less maintenance cost, low energy requirement operation, and simple eco-technological application. The treated wastewater with 1 mg/l of biological oxygen demand (BOD) is being used for toilet flushing, garden irrigation, and supplementary water source of recreational ponds. A model study of small-scale distributed type of treatment system is shown in the case of Tunisia for "Initiative for Collaboration to Control Natural Resources Gradation (Desertification) of Arid Lands. The application of small-to-medium scale distributed-type wastewater treatment and recycling system, which will be the supplementary water source of man-made artificial oasis, has advantages for sustainable development of people and their cultures in dry lands.

WATER INDUSTRY: ADVANCED WASTE-WATER TREATMENT

The Japanese water industry has long been engaged in developing advanced water treatment technologies, including desalination and re-use of treated wastewater, since the Water Re-Use Promotion Center was established in 1973. The research program had a focus to develop membrane-separation technology with application of advanced water treatment systems including reverse osmosis (RO), ultra-filter (UF) and micro-filter (MF), which committed the Government-backed research project of "Aqua Renaissance 90" in the late 1980s. Significant progress was focused in the development of *reverse osmosis* membrane for desalination in the 1980s to export huge seawater desalination plants to the Gulf countries (Murakami, 1995).

The most reliable and conceivable method is to use the reverse-osmosis membrane not only for desalting

the saline water, but also treating the municipal wastewater for reuse. Reclaimed waste-water after the membrane separation, including reverse osmosis and ultra-filter is being supplied in some of the public parks to restore a clean-water environment and amenity value of small rivers and lakes in Japan. It is, however, too expensive and complicated to use the permeate from the reverse osmosis in recreational water use, taking into account the unit cost of US \$1/m³ of the permeate with WHO drinking water criteria (Murakami, 1996; Wangnick, 1998).

A typical example of integrating water recycling system to achieve the "Zero Emission" strategy, which combines reverse osmosis seawater desalination and advanced wastewater treatment with UF membrane, is seen at Hius Tembosh in Nagasaki, Japan. The drinking water for 40,000 people has been supplied from the reverse osmosis seawater desalination plant since 1992, and then the wastewater is to be treated up to the tertiary level by adapting the UF membrane for reuse. The reclaimed wastewater through the UF membrane process is being reused as a supplementary source of an artificial lake along the waterfront residential area and for garden irrigation with the aim of groundwater recharge through soil infiltration.

A system which applies new biotechnology and membrane technology for the treatment of organic materials has been developed since the end of the 1980s. The application of new biotechnology for treating the organic materials has three facets; *low energy*, *low cost*, and *low maintenance*, with aim of producing clean water for reuse at a feasible cost. The "Shimanto Method" has been developed since the end of 1980s to remove the organic materials as well as nitrogen (N) and phosphate (P) by adapting simple biotechnology at least cost.

THE SHIMANTO RIVER: CLEAN-WATER ENVIRONMENT

The Shimanto River has been intensively developed to sustain a clean-water environment of less than 1mg/l of BOD at the river mouth, introducing a cultural reputation in a sense of a "heritage" river as "the last clean and beautiful river in Japan". The people living in the watershed have a keen interest and willingness to provide a clean-water environment by developing a series of small-scale wastewater treatment systems such as "Shimanto Method" since the end of 1980s. The distinctive feature of the Shimanto method includes: 1) *low capital cost*, 2) *simple/low technology and energy*,

3) *simple operation and less maintenance*, and 4) *reuse of local waste as a bio-filter*, which made it possible to construct a series of small-scale treatment plants by steps in a short period, even in weakly financed vil-lages and towns in the watershed.

The preventive measure of constructing a series of small-scale distributed type of wastewater treatment plant, namely by the Shimanto Method, in the water-shed would lead to promote a comprehensive water management scenario, which includes the recycling treated wastewater in the upstream area not only for protecting the clean water environment of the down-stream, but also reducing the amount of water use or conserving the water resources in the region.

Small-Scale Wastewater Treatment and Recycling System

The water environment infrastructure in the Kochi University of Technology campus seeks to demonstrate *efficient water use*, conserving water resources as well as environment, by recycling treated wastewater with the aim zero emission. The wastewater is treated by two steps: 1) *Secondary treatment* as "Intermittent Aeration and Circulation Method (IACM)" and 2) *Tertiary treatment* by the "Shimanto Method". The design capacity of the treatment plant is 460 m³/day by taking into account the 2,200 people served. The sys-tem diagram of the water recycling system is shown in Fig. 1.

Prior to the tertiary treatment system as the Shimanto method, the secondary treatment system as "Intermittent Aeration and Circulation Method" is used to remove 95% of BOD, 86% of chemical oxygen demand (COD), 92% of suspended solids (SS), 70% of total N, and 50% in the raw wastewater. The intermit-tent aeration is being carried out to keep the alternative aerobic environment (30 minutes) and non-aerobic environment (90 minutes), not only to move the organ-ic materials in the aerobic phase but also to reduce the concentration of N and P in the non-aerobic (zero-dis-solved oxygen) phase. The temporary result of water quality measurement demonstrates a high efficiency to exceed the design criteria.

The tertiary treatment system (Shimanto Method), which receives the effluent from the secondary treat-ment plant, is composed of an "over and under" baffled channel system. Fig. 2 shows the schematic profile of the baffled channel comprising seven sub-units with alternating aeration. The materials to be used for the bio-filter are not expensive, e.g., recycling the waste materials such as fragments of plastic/polyethylene, withered tree, activated carbon, shells, limestone, etc. Each unit of the box chamber is filled with the filtering materials (P, Co, Z, Cb, Ca, C, L) to treat the organic materials, N, ammonium, P as shown below:

- Plastic or polyethylene (fragments/disposal); treat-ment of organic materials and ammonium and nitric acid (P).

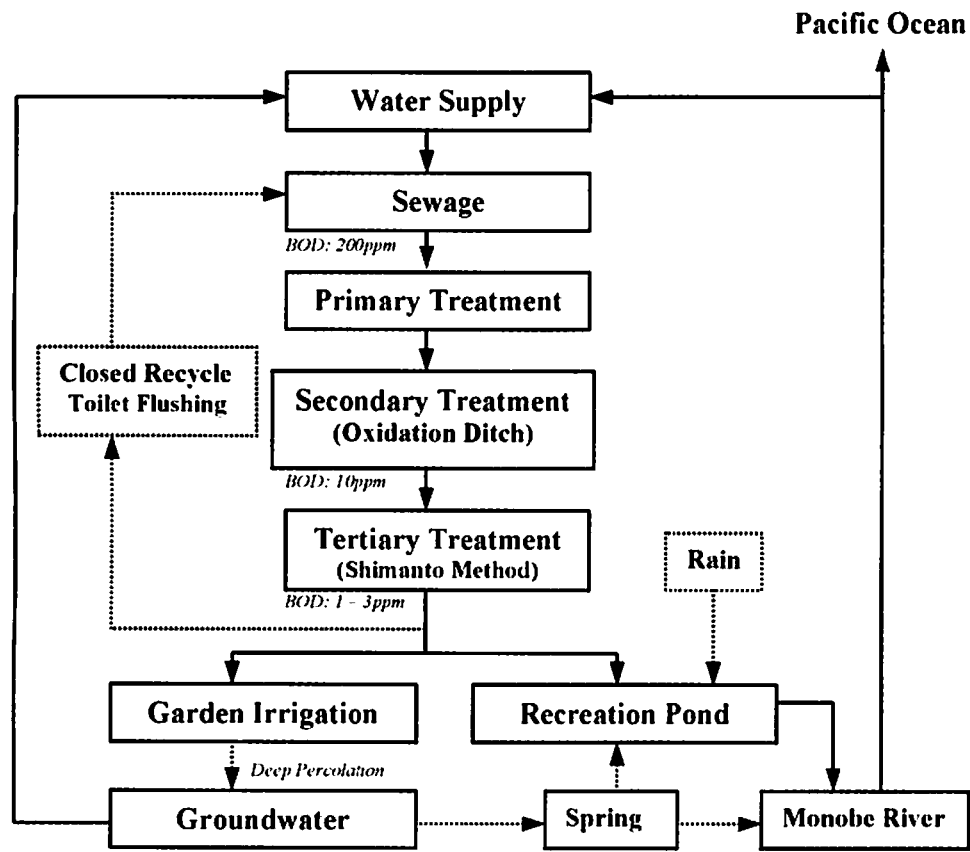


Fig. 1. Flow diagram of water recycling system in the KUT Campus.

- Organic carbon (withered Shiitake mushroom nursery tree); treatment of N (Co).
- Activated carbon (chitosan coating); treatment of organic material (Cb).
- Zeolite; treatment of ammonium (Z).
- Calcium ball; treatment of phosphate (Ca).
- Activated carbon; bleaching and deodorizing (C).
- Limestone (fragments); absorption of phosphoric acid (L).

The Shimanto Method is designed not only to remove the organic materials (50% of BOD, 65% of COD, and 90% of SS), but also to reduce the concentration of N, P, and LAS such as 60% of T-N, 60% of T-P, and 80% of LAS. The treatment also aims to control the organic materials as well as N and P taking into account the eutrophication problem in the warm temperate climate in Kochi. The temporary result of water quality measurement demonstrates high efficiency to exceed the design criteria except for removing the total N.

The reclaimed water with 1.2 mg/l of BOD, 5.1 mg/l of COD, less than 1mg/l of suspended solids (SS), 4.2 mg/l of T-N, 1.4 mg/l of T-P and less than 0.005 mg/l of LAS is being used in toilet flushing with dual-pipe system, garden irrigation and supplementary source of an artificial lake in the KUT campus, which results in preserving the clean water environment of the Monobe River and the water resources in the region.

This proposal suggests several non-conventional approaches highlighting the economic and environmental gains of applications that would have the potential to resolve this persistent problem, and thus contribute towards peace among the water users in the Middle East. The proposed pilot project was conceived at the level of social development study to take into account the future application in promoting the Middle East Peace Process in line with the multi-lateral cooperation by the World Bank and bilateral cooperation with the Japanese Government.

The first Pilot Project was conceived in north/central Tunisia to demonstrate some advanced water management system using reclaimed wastewater after the second treatment level. The integrated water reuse project aims not only to reuse the reclaimed wastewater at the secondary treatment level for irrigation, but also to restore the groundwater environment of the aquifer system, easing the long-stand constraints of water quality and health and seasonal water demands. This project is designed to demonstrate an advanced model and its management system for the reuse of reclaimed wastewater in the region by taking into account the seasonal water demand and use.

The Pilot Project, which includes some applications in groundwater management to recharge the treated wastewater at secondary to pre-tertiary level into shallow aquifer system along the coast, will examine the legislation restricting treated wastewater reuse to a specified list of crops. The legislation may need to be

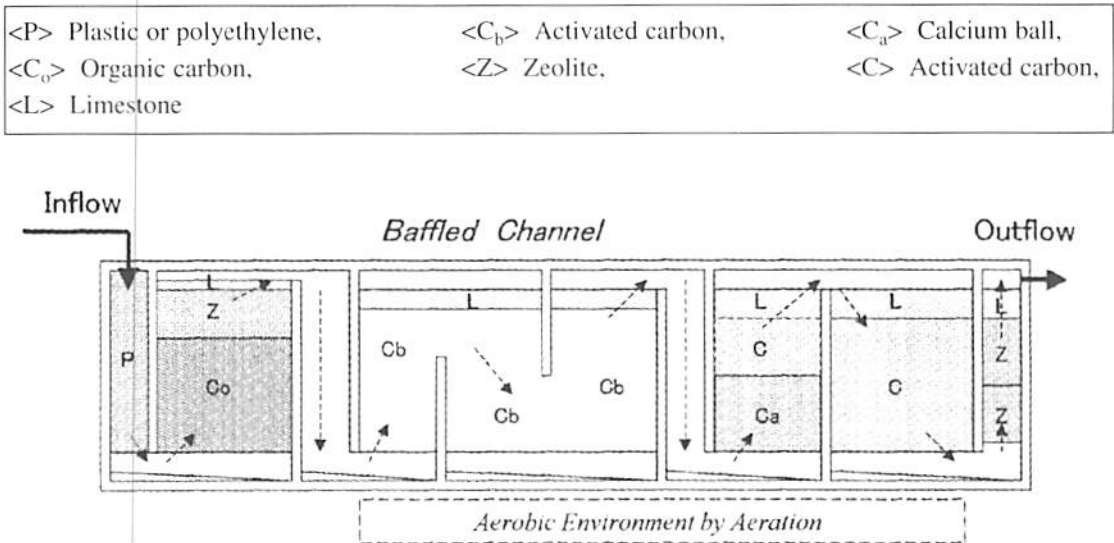


Fig. 2. Schematic profile of Shimanto Treatment Unit.

Proposed Application in Dry Lands

The aim of the proposed pilot project in dry lands is to provide some technological answers to the fundamental questions of how to sustain the water supply by introducing the marginal water development and management without having an adverse effect on the eco-system and environment now and for the 21st Century.

revised to allow a broader choice where treatment quality is higher by adopting the advance treatment including the technical option of the Shimanto Method. The study comprises the following five major objectives:

- Elaborate comprehensive view of future options by taking into account the next era of Tunisia's investment in treatment stations.

- Protect the water quality environment of the Mediterranean Sea by reducing the amount of effluent (treated wastewater at secondary level) by not only use it for some purposes of irrigation but also divert it into the aquifer system through soil infiltration.
- Protect the seawater intrusion of shallow aquifer system by restoring the groundwater table or creating the watertable mounds along the coastal line.
- Develop an integrated cyclic reclaimed wastewater use system by recharging it artificially into shallow aquifer systems through soil filtration or percolation in irrigated lands, irrigating higher-value crops, by either pre-tertiary to tertiary level of treated water or restored groundwater, which is a mixture of natural groundwater and treated wastewater after soil percolation.
- Revise legislation which may need to allow a broader choice of crops where treatment quality is higher, taking into account policies, regulations, technologies, environment and economics.

The seasonal groundwater recharge scheme will include the following five optional methods, either single application or combined in a framework of the integrated water management system:

- Intentional deep percolation in the irrigated land using reclaimed wastewater at secondary-tertiary level.
- Infiltration pond/ditch (expanding existing experimental facilities).
- Temporal storage pond (existing test pilot ponds with various depths) + infiltration pond/ditch.
- Induced wadi floods and retention + infiltration pond/ditch.
- Groundwater recharge well (pumping in summer and recharging in winter) + pre-tertiary to tertiary treatment system.

The recharge well method using the treated wastewater at secondary level is not recommended to avoid significant waterlogging problems. In any case, the treatment level and its standards will be improved by steps corresponding to the technological developments and application in higher value crops. The advanced treatment may suggest the three strategic alternatives: 1) *Pre-tertiary Treatment* such as "gravel filtration (+ sand filtration +chlorine)"; 2) *Tertiary Treatment* including ozonation, or MF/UF/REVERSE OSMOSIS membrane filtration; and, 3) *Advanced Treatment* as the Shimanto Method. The reclaimed wastewater in pre-tertiary to tertiary level will be used to include the following four:

1. Indirect use for groundwater recharge, taking into account seasonal water demand.
2. Direct use for high-value vegetable crop irrigation, including some specific crops or vegetables such as peppers, potatoes and sugarbeet, etc.,

3. Direct use to restore water environment or supply recreational water in the park.
4. Mixing or dilution with other conventional water sources for high value vegetable crops.

Some emphasis would be put on the salinity constraints in crops and soils to sustain irrigation using the treated wastewater. Special attention will also be paid on the social awareness with private sector and NGOs and the gender issue.

Both Israel and Palestine agreed on the Article 40 in the Oslo II Peace Treaty in 1996, including that any water supply project to increase the supply capacity shall not be approved unless otherwise appropriate sewage system is simultaneously equipped not only to preserve the environment, but also to protect the existing water resources from contamination. It was the first alarm for the projects designed for international cooperation, along with the Middle East Peace Process, to integrate the linkage of water supply and sewage in the social development program, adapting sharp political decision making on water development and management policy.

CONCLUDING REMARKS

The wastewater treatment to combine the secondary treatment as "Intermittent Aeration and Circulation Method" and the tertiary treatment as "Shimanto Method" demonstrates a high efficiency to reduce not only the organic contaminants but also some of the N and P at least cost. Small-to-medium scale distributed type of the wastewater treatment system demonstrates some good advantages if it takes account of the reuse and recycling. There is also a paradigm shift in the policy of international cooperation since 1992, adopting rather small-to-medium scale of development projects by taking into account the finance capacity, aid efficiency, environment, gender such as "women in development", and conflict prevention/resolution and peace.

Japan International Cooperation Agency (JICA) has just offered the special training course on "Regional Water Environment Management" at the Kochi University of Technology in 1999 to transfer the technology of managing small-scale distributed type of treatment and recycling system. It is evident that the application of small management technology in the dry lands has significant implications and effects on sustaining the life, environment and society in the 21st Century.

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REFERENCES

- Adham, S. 1998. Development of an innovative advanced treatment system for indirect portable use. *Desalination and Water Reuse*, 8/2: 16.
- Bouwer, H. 1993. Urban and agricultural competition for water, and water reuse. *Inter. J. Water Resources Development*, 9/1: 13-25.
- Hosper, S.H., and M.L. Meijer. 1993. Biomanipulation, will it work for your lake? A simple test for the assessment of chances for clear water, following drastic fish-stock reduction in shallow eutrophic lakes. *Ecol. Eng.* 2: 63-72.
- Hosper, S.H. 1997. Clearing lakes, an ecosystem approach to the restoration and management of shallow lakes in The Netherlands, 3: 63-72.
- Murakami, M. 1996. Managing water for peace in the Middle East, alternative strategies. United Nations University Press, Tokyo-New York-Paris. p. 251-266.
- Okada, T., and O. Oba. 1993. Recycling of wastewater from buildings by application of membrane. *Proceedings: IDA and WRPC Conference on Desalination and Water Treatment*. Vol. II: 495-504.
- Udagawa, T. 1993. Water recycling system in Tokyo. *Proceedings IDA and WRPC Conference on Desalination and Water Treatment*. Vol. II: 463-470.

X. Socio-economics and Anthropology

Resource Management: Perceptions and Strategies of Households in Bershaya Village, El-Bab District, Syria

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ABSTRACT

Poverty alleviation has become one of the most important issues that concern the international community. In agriculture, loss of natural resources forms a great threat to rural people who depend on land and water for their subsistence. In Bershaya village in Syria, the International Center for Agricultural Research in the Dry Areas (ICARDA) introduced new technologies to support farmers in protecting their natural resources. The impact of ICARDA's contributions is dealt with within the framework of households' economic strategies. The household is a small enterprise wherein its members cooperate in different ways to sustain themselves. Their strategies may or may not target the protection of the natural resources. Evaluating these strategies reveals their limitations, aspirations, and constraints. This evaluation takes into consideration the dynamism of household division of labor, gender dimension, and off-farm activities.

BACKGROUND

Agriculture is an important domain as far as preservation and conservation of natural resources are concerned. Current research focuses on two major elements that will affect our future, namely *biodiversity* and *increasing land's productivity*. As a matter of fact, the two areas of research are interrelated (Ceccarelli, 1997). Within this context, sustainability has become the term that is continuously used to emphasize preservation. *The goal of sustainable agriculture is to ensure that the production capacity will be maintained for future generations.* That goal can only be achieved through preservation of natural resources. Natural resources conservation is directly and indirectly related to the well-being of the rural poor whose capital of these resources is the backbone for their survival.

Within the Consultative Group for International Agricultural Research (CGIAR), in general, and at ICARDA, in particular, there is a rising interest in a people-centered focus (CGIAR, 1997); as such, technology is designed to respond to farmers' needs. As a result of this trend, social science approach has gained more importance during the last few years, especially through a participatory approach.

The present study partly fulfills some of ICARDA's objectives and responds to its aspirations. It was designed and implemented informally, but it was meant to be in harmony with ICARDA's plan of work

(ICARDA, 1997). Considering the household rather than the individual farmer as the main unit that constitutes a community and a system of resource allocation (Feldstien and Poats, 1989), this study considers the household as its unit of analysis. The preservation or misuse of the resources is related to a complex structure of the household members' demands, aspirations, and environmental conditions. Not incorporating the household in socioeconomic studies leads to overlooking the importance of its members' roles, including the gender dimension (Feldstien and Poats, 1989; Schuh, 1988).

STUDY OBJECTIVES

The objectives were to:

- Define problems that are related to natural resource management on the community and society levels.
- Evaluate households' strategies for resource management.
- Assess the impact of ICARDA's assistance on those strategies.
- Analyze households' economy taking into account the gender dimension.
- Insure Natural Resource Management sustainability.

General Characteristics of El-Bab District and Bershaya Village

Bershaya is located in El-Bab district, northeast of Aleppo. ICARDA surveyed that district for the first time in 1984. In order to monitor changes in farm resources and land use, the district was revisited in 1995. It was noticed that fallowing the farmland and the practice of crop rotation decreased by 30%. From 1985 till 1995, cereal monoculture has increased, which caused diseases and yield depression. Irrigated land had increased from 2.8 to 8% of the total cultivated land. The expansion of the irrigated area resulted from the increasing number of wells, which have been drilled in the area; 20% of the wells were less than 5-years old.

The average productive period of a well is 5.2 years. Existing water resources are being rapidly depleted due to the low recharge rate and because digging for water became a common practice in the area (ICARDA, 1995). Livestock size has steadily decreased because of the rising expenses of foodstuff and long-hand feeding period. The adoption of food and forage legumes was constrained by the higher expenses of human labor.

Bershaya falls in the zone which receives an average of 250 mm or more with maximum of 350 mm, but not less than 250 mm in two-thirds of the years (Zone 2). The land is suitable for cultivating barley, wheat, and legumes. Most of Bershaya is shallow land. Pastoral activities are therefore very common in the village. While there are wells in different places, people expect that they will dry up in a short period of time. For drinking water and every day use, Bershaya inhabitants depend on a Governmental water pipe coming from a nearby village, Shewayeha, 7.8 km from Bershaya.

Aiming at conserving soil fertility and using the minimum amount of water for irrigation, ICARDA introduced the mower in 1995, an equipment that can easily fit to tractors, and is used to harvest vetch and other legumes. It would replace human labor and encourage farmers to plant vetch. As a result of research on germplasm enhancement, drought-resistant, high-yield barley varieties were introduced for experimentation in Bershaya.

The plan-of-work that is designed in this study focuses on resource management from the farmers' perspective and based on the households' strategies. Introducing variations and differentiation of households within the community opens avenues for better understanding of how those households deal with available resources. The selected 16 households which represented our random sample vary in lineage affiliation, economic activities (on- and off-farm), income and revenues (rich or poor), types (extended or nuclear), and land-holding size. They are similar in other aspects, such as their way of life, appreciation of land-holding, and expectations with regard to female and male roles within the households.

FIELD WORK

The study was accomplished in two phases, the first phase being exploratory, where informal non-structured meetings with the members of households and their guests were held. During the first phase, the team got familiar with the village environment and its people.

During the second phase, random households from different locations were selected. There were households of common lineage (*Sinjar*) that had no access to ICARDA's technology. It seemed that there was one family's households (*Sheikho*) that monopolized the use of that technology. Ensuring that the support should go to the targeted group could have occurred if anti-analysis of the village's social structure were carried out, followed by the introduction of the new technology. The *Sinjar* lineage was included in the study, a fact that serves greatly the objectives of our research, since it provided an independent group to refer to.

During this phase the following steps were implemented: (i) Surveying the major families in Bershaya; (ii) Tracing the land fragmentation through two or three generations (Fig. 1); and (iii) Analysis was conducted taking into account the gender dimension within the

households. About six hours were spent with each household. The members of the households were asked to attend the meeting, yet women were rarely present. They had no time to sit and talk. Therefore, we moved to where they work and held informal discussions, observing their activities.

During the second phase, we used a checklist covering what we considered the main variables that affect the economic strategies of households. Those variables included mode of production, new technology's impact on perception and choices, fragmentation of land, holding size vs. family size, family labor, off-farm income, added value products, the cultural value of land, use of water, evaluation of natural resources problems, and women's contributions to the households' economy. The household is defined as a unit of kinship living together, consuming together, and not necessarily sharing the same mode of production.

NATURAL RESOURCES' PROTECTION/DETERIORATION

Strategies and Farmers' Perceptions

Land fragmentation, soil preservation, and use of water are the three areas that were investigated in relation to farmers' awareness, and practices.

Land Fragmentation

The process of land fragmentation due to population increase, and the continuous decrease of land holdings' size, is threatening the well being of the coming generation, as the ratio between land versus number of households is falling dramatically, and places great pressure on the land (Table 1).

Soil Preservation

After the introduction of forage legumes, farmers' areas of cultivated land and /or fallow were considered criteria of soil preservation (Table 2). Cases 12-16 were not involved in ICARDA's research activities in Bershaya. When they had access to vetch and barley seeds, they planted vetch in 97/98 and "Arta" barley variety in 98/99 respectively. Most farmers still use fertilizers, thinking that as such they are contributing to maintenance of soil fertility. In most cases, farmers are still unable to abandon monoculture practices and depend on rainfall (Table 2).

The following comments represent farmers' perceptions of how to maintain land fertility: "Fertilizers are good for the soil and should be used frequently" (Cases 1, 7, 13, 15). There was a consensus among farmers to continue planting vetch because of the following reasons: "Grains and straws are good as feed", "Increases the land fertility and as such it saves the use of fertilizers", "It is better to plant vetch than leave the land fallow", and "Good selling prices in the market for both grain and straw".

Some farmers express their need for Governmental support in two areas, namely land reclamation, and tree

Table 1. Land fragmentation.

Case No.	Original Holding Size	First Distribution	Share	Second Distribution	Share/Person+ Bought Land	Expected Share
	---ha---		-----per person-----			
1	100	4	25	3	$8 + 27 = 35$	4.2
2	100	4	25	3	$8 + 6 = 14$	1.9
3			28	4	$6 + 6 = 12$	3
4			30	5	$6 + 7 = 13$	1.6
5			16.5	4	4	1.3
6	100	4	25	3	$8 + 14 = 22$	7
7	420	7	60	1	60	15
8	100	4	25	3	$8 + 6 = 14$	3
9			35	5	$7 + 6 = 13$	6.5
10	80	4	20	6	$3.5 + 37 = 40.5$	2
11				6	40	8
12	120	3	40	3	$13 + 4$	8.6
13	60	7	$8 + 12 = 20$	2	$10 + 2 = 12$	2
14	-	-	10	8	0.12	0.04
15	-	-	16	5	3.2	1.5
16	-	-	15	3	5	1

Table 2. Soil Characteristics.

Case No.	Land Quality	Rainfed	Fallow	Vetch		Fertilizers
	--ha--			96	97	
1	20 non-arable, 3.5 trees, 11.5 shallow	20	Yes	2	2	Yes
2	11 shallow	11	Yes	3	3	Yes
3	6 shallow, 6 deep	8.5	No	2	3	Yes
4	3 deep 1.5, trees, 9 shallow	13.5	Yes	2	4	Yes
5	3 shallow, 1 deep	3	No	1	1	Yes
6	4 deep, 4 tree, 14 shallow	18.5	No	3	4	Yes
7	24 deep soil 46 shallow	54	Yes	3	3	Yes
8	14 shallow	14	No	1	3	Yes
9	4 deep good quality, 7 non-arable	7.2	Yes	1	3	Yes
10	15 deep, 25 shallow	37	No	7	8	Yes
11	6 deep, 34 shallow	37	No	3	5	Yes
12	Shallow	34	No	-	-	Yes
13	5 shallow, 5 deep	7	No	-	-	Yes
14	Shallow soil	6	No	-	-	Yes
15	1.2 deep, 2 shallow	2	No	-	-	Yes
16	2 deep, 3 shallow	3	No	-	-	Not much

cultivation. While there are private companies, which take charge in land reclamation, farmers in Bershaya village cannot afford such expenses (Cases 6, 9). Some farmers suggest that if the Government provides them with nominal aid, they will cultivate trees immediately. Trees take some years to grow before they produce. They are not productive immediately. As the main trees planted in the area are olive trees, they take at least 5 to 6 years before producing. Meanwhile, farmers can grow other crops between the trees to supplement their income and to secure their living.

The very poor farmers (Cases 15, 16) follow monoculture because they cannot afford learning font of the land fallow, while another (Case 14) cannot afford even buying barley seed to cultivate his land every year. A farmer (Case 14) cannot afford buying fertilizers.

Planting vetch in different areas annually is a strategic and rewarding way of improving the quality of soil.

Water Use

The majority of farmers depend on rainfall, and are not familiar with water harvesting, except in few cases (Cases 1, 4). They collect rainwater in large containers and use it for washing and other domestic uses. In the eighties and nineties, drilling wells in the hope of finding water became a very common practice (Table 3). As some farmers report, people do not follow the Ministry of Agriculture's regulations, and they do not keep enough distance between one well and the other. This leads to water depletion and the drying up of wells in a short period of time. Most farmers have one or two

wells, and irrigate a limited area of land (Table 3). Sometimes farmers buy water to irrigate trees during the first few years of their growth.

The majority of the participants recall the time when they used to plant cotton, sugar beet, and other

some people of the new generation started looking for off-farm activities and intend to have different plans for their children (Cases 2, 4, 8, 16).

Ownership of land is highly appreciated. Most revenues of off-farm activities are reinvested in improving

Table 3. Irrigation details.

Case No.	Wells	Size of Irrigated Land	Year of Drilling	Expected Duration	Dried-Up Wells
	--No. --	---ha---		--Year--	--No. --
1	1	1	92	-	1 (60-75)
2	None	None			1 (62-82)
3	1	3.5		Unknown	
4	None	None	-	-	None
5	2	3	85-94	Unknown	
6	1	3.5	86	5 years	None
7	1	6	80		None
8	1	3.5	80	Unknown	None
9	1	4h	Not sure	3 or 4 years	1 /1982
10	2	6 irrigated	71-90	Unknown	None
11	2	2.5			None
12	2	6	90-95	Unknown	1
13	2	3	85-92	1 yr.-5 yrs.	1
14	1	0.6	54	2 yrs.	None
15	1	1.2	53	Soon will dry	None
16	1	0.1	83	Unknown	1 (53-73)

crops that require great amounts of water. They used underground water to irrigate their lands, which could have accelerated the drying up of wells in the area. Farmers have their own perception of the reasons of degradation of water resources. Some of them think that it is due to the frequency of drilling wells in addition to the scarcity of the rainfall and/or snow in the area. Others think it is due to earthquake, which contributed to changes in underground water's level.

HOUSEHOLDS' ECONOMY AND GENDER DIMENSION: SUCCESS OR FAILURE

Natural resource management in its broadest sense means that the household can use these resources without exhausting their base. In the subsistence type of rural life, agricultural activities ideally should provide the households with revenues that guarantee a decent life where basic needs are satisfied for all its members. Household members distribute tasks and duties among themselves to produce their needs. Relationships between members are culturally shaped and defined, and have their impact on gender roles. Households in Bershaya share common features, yet there are interesting variations that are worth mentioning and reflecting upon.

Households are patriarchal, men as heads of households have control over land, revenues, and the decision-making process. Women and children work in different agricultural domains without objecting or expressing their opinions. They internalize the situation as a natural one. With the decreasing land-holding size,

the farm system or buying more land. There are some strategies to keep the land intact without fragmentation. In many cases, married brothers who live and consume independently work together in agriculture, and divide the income without differentiating between who owns what (Cases 5, 12).

They also do not allow women to own land by inheritance in order to keep the land undivided and not to permit aliens (women's husbands) to interfere in the family's business. Women may own sheep or any livestock. They are given jewelry as a compensation for non-inheritance of land. Sometimes fathers reward their clever daughters by giving them gold jewelry. Gold is considered as an asset and a sort of saving, not just for women, but also for the whole household. They can be sold at times of hardship, or when the household starts a new project. In Case 13, the wife's jewelry was sold for buying a drill. When the business grew, more land was bought.

Within the households, wives are the "executive managers" who lead the process of production and small industries. They define the tasks for their daughters and other females in the household (sisters-in-law, a second wife, daughter(s)-in-law). In households that depend on sheep husbandry, women take care of feeding, milking, and dairy products' processing. Some households deal with these products as small business' projects. They use machinery to increase production (Case 1).

In Bershaya, unlike other villages in El-Bab district, women do not work for others, because they spend

their time working for their families. There are different tasks assigned to women, such as weeding, seeding, collecting vegetables, and preparing them for the market. The mechanized tasks are assigned to men. Men are also responsible for marketing the farm products. On the women's shoulders falls the burden of preserving food in summer to be consumed in winter. They may use their own products or buy their needs from the market. They dehydrate almost all the available vegetables by exposing them to the sun. They make concentrated tomato paste by using the sun to dehydrate the moisture from the tomato juice. They collect or buy immature grapes and extract the juice, boil it, store it, and use it to enhance food taste. In most of this food preservation process, they use the free energy of the sun.

In certain cases, marrying a woman from urban background creates tension among the extended family household's female members, and threatens the traditional role of women (Case 5). Urban women may share in the process of food preservation, but never in the agricultural tasks in the field. In Cases 5, and 12 brothers who used to consume together decided to separate and live independently as a result of wives' different cultural background.

Young male children work as shepherds or help in harvesting or other agricultural work, but never participate in the house domestic works. Female children do the domestic jobs inside the house, such as washing clothes and dishes, cleaning, helping in cooking, and so on. Meanwhile, they are trained to feed and milk the sheep. They also share in the dairy products' processing.

Most of farmers, except three cases (6, 14, and 16), consider the big number of children as an asset for their present well-being. Some of them marry twice for the sake of bearing more children (Case 7). The continuous decrease of the size of land holdings will cause poverty for the coming generation. In some cases, owning mechanized farming equipment such as tractors, compensate for low income in small size holdings (Case 5). Off-farm activities are other ways of getting over limited resource (Cases 12, 13).

CONCLUSIONS

In Bershaya, it is obvious that ICARDA's research activities have dramatically changed farmers' strategies towards their resources. These changes are apparent in their plan to follow the cereal/vetch rotation, and to select drought-resistant crops in cooperation with scientists. Following these strategies has enabled them to get more production out of the same area of land, save the expenses of fertilizers, and have a good quality livestock feed either to use for their sheep or to sell in the market. The only constraint which they face in this regard is the fact that the price of a mower is too expensive (\$3,000). This constitutes a real obstacle to sustainability.

Farmers are liable to abandon new technologies if they require a high rate of initial investment

(Rajasekaran and Martin, 1988). The problematic issue, as revealed in this paper, is the contradiction between what is best of resource management and women's empowerment. Women's deprivation from land inheritance maintains solidarity among the patrilineal side of the household and protects their resources from an alien interference, yet it creates a situation where women remain economically dependent on males (father, brother, husband or son).

The cultural definition of women's role limits their benefit from the increase of income. In poor and rich families, women do not have the chance to get educated. While male children may be given the right to develop their potential through education, female children may finish primary education, but rarely if ever do they proceed to higher levels. They can never be thought of as employees, teachers, or doctors. The increase of the household income does not necessarily lead to the improvement of the life quality of all its members. Dealing with poverty should include the disadvantageous segments of households and search for ways to help them without provoking the cultural setting.

Within the households studied, there was a growing tendency to teach male children crafts and train them to do other off-farm jobs in order to solve the problem of the decreasing size of land holdings. This may release the pressure on the land as the only source for subsistence.

Last, but not least, eradication of poverty as a dream of the world community and a target for international organizations may turnout to be a reality if greater attention is given to implement inter- and multi-disciplinary approaches with innovative research methods. While the CGIAR system can provide the scientific knowledge and supervise its implementation, eradication of poverty or even alleviation of poverty requires the support of the entire international community. Collaboration with the civic society as well as national research centers, not only in agriculture, but also in social sciences provides the base to turn this dream into reality.

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REFERENCES

- Ceccarelli, S. 1997. Three among the millions. *CARAN*, 1(4): 6-7.
- CGIAR. 1997. Mid-Term Meeting. CGIAR, Washington, DC.
- Feldstein, H.S., and S.V. Poats. 1989. Working together: gender analysis in agriculture. H.S. Feldstein, and S.V. Poats (Ed.), Vol. 2. First Ed. Kumarian Press, Connecticut, USA.

- Feldstein, H.S., and S.V. Poats. 1989. Working together: gender analysis in agriculture, H.S. Feldstein, and S.V. Poats (Ed.), Vol. 1. First Ed. Kumarian Press. Connecticut, USA.
- ICARDA. 1995. *Annual Report*. International Center for Agricultural Research in the Dry Areas, Aleppo, Syria.
- ICARDA. 1998. Medium-Term Plan: 1998-2000. The International Center for Agricultural Research in the Dry Areas, Aleppo, Syria.
- Rajasekaran, B., and R.R. Martin. 1988. A Dissemination and utilization model. p. 652-653. *In*: P. Unger (Ed.), Texas, Amarillo Bushland, Texas, USA.
- Schuh, G.E. 1988. Social economy and policy issues in dry land agriculture. *In*: I. W. Pau (Ed.), Texas, Amarillo, Bushland, Texas, USA.

Land-Use Dynamics and Farmer-Perceived Degradation Processes: Case Study from an Agro-Pastoral Syrian Village

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ABSTRACT

The degradation of drylands is a result of complex processes and developments. In the context of a typical agro-pastoral village in northwestern Syria, the effects of demographic and social changes, reduced soil productivity, changes in agricultural technologies, and historical events on land use, and the natural resources degradation are examined.

Decreasing yields, mainly the result of reduced fallow periods and a reduction of soil productivity, and the deterioration of the grazing resources are the two main signs of land degradation in the area. The growing population obliges the villagers to practice continuous rainfed barley cultivation with no or only occasional fallow, and without any application of plant nutrients. Also, a technological change, from the use of donkey ploughs and hand-harvest to less labor- and time-consuming cultivation practices with tractors and combine harvesters, and the increased importance of stubble in the livestock diet have contributed to the reduction of the fallow periods.

The villagers' attribute the yield decreases mainly to the lowering of the groundwater table and the low rainfall in the area. The high rainfall variability discourages the fallowing of fields because continuous cultivation maximizes the chances for good harvests in years with high rainfall. Another effect is that the arable land now expands even onto sloping areas, which are subject to high erosion risk. Population growth, increased numbers of livestock and the expansion of cultivated land into grazing areas also has put pressure on the grazing resources of the village and caused their deterioration.

The possession of livestock is seen as a sign of wealth and the villagers aim to have large flocks of animals. For them, livestock is also an important means for investment of cash earned from off-farm work, which is the main income for most of the households in the village. The stabilization of the natural resources in this dry environment requires the combined and interdisciplinary effort from both the land users and the policy-makers.

INTRODUCTION

Changes in land use and the management of natural resources play an obvious role in the process of land cover-change and can be seen as a likely cause of land degradation. It is recognized that these mechanisms

have an important role in the global environmental change (Turner et al., 1995). Human resource-management strategies for agriculture and livestock grazing significantly influence land use. To understand the association between socio-economic alternations, human use of the natural resources and degradation processes is essential in order to achieve sustainable natural resource utilization (Hare, 1985). In this respect, increased intensity of cultivation and grazing and their effect on land use in marginal areas are topics that should be dealt with to a larger extent.

This paper addresses the issues of land-use changes in a low-rainfall area at the fringe of the Syrian steppe. It aims at illustrating how these land-use changes are related to socio-economic changes and how they affect farmer-perceived deterioration processes on arable as well as pastoral land.

Field Expansion and Intensification

The relationship between population growth, agriculture and pastoral production strategies, and environmental degradation has been discussed in several, often-cited publications, e.g., Boserup (1965) and Mortimore (1995). In cases where arable land is abundant, the cultivated area is expected to increase as an effect of the growing population (Rostom and Mortimore, 1991). Other driving forces are the degradation of the biophysical environment and increased demand for land to grow cash crops (Copan, 1974; Scott, 1979; Greenland et al., 1994; Snrech, 1994; Reenberg, 1996). Further, technological change might constitute a vital driving force for agricultural expansion, but it should not be seen as the sole engine for agricultural change (Netting, 1993).

Different theories have been put forward to explain the relation between population growth and agricultural production strategies, when land is saturated with population. The two best known are the pessimistic Malthusian theory, which links population growth with land degradation, and the optimistic ideas of Boserup, who believed that population growth increases the labor input and is promoting agricultural innovations (Mortimore, 1995). In the long run, Mortimore (1995) agrees with Boserup. He stresses that an area has to be saturated in terms of population density before a stable or positive intensification can take place. If an area has not yet reached the threshold, no transition from degradation to an intensification pathway will arise. In his transition model, he states that increased frequency of

cultivation without technology change may be expected to result in irreversible degradation. However, adaptive technology change opens up for stable intensification under which fertility management compensates for fertility loss, yields per area stabilize while yields per capita fall as population grows. An improving intensification might occur, where fertility and productivity gains are made. An attempt to induce intensification when the labor-to-land ratio is low is premature and may be expected to fail.

Several factors, however, influence the effect of demographical change. Mortimore (1996) puts forward the effect of a growing market, access to labor, and capital. The development of a market facilitates and promotes change. It amplifies the effect of population growth and its effects are difficult to separate from the effects of a growing population. For instance, may capital substitute labor through technologies and the hiring of labor increase the labor force for production. Market growth may also encourage the cultivation of higher value crops, resulting in increased output per hectare (McCrown et al., 1979). Other influencing factors are price policies of inputs and of agricultural products, and the priority of the development policies, especially the rural versus urban (Lindskog and Tengberg, 1994).

From case studies, it was shown that population growth does not necessarily result in environmental degradation and may translate into increased input of agricultural labor, and thereby promote intensification. Increased migration of the active labor force to urban areas may be a response to the increased pressure on the land as the population grows (Snrech, 1994). Labor inputs in agriculture and increased pressure on the local resources are influenced by the opportunity to invest labor in alternative income-earning activities, home or away. These factors are influential and it is to separate their effect from the effects of demographic changes (Snrech, 1994).

Crop-Livestock Integration

The land-use systems in the semi-arid regions are generally characterized by the co-existence of agriculture and pastoral activities. Pastoral production has often existed in some sort of symbiotic interaction with agriculture (McCrown et al., 1979; Scott, 1979; Sandford, 1993). Such relations have multiple forms which range from co-existence of livestock rearing and cultivation in the same farm units to systems based on exchange of different items such as products, manure, labor, etc. between two principally independent production systems. Increasing demographical pressure and environmental deterioration has put not only agriculture and pastoral activities under stress, but also the entire system.

In farming systems with low population densities, there is a low degree of crop-livestock integration. Fallowing of fields is used rather than manure and fertilizer, and pastures and fallow vegetation are principal sources of livestock fodder. Higher population

densities, the expansion of arable land and reduced fallow periods limit the land available for grazing. Grazing of crop residues then becomes increasingly important. With further intensification, there is a claim for stall-feeding and the cultivation of fodder crops. Manure or fertilizer, if available at the market, is used as a substitute to maintain soil fertility as the fallow period is reduced (Pingali et al., 1987; Mortimore and Turner, 1993; Harris, 1996).

As the farming system intensifies, there is a choice to continue the interaction via markets or a stronger integration of crop and livestock within the system. The choice depends on the constraints, such as transport costs, prices of fertilizers and processed feeds, and also on the competition for land and labor (Pingali et al., 1987). Tutwiler et al. (1995) argue that in West Asia and North Africa there is a tendency that market forces encourage crop-livestock integration through the market, but discourage integration at farm level. With differentiated farm types emerging, production will be based on specialization rather than integration of farm enterprises.

Three examples of the market forces separating on-farm crop and livestock production and encouragement of market crop-livestock integration are: (i) a growing feed market, (ii) a market which favors the cultivation of cash crops to fodder crops, and (iii) where farming households seek off-farm income to relieve dependence on farm income and therefore isolate their farm production decisions from market forces. It should be noted that not only population dynamics and market relations affect the crop-livestock integration. Also, social and cultural issues are important.

Phases of Land-Use Changes

Bilsborrow and Ogendo (1992) describe the population-driven changes in land use going through four phases: (i) tenurial, (ii) extensification, i.e., area expansion, (iii) technological, and (iv) demographic. The type of responses that occur depends on several factors, such as natural resource endowment (land quantity and quality, topography, climate, rainfall etc), institutional and attitudinal factors deriving ultimately from the country's history (including prevailing land size, existing tenure arrangements and community control), and governmental policies (including how they mediate the effects of international factors).

Changes in tenure arrangements take place when the demands exerted on the land by a growing population generate questions about individual and group entitlements to its growing scarcity, and when out-migration is not a desirable option (Bilsborrow and Ogendo, 1992). Expansion of the arable land may occur simultaneously with changes in tenure arrangements. This occurs as soon as the community no longer has sufficient land in its immediate area for the present or the future. The extensification often takes place in frontier areas not controlled by or perceived available to a given community. Bilsborrow and Ogendo (1992) state

that the adoption of new technologies of land use is often a measure of social and cultural flexibility in the society. It is not therefore always a response to external stimuli.

The distinctive feature of technological change, associated with population growth, is, therefore, that it is accompanied by intensification, i.e., increased land productivity. The demographical phase, usually in the absence of outside intervention, is the last response in the population/land use continuum. It involves population reduction through either (or both) postponement of marriage or reduction in marital fertility. The extent to which this phase occurs is interrelated to the extensification and technology phase in that out-migration is an alternative to fertility reduction and to the extent intensification makes possible the survival of larger family units.

THE CASE OF IM-MIAL

Regional Context

The fieldwork, on which the present study is based, was conducted in the Khanasser Valley, 80 km south-east of the city of Aleppo, in northwestern Syria. The area can be classified as semi-arid and is located at the fringe of the Syrian (Soumi, 1991). The annual rainfall of the area is 200-250 mm, with high annual and inter-annual irregularity. The rainfall comes as winter rain and falls in the period between November and April/May, with a peak in January.

The orientation of the Khanasser Valley is north-south. The valley lies 300-400 m above sea level and separates Jebel Al-Hoss in the west and Jebel Shbith plateaus on the east. *The highest point of the valley floor is 375 m above sea level, and the lowest point is approximately 275 m. The local relief seldom exceeds 10 m (Reconnaissance Soil Survey, 1982).* It connects the Harayeq Depression in the south with the Jabul Salt-Bottom Depression in the north (375 m above sea level). The plateau surfaces of Jebel Al-Hoss on the western side are gently inclined southward, its absolute height decreasing from 600 m to 400-350 m. The surface of the Jebel Shbith plateau in the East has an elevation of 450-475 m above sea level (Technoexport, 1966). Jebel Al Hass and Jebel Shbith are gently rolling plateaus. The edges of the plateaus end in well-defined steep scarps. Here, numerous V-shaped erosion channels dissect the slopes. On the eastern slopes, coarse alluvial and talus deposits are characteristic. (Louis Berger International, 1982). The Valley is composed of a gently undulating plain with a shallow network of wide dry erosion channels.

The soils of Jebel Al-Hoss and Jebel Shbith plateaus are Inceptisols. In general, they are well drained and have a high infiltration capacity (Louis Berger International, 1982; van de Steeg, 1999). The slopes and the plateaus are extremely stony. The dominant soils on the slopes and foot slopes are Leptosols; in the Valley, Calcisols are characteristic (De Pauw,

1999, personal communication). Their depths range from less than 1 m at the foot of the slopes to 16 m in the center of the Valley. The soils are fine and moderately textured dark-brown to brown. They generally show favorable infiltration and water-holding characteristics (van de Steeg, 1999).

The water resources of the Khanasser Valley are limited to the shallow-aquifer groundwater. There are no surface-water sources. The water quality, especially in the northern part of the valley, is poor due to salt-water intrusion from the Jabul Salt Lake in the north of the valley (Hooegeveen and Zöbisch, 1999). The residents of the area have also observed a decline of available water over the past decade.

There are three main types of agricultural production systems in the Valley, i.e., *rainfed farming*, *irrigated farming*, and *livestock rearing*. The three production types are closely related to the land-use patterns in the area. Most households make a living from a combination of crop production and livestock rearing, and make use of all three land-use types in their production, with small differences in the emphasis. The importance of the specific production systems differs from household to household. Generally, inter-village differences are high.

According the farming system typology evolved by Mortimore and Turner (1993), the farming systems in Khanasser Valley can be classified as intensive farming. Rainfed farming occupies the major part of the arable land, approximate 19,000 ha, with some irrigation in the middle of the Valley. On the stony foot slopes, the land is not suitable for irrigation and access to groundwater is difficult. In locations with less than 200 mm rainfall, i.e., on the eastern plateau and to the south, the Government has banned rainfed cultivation. These areas are now reserved only for grazing. To protect the drylands - especially the steppe areas - from further degradation, the Government has forbidden cultivation in these areas by Presidential Decree already in 1973 (Government of Syria, 1973) and re-confirmed its determination to protect the steppe areas from further degradation by a Ministerial Orders in 1992 and 1995 (Government of Syria, 1992; Government of Syria, 1995). Barley is the primary crop and wheat the secondary. Households with no or few sheep sell the grain, whereas households with bigger herds feed the barley to the animals. Three barley varieties can be found in the area, i.e., *Arabic Aswad* and *French Barley*. The local *Arabic Aswad* variety requires less inputs, is more adapted to the local conditions, and the villagers claim that the sheep prefer it. The Government distributes the seed, and therefore this variety is the most common grown in the area. The *French Barley* is less cropped in the area, gives higher yields, but requires more water and fertilizer. Seeds are only available on the "black market". The third variety, *Arabic Abiad*, has also high water requirements and is therefore only occasionally grown in the western part of the Valley, where slightly higher rainfall can be expected (van de Steeg, 1999).

Irrigated cultivation is practiced only on the Valley floor with more fertile soils and easier access to groundwater. The land under irrigation covers approximately 150 ha. The general trend is that farmers with plenty of water for irrigation practice a rotation system with cotton and wheat, and sometimes fallow. Land irrigated from wells with sparse water resources is cultivated with wheat and a part of the land is fallowed or cultivated with rainfed barley. The crops are rotated annually. The dominant cotton types are *Mattawa*, and the main wheat type is *Cham* (van de Steeg, 1999). Around the wells near the homesteads, small plots of vegetables (e.g., pepper, tomatoes and onions) are cultivated by the female members of the households. In a few cases, fruit trees (mainly pomegranate) and olives are grown, mainly for home consumption.

The mountain slopes and the eastern mountain range are exclusively used for grazing of natural vegetation. The pastoral areas of the villages are well defined and limited in extent. The livestock graze almost only within the village territory; however pastoral land is common land, and the villagers cannot prevent outsiders from grazing there. However, it seems that there is an unwritten rule that grazing within village territories is restricted to the population of the village. Due to intensive grazing, the natural vegetation is diminished. The number of palatable species has decreased and the biomass and the available fodder for the animals vary from year to year due to the high variations in annual rainfall (Deiri, 1990).

The population of Khanasser Valley is about 11.000 people. Due to insufficient population statistics, the total population of Khanasser Valley is a rough estimate based on farmers' estimation of the inhabitants of each village in the Valley. It has to be kept in mind that a large number of families have permanently moved from the area, but they may still be registered in the Valley. Their relatives cultivate their land, living in 24 villages, which differ greatly in size, and also have dif-

ferent family origin. The Khanasser Valley is a typical area in a second demographic transition, characterized by low death rates as a direct function of improved health conditions, which is problematic since the high birth rates remain, due to the positive social value of children.

Local Context

Im-Mial village is located at the foot of the eastern mountain Jebel Shbith. The village territory has 2704.8 hectares of which 978.9 hectares are arable land. The rest of the territory consists of the village area and grazing land, i.e., 27.8 and 1695.1 hectares. After the land reform in 1968, the land of the Khanasser Valley was allocated to the villages in the area. In some villages, the farmers own the land. The villagers of *Im-Mial* have only the user-right to the land and pay a yearly rent to the Government. At the time when the present village territories were drawn, the arable land was divided among the villages. To make the distribution fair, the farmers, in cooperation with the government, divided the arable area into sub-areas according to production potential. The farmers were allocated pieces of land in both high and low productive areas.

The farmers' opinion of cultivation suitability of the sub-areas is described below. In *Im-Mial*, the arable land is divided into nine sub-areas (Fig. 1 and Table 1). The sub-areas differ in characteristics. Information on the land characteristics of the sub-areas and the ranking of the areas according to their productivity was obtained from informal interviews with three farmers.

According to the farmers, the quality or importance of the area for cultivation depends mainly on the soil and the water (i.e., moisture) conditions. The soil conditions vary only slightly from area to area. Soil moisture is a more important factor in the suitability ranking. Also, the slopes of the fields are important. Flat areas are given higher ranking than sloping areas. The

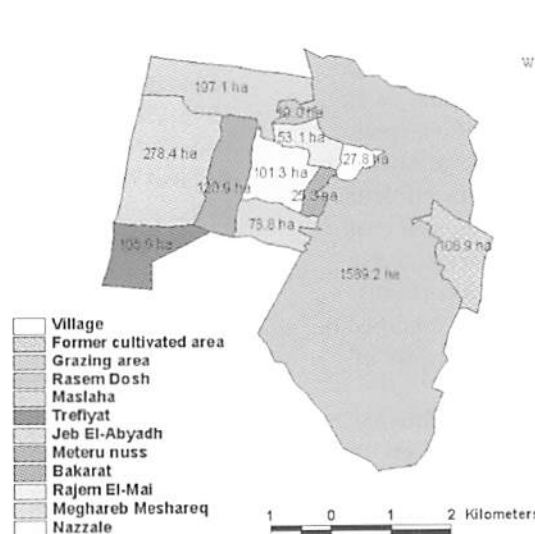


Fig. 1. Location of the sub-areas in *Im-Mial* village territory.

Table 1. Arable sub-areas in Im-Mial village territory, their characteristics and importance for cultivation.

Name of Area	Meaning of the Name	Importance Ranking ⁽¹⁾	Characteristics
Rasem Dosh	Old buildingHill	2	Black fertile soil, good soil moisture content, small valley, slightly sloping land
Maslaha	Large open area	1	Soil fertile, small valley, good soil moisture content, flat land
Trefiyat	Name of man, who owned the land before the land reform	7	White less fertile soil, less soil moisture content, slightly sloping land
Jeb El-Abyadhi	White well. A well with a white heap of soil next to it is located in the area	4	Yellow, red/white medium fertile soil, high soil moisture content, valley, large area
Meteru nuss	The length of the area 1.5 km	6	White to red/white fertile soil in the northern part, less soil moisture, small valley, close to the village
Nazzale	Settle for a short time. Previously this area was not cultivated, but used for grazing. Bedouins settle there.	3	Sandy fertile soil, low soil moisture content
Bakarat	Meandering piece of land	5	Red/white sandy medium fertile soil, less soil moisture content, small area
Rajem El-Mai	Heap of stones next to a basin of water, which previously was present in the area	2	Fertile soil, good soil moisture content, flat land
Maghreb Mashreq	East-west direction of the fields	3	Deep fertile soil, good soil moisture content, flat land

¹Importance ranking by the farmers of Im-Mial, 1 preferred for agriculture, 7 least suitable for agriculture

size of the fields was also seen as important. They believed that on larger fields, the total yields are higher. Therefore, the farmers do prefer these larger areas. Finally, the distance to the village and the access to the fields are important factors.

In Im-Mial, the land is rented from the Government. The villagers pay approximately the equivalent of US \$6 per ha per year. Only in one case, the villagers own the land because of specific historical circumstances. Although the land users only have user-right for the land, these rights can be sold and bought. The trade with land is, however, unofficial and kept confident between the villagers. The village has 575 inhabitants and the population growth is 3.9%. *The population number for 1999 is based on household interviews in Im-Mial.* Several households have permanently left the

village they are counted and included. *The calculation of the population growth is based on population data from 1999 (575 inhabitants of Im-Mial) and 1981 (287 inhabitants). The latter is delivered from official statistics (Department of Statistics, 1984).* The population is very young (see Fig. 2). The village consists of 71 households presently living in Im-Mial village. For this study, a household is defined as a family unit with a common economy. The households vary in size from 1 to 29 persons. An extended family first separates when the farther is dead or the youngest son marries.

The main means of production in the village is rain-fed barley cultivation and livestock rearing. Only three households in the village have wells for irrigation, of which one well has not been used for the last few years because the pump was out of order 68% percent of the

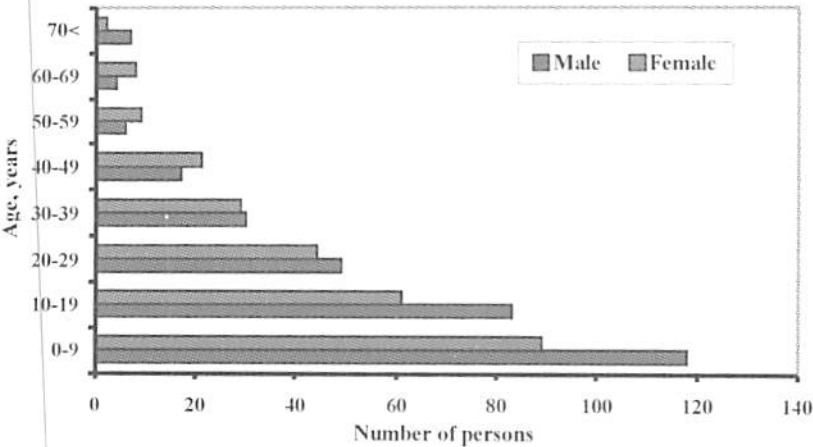


Fig. 2. Population of Im-Mial village divided by age and sex.

households' own livestock, i.e., sheep and goats. The flock sizes vary from 1-200 heads of small ruminants. However, off-farm activities are the major contributor to the household economy. The main off-farm activity is contract cultivation in irrigated farming areas around the city of Aleppo. For their work, the villagers receive 25-30% of the harvested crop, and the owner of the land receives the rest. In 1998, 73% of the households spent 7-10 months outside the village.

PROCEDURES

The information obtained has been collected on four different scales: (i) field level, (ii) household level, (iii) extended family level, and (iv) village level. Information on cultivation strategies, such as field size, yields etc. was obtained on the field level. Data on, for example, the household economy, family structure, alternative income, labor allocation, livestock rearing were obtained at the household level. Information about family structure, relations, family corporations, and transfer of goods between relatives has given at the extended family level. The management of the resources within the village territory, which contain decisions on activities such as sowing and harvest time, is made by the farmers at a community level. The land use patterns and land tenure systems are crucial issues at this level. Further, agricultural activities, such as sowing and harvesting time are often related to a communal decision-making.

For the collection of primary data, questionnaires were used. Semi-structured and open-ended interviews were carried out with the heads of the households. The head of a household is defined as the person in charge of the family economy. Topic-focused interviews were made with elders with elders in the village to acquire a picture of the former natural-resource use and agricultural and pastoral activities, and to be able to draw the village history. The facts were obtained by observing and through informal conversations with the villagers.

The village territory, arable area, and grazing area were mapped in order to get a spatial view of the natural resources and their use in the village. Cross-checking, getting the farmers' confidence, and keeping the survey relatively informal assured data reliability. For the mapping, a GPS receiver was used. The mapping was guided by the farmers and partly carried out by the farmers themselves.

Farmer-Perceived Land Use Changes

The land-users in *Im-Mial* identified two main signs of change of the natural resources, i.e., decreasing rainfed barley yields and the deterioration of the natural vegetation cover. The farmers attribute the decreasing yields to reduced soil moisture and poorer soil fertility. As expressed by some farmers, the diminished soil moisture is due to "increased dryness in the area" and by others "less water in the soil".

The soil fertility has decreased with the introduction of continuous cultivation without adequate nutrient

supply and the reduction of fallow. Another reason for decreased yields is that the reduced fallow has increased the incidence of root pests, such as ground pearls (*Porphyrophora Tritici*).

For the pasture vegetation, the villagers observed reduced plant diversity and decreased vegetation cover. Species, such as Neitoun (*Haloxylon articulatum*), Sser (*Noaea mucrouata*), Zaaror (*Crataegus azorolus*), and Shiih (*Artemisia herba-alba*) were previously plenty on the slopes in the grazing areas, but today they are only very sparsely present. Formerly, the feeding of the livestock was based mainly on local resources. Today, the natural vegetation of the grazing lands contributes to the animals' diet for one to two months per year. These changes in the natural vegetation are seen as a result of "a shorter spring period and the general dryness" but also the "increased number of livestock" in the area.

In the following sections, the relationship between natural resource deterioration problems mentioned by the farmers and the land use changes and their multifactorial causes will be described.

Abandonment of Fields, and Government Laws

Four farmers in *Im-Mial* own fields on the plateau of the bordering Jebel Shbith, which the farmers classify as the area that has the most fertile soil for cultivation within the village territory. The plateau part of *Im-Mial's* territory falls within this area with rainfall below 200 mm and thus cultivation was forbidden by law. It was only in 1993 when the Government implemented and enforced the law that the farmers finally had to stop cereal cultivation in the area. Through the cultivation, the natural vegetation had been removed completely and no revegetation measures were implemented. Today, the area is very sparsely vegetated and extensive wind erosion is taking place.

Field Expansion and Technology Change

In the last decade, there has been an expansion of the cultivated area in Khanasser Valley. In former times (more than 100 years ago), people with a nomadic lifestyle utilized the area mainly for grazing; only very limited cultivation was practiced. The expansion boom took place in the early 1900s, when the *Misham*, a Bedouin from Saudi Arabia, claimed the land and ruled it. People from areas north of Khanasser Valley were moved to the Valley to cultivate and work for the *Misham*. The population of *Im-Mial* moved to the Khanasser Valley at that time from a village called Fishdan. During that period, the arable area of the Khanasser Valley grew significantly.

Today, the entire Valley is cultivated, except from some stony patches and the mountain slopes. The expansion still continues from the edges of the arable land onto the mountain slopes, which are more prone to erosion, and also to the few stony areas within the Valley, where stones are removed, to enable the use agricultural machinery.

The cultivated area has increased and the area for grazing diminished as the fallow is reduced. Traditionally, the farmers in *Im-Mial* practiced a one-year fallow system, because labor and time constraints limited the area that could be cultivated. Draft animals were replaced with tractors in the beginning of the 70s, and hand harvest replaced combines in the beginning of the 80s. Thus, the labor and time demands for agricultural activities were reduced, which led to the total cultivation of all the fields in the village territory. Today, the fields are continuously cultivated, and only occasionally does a farmer choose to fallow his land. This intensification of the rainfed barley cultivation has put a strong pressure on the soil and vegetation resources of the village. In *Im-Mial*, mechanization has not led to an increase in output per hectare. The farmers have not introduced fertilizers, other yield-enhancing technologies, or land-improvement investments and the mechanization alone has shown to be insufficient to increase productivity. The result is a loss of soil fertility and increasing soil degradation. Together with the low available soil moisture, this has led to sharply declining crop yields.

Population growth and the settlement of laborers from other areas, and the mechanization of farm operations are not the only reasons for the expansion of the arable land, i.e., the extension of fields and reduced fallow periods. Erratic rainfall and diminished soil moisture, resulting in lower yields are other factors driving the expansion. Because of the erratic rainfall, and thus uncertain and fluctuating barley yields, the farmers cultivate the entire field area each year, in the hope that that particular year will be the one out of several with better rainfall and thus higher yields.

Another reason for the expansion of arable land, stated by Al-Ashram (1990), is the raise of agricultural commodities prices after the Second World War. This has encouraged land-users to expand the area of cultivated land in order to increase production. However, of all these important factors driving the expansion of the arable land, the farmers emphasize the change to mechanical cultivation as the most important determinant of the increased field acreage.

The low level of available agricultural technologies, such as mechanization, was the limiting factor to the land area that could be cultivated. The growing population called for an increase in yield per capita. Through mechanization, farmers could achieve the goal to cultivate larger areas. Government policies encouraged the mechanization. The Agricultural Cooperative Bank increased its loans to farmers between 1973 and 1985. Most loans went to cotton production, followed by cereals and machinery. In its program of 1965, the government planned to form large agricultural units and apply modern technologies to increase agricultural productivity.

In 1968 and 1971, the Government re-emphasized the application of new technologies, especially mechanization. The encouragement of mechanization has

increased the number of agricultural machines of all types two-to eightfold (Al-Ashram, 1990). However, it is impossible to replace labor with capital without cash for investment. Therefore, in the Khanasser Valley, mechanization is clearly related with off-farm employment and the involvement in the market economy. Thus, migrant income is important for the farmer in the implementation of mechanization.

The family-labor requirements for cultivation decrease with increasing mechanization. As cultivation is primarily a male task, male labor demand is reduced. As male family members are the main group performing migrant work, women and children often add remaining male cultivation responsibilities to their own workloads. Thus, mechanization may not only decrease the workload of the male, but also increase the women's duties on the farm and re-schedule the entire family labor. Some researchers state that the re-schedule of the labor may constrain productivity and lead to favorable consequences for the technology progress (Richards and Ramezani, 1990). Thus, it might affect the proper management of the natural resources.

Intensification and Population Growth

One land-use option to provide resources for a growing population and increased need for cropland and higher yields is the extension of fields and intensification of the cultivation by reducing fallow, as described above. Another intensification option is the digging of wells for the irrigation of cash crops, such as cotton and wheat.

In Khanasser Valley, irrigation has been in practice since 1953, when animal power was used to draw water from the first well located in the village of Shallaleh Kbire. In the early 1970s, some wells were dug in villages in the northern part of the Valley. Most of the wells in Khanasser Valley existing today were constructed during the period 1991 to 1994 (Hooegeveen and Zöbisch, 1999). In *Im-Mial*, irrigation is a new practice. The three wells in *Im-Mial* have been dug in 1999, 1993, and 1994. The reason for the limited irrigation in *Im-Mial* is the unproductive aquifer, which makes groundwater less accessible (Hooegeveen and Zöbisch, 1999) and also the lack of means for investment to construct deeper wells. The majority of the villagers state that their total off-farm income is spent on essential consumer goods, and no cash remains for investments.

Population growth - and thus increased available labor force - and the labor-saving mechanization of plowing, planting and harvesting, results in a surplus of labor. Some farmers use this surplus of labor for other agricultural activities to increase their production. One way to do this is the intensification of the cultivation by irrigation. Irrigation requires higher labor input compared to rainfed cultivation. Thus, the labor input increases as the output increases.

This study shows that the gross output from irrigated wheat, for example, is US \$500-540 per hectare

compared to US \$140 per hectare for rainfed barley. The increased labor inputs are required for the digging of irrigation canals and furrows, the daily irrigation practices, the thinning-out (cotton), the weeding (vegetables), applying fertilizers and manure, and hand-harvesting (i.e., cotton picking). Mainly the women are engaged in the increased labor activities. Only the watering of the crops is a man's task, often performed by the young men.

In *Im-Mial*, only three farmers own wells and practice irrigation farming. With the moderate water quality of the water in *Im-Mial*, soil salinization is not seen as a threat to the intensified cultivation. The farmers in *Im-Mial* practice supplementary irrigation and apply fertilizer to substitute soil fertility loss. This system might be able to sustain if the farmers continue proper rotation systems and maintain soil fertility.

Increased demand for agricultural products is not the sole factor driving the intensification. Turning to irrigation farming is associated with high economical inputs. Migration and off-farm employment contribute to not only mechanization, but also technology change, such as irrigation. Thus, the villagers' access to capital from off-farm income determines their possibility for intensification. Also, the feasibility of growing cash crops, such as cotton and wheat, and the positive balance between economical inputs and outputs, encourage investments in irrigation farming.

Already, before the mechanization of the agriculture in *Im-Mial*, the male members of the households sought wage work outside the village. The seasonal under-employment at that time developed into full under-employment with the introduction of machines and the growing of the population. The limited natural resources of the area can feed only a limited number of people. The area is saturated in terms of population. The continuous growing population has been forced to migrate and work outside the Valley. The migration is promoted by the considerable earning gap between farm and off-farm work.

Off-farm employment opportunities, particularly in combination with the inheritance of small-to medium-sized holdings, have led to the phenomenon of part-time farming. The local farming has become more and more secondary to off-farm employment. Some families in *Im-Mial* are totally dependent on off-farm income, because they have no land or livestock in the village. The most popular off-farm activity is the renting of irrigated fields in the regions around Aleppo and Deir Ez-Zor along the Euphrates River. In 1998, 73% of the household of *Im-Mial* spent 7-9 months outside the village. When whole households leave, relatives cultivate their fields in the village.

For the case of *Im-Mial*, the capital from migrant work is most commonly spent on consumables for every-day needs. Only a few households have invested in agriculture in the form of machinery and advanced technology. In *Im-Mial*, the farmers who have chosen to invest in irrigation farming tend to be the wealthier

ones. The evidence that off-farm work income is very important in the household economies of *Im-Mial* means that the population has not only become more depended on external resources, but also the measure of wealth among the villagers has changed. Not only is family wealth a question of having a large number of livestock, but also a high number of young men doing migrant work.

Al-Asham (1990) claims that the emigration of young adult men causes a lack of agricultural labor and has a negative effect on the productivity. However, this cannot be confirmed by this case study. It might be the case in more intensive irrigation farming, but not in low labor-input rainfed barley farming, which is the dominant cultivation system in *Im-Mial*. The absence of male labor has increasingly engaged the women in the agricultural activities, and led to the "feminization" of the farm-labor force. The women's labor is substituting men's labor in agriculture. This has caused an increasing workload for the women, which can have influence on the health of the women.

Still, it should be noted that women traditionally have been engaged in certain hard cultivation tasks, such as the harvest. The intensification may not cause a re-scheduling of the farm labor as a whole, but rather save labor in male tasks and add labor requirements for the women for cultivation. Further, with migration, the men's attitudes towards agricultural work may have changed and agricultural work has been given a lower status. The literacy of the children is also affected by the increased migration. Whole households spend the major part of the year in external areas, and the children rarely follow classes in schools outside their home village, possibly because their labor is needed on the fields.

Crop-Livestock Integration and Population Growth

Khanasser Valley has traditionally been used for animal grazing. The introduction of farming exploded at the time the *Misham* arrived and people with an arable farming tradition settled in the area to cultivate. Both pastoral and agricultural production, are still practiced in the area today, though, more intensively and more integrated than formerly. Most farmers in *Im-Mial* have grazing animals and cultivate fields. Mixed farming systems represent a diversified production strategy with a certain flexibility to respond to the fluctuations in rainfall.

A recent tendency in *Im-Mial* is that households, which are totally dependent on migrant work, irrigation farming in external areas, and maybe do not have cultivated land in the village, have sold out their sheep flock. The reason is that livestock rearing is difficult in areas with limited grazing resources and dense cultivation. Another tendency is the turn to commercial livestock production. Intensive commercial livestock production was stated by the farmers as a future production strategy and as a response to the decreasing crop

yields. Farmers in other villages in the Valley already adapt this strategy.

Irrigation farmers who experience decreasing yields because of increasing water scarcity and groundwater salinity (Hoogeveen and Zöbisch, 1999) are turning from production systems depending on irrigation to sheep fattening. Commercial livestock rearing introduces generally larger herd sizes and the producers appear not proportionally to increase their on-farm feed production. Rather, they practice a strategy of mobility. The herds are transported to external areas, where crop residues and stubble fields are available at relatively low cost, or the herd is stall-fed with barley and residues of wheat and cotton, purchased at the local markets.

Generally, the integration of crop and livestock has increased, both directly and indirectly, i.e., through the market. A biological interaction is the use of manure to maintain soil fertility. As already mentioned, application of manure is not practiced on rainfed fields. With the expansion of irrigation farming, where manure is widely used, the manure has become more valuable. One tractor-trailer of manure can be sold on the local market for US \$16-20.

The most pronounced interaction is the grazing of stubble and grazing of un-harvested fields in low-yield years. The stubble has become a considerable part of the sheep's diet. However, the stubble is not sufficient for the livestock and during stubble grazing, the sheep's diet is supplemented with purchased crop residues or barley. Poorly developed barley stands, which will not yield an acceptable grain harvest, are grazed by the livestock in April and May. Barley stubble fields are grazed after the harvest in May and June. In the case of irrigated fields, the barley is sown at the end of November and grazed by the livestock in December. After that, the barley produces new shoots, which will produce grains for harvest. Irrigated wheat is harvested in June. After cotton has been picked in October, the livestock graze the residues.

Thus, the stubble fields of barley, wheat, and cotton have increasingly economical value in Khanasser Valley. Households with no or only small herds of sheep rent out their fields to others within the village for grazing either the stubble or the un-harvested fields. In an average rainfall year, barley stubble has a value of \$10 per hectare. In 1999, a year with very low rainfall and large numbers of Bedouins coming with their herds from the steppe to graze in the Valley, the grazing charges for un-harvested fields climbed to US \$50-60 per hectare.

Households with larger animal herds may choose to move their animals to external areas and rent irrigated cotton, barley, and wheat or vegetable stubble fields. In *Im-Mial*, one family, which has fields located in the area where cultivation is officially forbidden, practices only this; the family has therefore no access to stubble. Families that seasonally migrate to cultivate irrigated crops outside Khanasser Valley, may take smaller herds

with them, and feed them with the residues and stubble from the irrigated fields.

Nowadays, the villagers practice more hand-feeding and less grazing of the natural vegetation than traditionally, because of the increasingly limited available natural vegetation. The importance of the livestock is evident, and the growing number of farmers has led to an increased total number of livestock in *Im-Mial*. This, together with an expansion of the arable land into the grazing areas, has increased the pressure on the natural vegetation. The villagers believe that the reduced available vegetation for grazing is due to not only a smaller grazing area and the degradation of the vegetation cover caused by heavy grazing, but also the result of 'less rainfall' in the area.

At present, the natural vegetation provides only a limited part of the livestock diet over the year. The livestock diet consists exclusively of natural vegetation just 1-2 months (April-May) per year. From June to March, the animals are stall-fed with crop residues, such as cottonseed, cotton peal, bran, barley, and left-over dry bread. The livestock fodder is available at the local market for a reasonable price and with low transport costs, or from the farmers' own production, especially in the case of households with larger herds.

There are two major economical crop-livestock interactions in *Im-Mial*. First, economical returns are used to buy cropping inputs, but also food and goods. Households with larger herds sell animal products, mainly cheese and yogurt, to the local market. Though, the majority of the farmers have relatively small flocks and the animal products are consumed within the family. They usually have no or only little surplus for sale. The second economical interaction between crop and livestock is livestock as a means of accumulating wealth and as an investment of migrant-work income. Accumulation of livestock can be an economical buffer to offset variations in crop production.

CONCLUSION AND PERSPECTIVES

Farmers recognize two major signs of degradation in their environment, i.e., *decreased yields* and *reduced vegetation cover*. These signs are clearly related to the changes in the utilization of the natural resources. Expansion of fields, reduced fallow periods, a change to irrigation farming, and the increased grazing of stubble fields are the four major land-use changes. The driving forces for these land-use changes are multifactorial. They include climatic conditions, population growth, Government laws, market relations and forces, technology changes, and increased crop-livestock integration.

In *Im-Mial*, both the degradation-and intensification pathways of land-use change can be observed. The reduced fallow with no application of manure or fertilizer has caused a loss of soil fertility and correspondingly decreasing yields. The expansion of fields into the sloping areas of the mountain foot slopes and, with it, the complete removal of the protective stones from

the soil surface led to increased soil erosion. The expansion of the land and reduction of fallow is due to the increased demand for outputs as the population grows. It is also an effect of the encouragement of the farmers by the Government for technological changes towards mechanization.

This has changed the cultivation practices from being labor-intensive to labor-extensive and allowed for an increased area to be cultivated. The continuous cultivation also has the aim to secure good overall yields in years with high rainfall. Whether this is also a response to the observed decreasing yields, cannot be clarified by this case study.

The few households in *Im-Mial*, who have turned to irrigated cultivation of cash crops, experience increased output with the increased inputs (labor, fertilizer, etc). Due to the location of the village on the eastern mountain slopes, the quality of the water is relatively good compared to other villages, especially in the northern part of the Valley, although the productivity of the aquifer in this area is low. Salinization should not be a problem and the yields can probably be maintained under the current cultivation practices. The technology change to irrigation is constrained by the limited groundwater availability and access to cash.

In this context, migration plays an important role. With the out-migration of villagers induced by the limited available land resources for the growing population and favorable earning opportunities from off-farm work, farmers are encouraged to invest in small-scale irrigation.

Larger livestock numbers and the expansion of arable land into grazing land increasingly put pressure on the natural vegetation and have led to decreased and less diverse vegetation cover. Therefore the natural vegetation now plays a less important role in the diet of the animals. Consequently, stall-feeding with crop residues and stubble grazing is of increasing importance and the interaction between crop and livestock has intensified, encouraged and facilitated by the market forces.

According to the conceptual framework of land-use change by Bilsborrow and Ogendo (1992), *Im-Mial* is characterized by all four described land-use change phases, which are occurring concurrently. The creation of village territories and the allocation of arable land took place during the land reform and had a significant influence on the land-tenure system in the area. The increased pressure on land, though, seems to have resulted in community regulation and unofficial local conventions related to the grazing areas.

There is a tendency that the grazing of the natural vegetation is increasingly restricted to the village territory. For the arable land, the high population growth and the inheritance system in the village have caused a fragmentation of land to an extent that a re-classification of the resource is taking place. Farmers, who live

and work outside the valley, may not claim land nor receive a share of the yields to make more resources available for the permanent members of the village.

The extensification of land does not only involve an enlargement of the arable area. It occurs involving a rural-rural out-migration. The villagers rent land and are engaged in rural labor work in other regions of the country. The introduction of irrigation schemes intensifies the cultivation as already described before. The cash for investments in the technology change are returns from migration work. *Im-Mial* is slightly approaching the demographic phase, when the response to the growing population is fertility reduction. A few young households are already practicing birth control.

A large number of villagers believe that in the future more people will out-migrate for off-farm work and that within the village territory, more people will take up sheep fattening. These two trends of development can already be observed in the village. An increased number of households are depending totally or mainly on off-farm incomes, particularly cultivation of rented irrigated fields. They live most of the year outside the village and return only for the winter period. Their cultivation in the village has turned into 'hobby farming' and is of very little financial importance to the farmers. Some farmers do not cultivate any land in *Im-Mial* or get any of the returns for the on-farm cultivation at all. The other trend is that some farmers have started sheep fattening. These sheep are kept for the meat and not as the domestic sheep for the milk. The sheep are fattened mainly on purchased crop residues.

The conservation of the natural resources in the area - the establishment as well as the maintenance of the conservation measures - should require only minor financial and labor input from the farmers. The major activities should be in the winter period after the sowing of the rainfed fields, when the farmers are present in the village. One should be aware of the possibility that the establishment and maintenance of conservation measures might add to the heavy workload, which already exists for the women.

Tree plantations on the upper parts of the fields located on the mountain slopes can conserve the soil and prevent erosion. At the same time, trees such as olives require only minor inputs when the plantation first is established. The harvest time for olives is in November, when most of the farmers have returned to the village.

The farmers spent a large amount of money on market crop residues to feed the livestock. The rainfed fields have reduced outputs due to lack of fallow. Increased on-farm integration between crop and livestock, where fodder crops could be cultivated instead of fallow, so the on-farm available fodder increased and a crop rotation system introduced to improve the soil fertility.

REFERENCES

- Al-Ashram, M. 1990. Agricultural Labor and Technological Change in the Syrian Arab Republic. p. 163-183. *In*: D. Tully (Ed.). Labor and Rainfed Agriculture in West Asia and North Africa. Kluwer Academic Publ., Amsterdam, The Netherlands.
- Bilsborrow, R.E., and H.W.O.O. Ogendo. 1992. Population-driven changes in land use in developing countries. *Ambio*, 21, 37-45.
- Boserup, E. 1965. The conditions of agricultural growth. The economies of agrarian: change under population pressure. George Allen & Unwin, London.
- Copan, J. 1974. Sècheresse et famine du Sahel. Maspero, Paris.
- Deiri, W. 1990. Contribution à l'étude phyto-écologique et de la potentialité pastorale en Syrie aride. Thèse. Science et Techniques du Languedoc. Université de Montpellier II, Montpellier, France
- Department of Statistics. 1984. Numbers of people, families and houses according to administrative districts. 1981. Aleppo region. Syrian Arab Republic, Prime Ministry, Central Office for Statistics. Aleppo, February (first results). Aleppo, Syria.
- De Pauw, E. 1999. Natural Resource Management Program. ICARDA. (Personal communication).
- Government of Syria. 1973. Presidential Decree No. 13 of 19 February 1973. To prohibit any rainfed cultivation in the demarcated Steppe areas of Syria. President's Office, Government of Syria, Damascus, Syria.
- Government of Syria. 1992. Ministerial Order 17-1992. Prohibiting any ploughing and rainfed cultivation and reserving it for natural rangeland. Prime Minister's Office, Government of Syria, Damascus, Syria.
- Government of Syria. 1995. Ministerial Order 11-1995. Banning all steppe areas for rainfed agriculture. Prime Minister's Office, Government of Syria, Damascus, Syria.
- Greenland, D.J. G. Bowen, H. Eswaran, R. Rhoades and C. Valentin. 1994. Soil, Water, and Nutrient Management Research - A New Agenda. IBSRAM Position Paper. International Board for Soil Research and Management. Bangkok, Thailand.
- Hare, F.K. 1985. Climate, Variation, Drought and Desertification. World Meteorological Organization, Geneva, Switzerland
- Harris, F. 1996. Intensification of Agriculture in Semi-arid Areas: Lessons from the Kano Close-Settled Zone, Nigeria. *Gatekeeper Series* No. 59, IIED, Cambridge, UK.
- Hoogeveen, R., and M. Zöbisch. 1999. Well inventory and groundwater in the Khanasser Valley, Syria. *Report on a field study in northwestern Syria*. *Mimeo*, International Center for Agricultural Research in the Dry Areas, Aleppo, Syria.
- Lindskog, P., and A. Tengberg. 1994. Land Degradation, Natural Resources and Local Knowledge in the Sahel Zone of Burkina Faso. *Geo Journal*, 33(4), 365-375.
- Louis Berger International. 1982. Land classification and soil survey of the Syrian Arab Republic. Volume 2 (Reconnaissance Soil Survey of Syria, 1: 500,000). Louis Berger International Inc., Remote Sensing Institute South Dakota University, United States Agency for International Development, Washington DC, USA
- McCrown, R., G. Haaland and L. de Haan. 1979. The interaction between cultivation and livestock production in Semi-arid Africa. *Ecological Studies* 34: 297-332.
- Mortimore, M. 1995. Caring for the soil. agricultural expansion, population growth, and natural resource degradation in the Sahel. 1: 55-57 *In*: R. Reenberg, and H. Secher Marcussen (Ed.) Ethnobotany, Agricultural and Pastoral Strategies and Development Aid Strategies. *Proceedings: 7th Danish Sahel Workshop*, 4-6 January. SEREIN Occasional Paper.
- Mortimore, M. 1996. Natural Resource Management in Sub-Saharan Agriculture - Research Methodologies and Approaches. *Mimeo*
- Mortimore, M., and B. Turner. 1993. Crop-Livestock Farming Systems in the Semi-Arid Zone of Sub-Saharan Africa. Ordering diversity and understanding change. Agricultural Administration (Research and Extension) Network Paper 46. Overseas Development Institute, London, UK
- Netting, R.M. 1993. Smallholders, householders - farm families and the ecology of intensive, sustainable agriculture. Stanford University Press, California, USA.
- Pingali, P., Y. Biyot and H.P. Biswanger. 1987. Agricultural mechanization and the evolution of farming systems in Sub-Saharan Africa. The World Bank, Washington DC, USA.
- Reconnaissance Soil Survey. 1982.
- Reenberg, A. 1996. A hierarchical approach to land use and sustainable agriculture in the Sahel. *Quarterly J. Inter. Agric.* 35 (1): 63-77.
- Richards A., and A. Ramezani. 1990. Mechanization, off-farm employment and agriculture. *In*: N. Haddad, R. Tutwiler, and E. Thomson (Ed). Improvement of Crop - Livestock Integration Systems in West Asia and North Africa. Proceedings of the Regional Symposium on Integrated Crop-Livestock Systems in the Dry Areas of West Asia and North Africa, 6-8 November, 1995, Amman, Jordan. 49-66. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.
- Rostom R.S., and M. Mortimore. 1991. Environmental change and dryland management in Machakos District, Kenya 1930-90. Land use profile. ODI Working Paper 58, Overseas Development Institute, London, UK.
- Sandford, S.G. 1993. Crop Residue - Livestock

- Relationships. In ICRISAT. Soil, Crop and Water Management in the Sudano-Sahelian Zone. Proceedings of an international Workshop, 11-16 January 1987, ICRISAT Sahelian Center, Niamey, Niger.
- Scott, E.P. 1979. Land use changes in the harsh lands of West Africa. *African Studies Review*, XXII (1), 1-24.
- Snrech, S. 1994. Population, environnement et économique au Sahel. Population, In A. Reenberg, and B. Markussen (Ed.). Integrated rural development projects, research components in development projects. *Proceedings: 6th Danish Sahel Workshop*, 6-8 January 1994, Copenhagen, Denmark. AAU Report 32. Department of Systematic Botany, Aarhus University, Aarhus, Denmark.
- Soumi, G. 1991. Supplemental irrigation systems of the Syrian Arab Republic. p. 497-511. In E.R. Perrier and A.B. Salkini (Ed.). Supplemental Irrigation in the Near East and North Africa. *Proceedings: Workshop on Regional Consultation on Supplemental Irrigation*, International Center for Agricultural Research in the Dry Areas (ICARDA) and FAO, 7-9 December 1987, Rabat, Morocco. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Technoexport. 1966. The geological map of Syria, 1:200,000 and explanatory notes. Department of Geological and Mineral Research, Ministry of Industry, Damascus, Syria
- Turner II, B.L., D. Skole, S. Sanderson, G. Fischer, L. Fresco, and R Leemans. 1995. Land-use and Land-cover Changes. Science/Research Plan, IGBP Report No. 35. The Royal Swedish Academy of Science, Stockholm, Sweden
- Tutwiler, R., N. Haddad, and E. Thomson. 1995. Crop - livestock integration in the drier areas of West Asia and North Africa. In: N. Haddad, R. Tutwiler and E. Thomson (Ed.) Improvement of Crop - Livestock Integration Systems in West Asia and North Africa. *Proceedings: Regional Symposium on Integrated Crop-Livestock Systems in the Dry Areas of West Asia and North Africa*, 6-8 November, 1995, Amman, Jordan, 5-23. ICARDA, Aleppo, Syria.
- Van de Steeg, J.A., and M. Zöbisch. 1999. Effects of saline irrigation water on the biomass production of irrigated field crops and salt accumulation in the root zone. Progress Report on a Field Study in Khanasser Valley, Northern Syria. ICARDA, Aleppo, Syria. *Mimeo*.

Vegetation Cover Protection on Southern Tunisia's Desert Ecosystem

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INTRODUCTION

The Tunisian desert zone is characterized by a very hard and precarious climate, with a mean annual precipitation less than 100 mm, a large temperature range, frequent winds, and a very intensive evapotranspiration (Floret and Pontanier, 1982). The socioeconomic changes as expressed by sedentarization of ex-transhumant populations have caused the regression of rangelands, as a result of the development of occasional agriculture, and the quantitative and qualitative degradation of vegetal cover, as a result of overgrazing. Climate and man with his animals are the main factors that contribute to the degradation of the natural vegetal patrimony, and consequently to the acceleration of desertification process which constitutes the principal environmental problem in Tunisia.

The development of management strategy of a given ecological system is based on the good knowledge of its regeneration capacity in cases where it does not reach the ultimate stage of degradation (UNESCO, 1990). Several techniques were applied in Tunisian arid zones for degraded rangelands rehabilitation (Akrimi *et al.*, 1989), such as protection, appropriate grazing system, reseeding, planting exotic shrubs, etc., and they have produced encouraging results. However, the effects of these techniques, in desert ecosystems, were not well studied.

The present study deals with the evaluation of the effect of protection (the easiest technique) from 10 to 12 years on vegetation cover dynamics in four sites representing an aridity gradient and located in the natural region of Nefzaoua (south-west of Tunisia).

STUDY AREA

According to Sarfatti (1988), the region belongs to the Mediterranean-Saharan bioclimate stage, with a mean annual rainfall of 89.4 mm, a monthly mean temperature varying between a minimum of 8.62°C in January and a maximum of 42.2°C in July, and with powerful regular winds (120 days/year) whose velocity often exceeds 100 km/h, leading to frequent sandstorms. In addition, the region is under the influence of the very warm wind (*sirocco*) in summer, thus increasing evapotranspiration, which may exceed 1158 mm/year.

Four sites located throughout a region across an aridity gradient, were the subjects of an assessment of their vegetation cover dynamics. The first was located in the zone of Chareb at 37° 75' latitude north and 7° 54' longitude east. The soil is deep as a result of the alluvial deposit accumulations. The dominant vegetal

species are *Arthrophytum scoparia* and *Thymelaea hirsuta*. It is considered the most cultivated zone during the rainy years. The second site, Kebili, was located at 37° 44' latitude north and 7° 43' longitude east. It is characterized by a gypseous soil, sometimes covered by eolian veils. The main existing species were *Retama raetam*, *Limoniastrum guyonianum*, and *Atractylis serotuloides*.

The third site was that of Ailet (Jemna) and located at 37° 29' latitude north and 7° 47' longitude east. The soil is very salty and characterized by an accumulation of gypsum at middle depth. The main vegetal species were *Traganum nudatum*, *Suaeda mollis*, and *Zygophyllum album*.

The fourth site was located at 37° 8' latitude north and 7° 4' longitude east, at El-Faouar. It constitutes a transition zone between Chott Jerid (saline depression) and the "Grand Erg Oriental". The landscape appears as several mobile dune levels. The dominant vegetation species were *Limoniastrum guyonianum*, *Traganum nudatum*, and *Zygophyllum album*.

METHODS

In each site, the evaluation of vegetation cover dynamics was made in two plots of an area of 40 m × 40 m each. The first was unprotected and considered as control; the second was protected since 1986. Assessments were done throughout three years (1996, 1997, and 1998) during the vegetation-growing season (March-April). In other words, it was question of an evaluation of a 10, 11, and 12 years protection.

During each year, and within each plot, point-sampling method was applied for cover and species composition measurements (Floret, 1988). The destructive method was used for biomass estimation by clipping all the vegetation existing in a 8 m × 4 m quadrat (Floret *et al.*, 1983).

RESULTS AND DISCUSSION

The climatic conditions, based on precipitation during the period of investigation, which extended throughout three years, were characterized by their irregularity. The quantity recorded during the first year (1996) was relatively very important (247.7 mm) since it was about the triple of the mean annual of the region (89.4 mm). However, the second year (1997) was dry, since the quantity of rainfall did not exceed 60 mm, and the third year (1998) was very dry with very low precipitation (36.6 mm), which may negatively affect the development of vegetation, mainly that of therophytes.

The effect of protection on biological spectrum (Raunkiaer, 1934) as expressed by the relative importance of the different biological types is expressed by Fig. 1. Except the site of Kebili, where four types were recorded, only three biological types existed in the site of Chareb and that of Atillet. In every case, the biological spectrum is mostly composed of chamephytes, which were favored by protection (47.6% against 38.8% in the control at Chareb, and 61.1% against 53.8% at Kebili). Moreover, protection had no effect on spectral composition of El-Faouar (the aridest site) since only chamephytic type was represented.

The second important type was that of therophytes, but it seems that this type is more dependent on precipitation, diet, and grazing pressure, and that's why annual species were more diverse in the unprotected plots (Floret and Pontanier, 1982). The proportion of phanerophytic type was very low since it was repre-

sented by only one specie (*Retama raetam*) in the Kebili site. Hemi-cryptophytes were also slightly influenced by protection probably due to their low pastoral value (as the case of *Peganum harmala* in the site of Chareb).

Concerning vegetal species diversity, Table 1 shows that the beneficial effect of protection was more obvious in the less arid sites (Chareb and Kebili), especially during the dry year (1998), where the improvements reached 33.3 and 31.5%, respectively. However, in the driest sites (Atillet and El-Faouar) there was no significant effect of protection on species richness, probably due to edaphic constraints (high salinity of soils and presence of mobile dunes).

The results of species composition measurements of the different sites both in protected plots and in the controls are represented by Tables 2, 3, 4, and 5.

Table 1. Evolution of flora richness in the four sites throughout the experiment period.

Species	1996								1997								1998							
	Protected				Control				Protected				Control				Protected				Control			
	C	K	A	F	C	K	A	F	C	K	A	F	C	K	A	F	C	K	A	F	C	K	A	F
Ligneous	11	13	6	4	8	7	6	4	11	13	6	4	7	7	5	3	11	14	6	3	6	7	4	3
Herbaceous	10	5	5		10	6	5		10	5	4		10	6	4		10	5	3		8	6	3	
Total	21	18	11	4	18	13	11	4	21	18	10	4	17	13	9	3	21	19	9	3	14	13	7	3

C: Chareb; K: Kebili; A: Atillet; F: El-Faouar.

Table 2. Evolution of species composition at Chareb site.

Species	1996		1997		1998	
	P	C	P	C	P	C
<i>Arthrophytum scoparium</i>	5.88	3.84	5.32	2.94	5.22	2.94
<i>A. Schimittianum</i>	1.47	-	2.94	-	3.67	-
<i>Traganum nudatum</i>	2.94	5.76	14.78	8.82	13.39	12.30
<i>Thymelaea hirsuta</i>	1.47	4.84	3.76	2.94	4.35	2.94
<i>Astagalus armatus</i>	1.47	1.92	1.88	5.88	1.74	12.30
<i>Atractylis serratuloides</i>	1.47	1.92	4.35	0.87	6.95	-
<i>Salvia aegyptiaca</i>	1.47	-	1.88	-	2.17	-
<i>Pituranthos tortuosus</i>	2.94	0.92	2.88	-	2.17	-
<i>Moricandia arvensis</i>	2.94	-	12.47	-	12.04	-
<i>Helianthemum sessiliflorum</i>	1.47	-	1.47	-	1.31	-
Total ligneous	23.52	19.2	51.73	21.45	53.01	30.48
<i>Euphorbia guyoniana</i>	-	3.84	-	4.35	-	4.41
<i>Peganum harmala</i>	1.47	1.92	0.87	2.94	0.41	4.41
<i>Plantago albicans</i>	10.47	12.84	6.23	2.94	1.31	1.47
<i>P. ovata</i>	10.11	14.08	8.11	2.94	1.31	2.94
<i>Cutandia dichotoma</i>	19.11	11.53	8.11	9.89	9.57	1.47
<i>Lotus creticus</i>	8.82	7.69	4.35	3.84	1.78	8.82
<i>Argyrolobium uniflorum</i>	5.88	3.84	4.35	4.34	2.35	5.88
<i>Launea resedifolia</i>	5.88	1.92	0.87	2.94	0.87	1.47
<i>L. glomerata</i>	1.47	3.84	0.87	10.47	5.26	2.94
<i>Malva aegyptiaca</i>	1.47	4.53	2.04	3.84	0.87	-
<i>Matthiola longipetala</i>	5.88	6.47	4.35	10.47	5.26	12.30
<i>Ifloga spicata</i>	5.88	11.53	7.94	22.53	6.74	27.40
Total herbaceous	76.41	80.52	48.27	77.15	46.38	67.63

P: Protected plot. C: Control

Table 3. Evolution of species composition at Kebili site.

Species	1996		1997		1998	
	P	C	P	C	P	C
<i>Retama raetam</i>	15.52	13.58	9.74	31.75	10.62	44.82
<i>Arthrophytum schmittianum</i>	8.62	8.16	10.66	13.53	8.75	13.49
<i>Astragalus armatus</i>	6.89	-	5.88	-	6.25	2.9
<i>Atractylis serratuloides</i>	6.89	4.08	8.12	3.54	9.37	4.35
<i>Rhanterium suaveolens</i>	3.44	-	8.12	-	7.5	-
<i>Pituranthos tortuosus</i>	1.72	-	0.88	-	0.62	-
<i>Helianthemum kahiricum</i>	1.72	2.04	3.31	1.72	4.37	1.45
<i>H. lipii</i>	1.72	-	2.44	-	8.12	-
<i>Lygeum spartum</i>	3.44	-	3.31	-	4.37	-
<i>Gymnocarpus decander</i>	3.44	-	3.31	-	5	-
<i>Limoniastrum guyonianum</i>	8.62	4.08	6.89	8.62	8.12	14.49
<i>Traganum nudatum</i>	-	-	-	-	0.62	-
<i>Zygophyllum album</i>	1.72	4.08	0.88	3.54	0.62	2.9
Total ligneous	63.74	36.02	65.54	62.7	75.58	87.8
<i>Euphorbia guyoniana</i>	-	8.16	-	3.54	-	2.9
<i>Plantago albicans</i>	15.52	14.28	8.12	8.70	1.25	1.45
<i>Argyrolobium uniflorum</i>	5.17	2.74	3.44	4.35	0.62	2.9
<i>Lotus creticus</i>	6.89	12.24	3.44	4.35	1.25	1.45
<i>Ifloga spicata</i>	6.89	17.28	11.74	8.70	15.65	1.45
<i>Schismus barbatus</i>	1.72	8.16	6.88	5.79	4.35	1.45
Total herbaceous	36.2	62.86	33.62	35.43	23.12	11.6

P: Protected; C: Control.

The comparison of different values of species contributions to total cover permit to detect three main groups:

1. **The first group** involves the species which were favored by protection and more or less disappeared from the unprotected plots. They were mainly the palatable species such as *Helianthemum sessiliflorum*, *Salvia aegyptiaca* and *Arthrophytum schmittianum* in the site of Chareb and *Rhanterium suaveolens* and *Gymnocarpus decander* at Kebili, or the woody species which escaped from cutting such as *Limoniastrum guyonianum* in the sites of Kebili, Ailet and El-Faouar.
2. **The second group** consists of the species which were penalized by protection and were frequent in the unprotected plots. It concerns the species with low economical interests and pastoral value such as *Euphorbia guoniana*, *Peganum harmala*, *Zygophyllum album*, and *Arthrocnemum indicum*. However, the contributions of some other species such as *Argyrolobium uniflorum* (a high palatable legume species) and, to a lesser degree, *Plantago albicans* decreased in the protected plots at Chareb and Kebili as compared to their contributions in vegetal cover of the unprotected plots. It seems that these species do not tolerate the prolonged protection and relatively prefer modest grazing capacities (Chaieb, 1989).

3. **The third group** involves the species which were indifferent to protection. It concerns herbaceous vegetation both annual and perennials. It looks that they more dependent on precipitation than on management mode (Ayyad and El-Kadi, 1982).

The use of protection turned out, globally, to be beneficial on the total plant cover even though such effect decreases with the aridity gradient. This technique has led, in fact, to an improvement of a mean of 83% at Chareb (the less arid site), 57% at Kebili, 9.5% at Ailet, and 19% at El-Faouar. The improvements were more obvious during the dry years (1997 and 1998). Besides, after a 10 years' protection, the evolution of total cover became more dependent on the quantity of rainfall. That's why a general decrease of cover was recorded in the different sites throughout the last 2 years of the experiment, which were very dry.

The beneficial effect of protection on biomass of different sites was also observed. This fact is explained by the big gaps between the estimated biomass in the protected and unprotected plots, since the recorded mean values were, respectively, the following: 1311 against 312 kg DM/ha at Chareb, 1622 against 295 kg DM/ha, 860 against 653 kg DM/ha at Ailet, and 414 against 241 kg DM/ha at El Faouar. These values confirm that the beneficial effect of protection decreases with the aridity gradient. On the other hand, these gaps show again how is severe the human pressure (as expressed mainly by cutting and overgrazing) on the natural environment of Tunisian Saharan zones.

Table 4. Evolution of species composition at the Ailet site.

Species	1996		1997		1998	
	P	C	P	C	P	C
<i>Traganum nudatum</i>	19.35	7.31	22.58	22.72	32.81	17.95
<i>Reaumuria vermiculata</i>	3.22	3.22	3.22	4.54	9.38	-
<i>Zygophyllum album</i>	12.91	18.71	22.58	22.72	28.13	38.46
<i>Limoniastrum guyonianum</i>	3.22	4.87	9.66	9.09	9.38	25.64
<i>Suaeda mollis</i>	1.61	4.87	16.13	13.63	12.5	12.82
<i>Frankenia thymefolia</i>	-	2.44	-	-	-	-
<i>Atractylis serratuloides</i>	3.22	-	3.22	-	5.46	-
Total ligneous	46.75	41.42	77.39	72.7	97.96	94.87
<i>Plantago albicans</i>	6.45	14.63	6.44	9.09	0.78	2.49
<i>Cutandia dichotoma</i>	12.9	12.19	9.66	4.54	-	-
<i>Hedysarum spinosissimum</i>	4.83	4.87	-	-	-	-
Autres annuelles	29.03	26.63	6.44	13.63	0.78	2.49
Total herbaceous	53.21	58.32	22.54	27.26	1.56	5.13

P: Protected plot. C: Control.

Table 5. Evolution of species composition at El-Fauar site.

Species	1996		1997		1998	
	P	C	P	C	P	C
<i>Limoniastrum guyonianum</i>	66.66	66.66	52.63	38.46	52.46	39.53
<i>Traganum nudatum</i>	19.04	16.66	26.31	38.46	29.51	48.84
<i>Arthrocnemum indicum</i>	9.52	11.11	15.79	23.07	18.03	11.63
<i>Zygophyllum album</i>	4.88	5.55	5.26	-	-	-

P: Protected plot. C: Control.

CONCLUSIONS

The present study is a preliminary assessment of the effects of protection on vegetation cover dynamics in four sites located along an aridity gradient of Tunisian Saharan zone. The results show that the use of such technique for degraded land management is *relatively beneficial on cover, species composition, diversity, and biomass*, even though this effect decreases with the aridity gradient. After a 10 years' protection, vegetation dynamics was more dependent on precipitation, so that a total decrease of the different parameters studied was recorded throughout the dry years of the experiment.

On the other hand, the effect of protection on the spectral composition was in favor of chamephytes. We think that the sites had been subjected to a severe and continuous perturbation that a prolonged protection (12 years) has led to a new equilibrium state, which is different to that initially existing. According to Le Houérou (1995), in areas receiving more than 100 mm/year mean precipitation, less prolonged protection permits the evolution of shrubby steppe with chamephytes to grass formations dominated by range species such as *Stipa spp.*, *Aristida spp.*, ...etc.

REFERENCES

Akrimi N., M. Chaieb, M. Neffati, and J. Zemzemi. 1989. Synthèse des principaux travaux en matière d'écologie et d'aménagement pastoraux. p. 8-18. *Actes des travaux de l'atelier national sur les acquis de l'expérience tunisienne en matière d'aménagement pastoral*. IRA Medenine et CRDI.

Ayyad M.A., and H.F. El-Kadi. 1982. Effect of protection and controlled grazing on the vegetation of a Mediterranean desert ecosystem in Northern Egypt. *Vegetation* 49: 129-139.

Floret, C. 1988. Méthodes de mesure de la végétation pastorale. *Pastoralisme et développement*. IAV. Hassan II. Rabat/IAM. Montpellier, 157 p.

Floret, C., and R. Pontanier 1982. L'aridité en Tunisie présaharienne. Climat, sol, végétation et aménagement. Mémoire de thèses. *Travaux de l'O.R.S.T.O.M.*, 150, 544 p.

Floret, C., E. Le Floch, and R. Pontanier. 1983. Phytomasse et production végétale en Tunisie présaharienne. *Acta Oecologica. Oecol. Plant.* 4 (18): 133-152.

Raunkiaer, C. 1934. Plant life forms. *Clarendon Oxford*. 104p.

Sarfatti, P. 1988. Il climat del Governatorato di Kebili in Tunisia. *Rivista di agricoltura subtropicale e tropicale*. Trimestrale Anno LXXXII No.2 Gennaio-Giugno. p. 23-35.

Reducing Waterlogging and Salinization: Economics in Policies

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ABSTRACT

This paper examines the problems of irrigation-induced waterlogging and salinization from an economic perspective and describes policy alternatives that can be implemented to reduce the rate of increase in problem areas. Policies that can motivate farmers to consider the off-farm and long-term impacts of irrigation and drainage decisions include volumetric water pricing, water markets, and adjustments in area-based cost recovery programs.

INTRODUCTION

From the viewpoint of a natural resource economist, waterlogging and salinization in arid areas arise, in part, because two essential resources, irrigation water and the assimilative capacity of unconfined aquifers, are not priced or allocated correctly to reflect scarcity values and opportunity costs. As a result, farm-level decisions regarding irrigation methods and water volumes are not consistent with decisions that would maximize the sum of net benefits generated throughout an irrigated region. Policies that modify farm-level prices or allocations of irrigation and drainage resources may be useful in motivating farmers to improve water management practices in ways that reduce the rate of increase in waterlogged and saline areas.

Policies that can motivate farmers to consider the off-farm and long-term impacts of irrigation and drainage decisions include volumetric-water pricing, water markets, and adjustments in area-based cost recovery programs. Several of these policies have been implemented in recent years, with mixed success, as governments and water-resource agencies have increased their use of economic incentives in the design of irrigation and drainage policies.

In some cases, such as the promotion of private tubewells in India and Pakistan, efforts to improve the efficiency of water use can exacerbate problems of waterlogging and salinization. For example, a subsidy that reduces the price of electricity to encourage tubewell pumping may reduce water-table pressure in some regions, while increasing the salt load applied on irrigated land in others. In Egypt, the national Irrigation Improvement Project may increase the volume of water available to farmers in some regions, while reducing the volume available in others. The net effect on waterlogging and salinization is not clear in the absence of appropriate pricing and allocation policies for irrigation and drainage resources.

THE PROBLEM

Waterlogging and salinization have reduced the productivity of agricultural land in arid regions since the rise and fall of Mesopotamia, even though the irrigation-induced causes of these conditions have been known for nearly as long (Jacobsen and Adams, 1958; Kovda, 1983; Szabolcs, 1987; Ghassemi et al., 1995). Known also as the "twin menace" of irrigated agriculture, waterlogging and salinization affect most of the world's large-scale irrigation systems, and they continue to impose farm-level and public costs in the form of lost production and efforts to reduce the rate of increase in affected areas.

Waterlogged and saline soils are found naturally in many areas, but inappropriate irrigation also causes waterlogging and secondary salinization, resulting in economic losses when crop yields are reduced by high water-tables and soil salinity (Barrow, 1991; Szabolcs, 1987; Rhoades, 1990; Smedema, 1990; Dregne, 1991; Abdel-Dayem, 1997). The primary irrigation-induced causes include leakage from poorly lined irrigation canals and reservoirs, excessive water application, and inadequate drainage of agricultural land (Barrow, 1991; Scott, 1993). Seepage from irrigation facilities and deep percolation from farm fields enter unconfined aquifers that are usually saline. When a water-table rises within 2 m of the soil surface, the root zone available to plants becomes restricted, salts rise to the surface by capillary action, and the resulting salinization can render land unsuitable for agriculture (Stone, 1984, p. 141; Arnon, 1987 p. 147; Abernethy and Kijne, 1993; Abrol and Sehgal, 1994; Hillel, 1994, p. 56).

Some deep percolation is required in arid regions to remove salts from the root zone and sustain productivity over time (Oster, 1984; Hoffman, 1990; Rhoades and Loveday, 1990). However, actual leaching fractions often exceed leaching requirements, because the non-water costs of irrigation rise with farm-level efforts to increase irrigation efficiency (Letey et al., 1990; Dinar and Zilberman, 1991). In addition, many water allocation and pricing policies do not motivate farmers to use water efficiently (Abrol et al., 1988; Prasad and Rao, 1991; Sampath, 1992; Meinzen-Dick and Mendoza, 1996; Rosegrant and Meinzen-Dick, 1996). Excessive deep percolation occurs in rotational water delivery systems in which farmers irrigate according to calendar-based schedules that do not match crop water requirements (Dhawan, 1989; Qureshi et al., 1994). In many systems, water prices are too low to encourage farm-level improvements in water management or to justify investments in irrigation methods that minimize deep percolation (Mageed, 1994; Hillel, 1994, p. 217).

Perspectives Regarding Public Policies

Irrigation-induced waterlogging and salinization, in conjunction with water shortages and poor performance of irrigation systems, may constrain worldwide efforts to meet future food demands (Albertson and Bouwer, 1992; Scott, 1993; Bouwer, 1994; Biswas, 1996; Dyson 1996, p. 149-155; Carruthers et al., 1997; Rosegrant and Sombilla 1997; Wolter and Kandiah 1997; Falkenmark et al., 1998). Public efforts to reduce the extent of problem areas include constructing regional drainage systems (Amer, 1996), operating public tube-wells (Chaudhry and Young, 1990; Afzal, 1996), planting trees (Farrington and Salama, 1996), and providing economic incentives that encourage farmers to improve water management and reduce deep percolation (Wichelns, 1991; Wichelns et al., 1996)

Subsurface and open-ditch drainage systems can remove saline drainage water from an irrigated area, but these systems are expensive (UNEP, 1997; Kelleners and Chaudhry, 1998) and environmental issues can arise regarding the discharge of drainage water into rivers or lakes (Abdel-Dayem, 1997; Madramootoo, 1997; Wolter and Kandiah, 1997). Policies that motivate improvements in water management to reduce deep percolation may reduce the size and cost of regional drainage systems, and the volume of drainage water that must be disposed or re-used. Improved water management can also reduce the salt loads imported with irrigation water in arid areas.

Several authors recommend water policy and institutional reforms to encourage improvements in water management and enhance performance of irrigation systems (Jensen et al., 1990; Svendsen and Meinzen-Dick, 1997; Falkenmark and Lundqvist, 1998). Rosegrant and Ringler (1997) recommend policy reforms, including water markets and other economic incentives, to encourage water conservation. Pretty and Shah (1997) suggest that changes in existing policies are needed to promote sustainable use of soil and water in agriculture.

The World Bank (1992, p. 145) suggests that seepage losses, waterlogging, and salinization may be addressed more effectively by improving water management than by modifying physical structures. Dregne (1995) stated that social and economic factors must be given priority when addressing salinization and other forms of desertification. Greiner (1997) suggests that the lack of property rights to groundwater systems enables farmers to discharge deep percolation without restraint, regardless of any impacts on water-table depth.

Regarding individual countries, Faruquee (1996) suggests that fundamental changes in water pricing and institutions are required to improve the efficiency of allocating water and maintenance in Pakistan. Mellor (1996) includes water charges that recover operation and maintenance costs among his policy recommendations for Pakistan, while Pinstrup-Andersen and Pandya-Lorch (1994) suggest that appropriate

allocation mechanisms are needed urgently to prevent excessive water use.

Saleh (1994) describes an "incentive gap" between the scarcity value of water and the value generated by current water use and management efforts in India. He suggests that water policy reforms are required to close that gap, which currently encourages inefficient water use, resulting in aquifer depletion, waterlogging, and salinization in canal regions. Chopra (1990, p. 127) suggests that volumetric prices or quantitative controls are required to encourage efficient irrigation in Punjab, while Dev and Mungekar (1996) recommend volumetric-water pricing and metered electricity sales to address waterlogging and salinization in Maharashtra. Chand and Haque (1997) recommend similar policies to sustain agricultural productivity in Punjab and Haryana.

POLICY ALTERNATIVES

Water Prices

Placing an appropriate price on irrigation water or on water delivery services can motivate farmers to improve irrigation methods and increase water-use efficiency. Volumetric prices can also provide an economic incentive for public water agencies to improve delivery service and to reduce seepage along main and secondary canals, particularly if agency budgets are dependent upon the collection of revenue from water sales (Moore, 1989; Small and Carruthers, 1991, p. 52-53; Ellis, 1992, p. 271). Water agency personnel in regions where water is delivered at no charge to farmers and water rights are not assigned have little incentive to spend limited funds on canal improvement projects (Repetto, 1986). Placing a value on water at the agency level may reduce waterlogging and salinization caused by seepage from main and secondary canals.

Water Markets and Water Rights

Formal and informal water markets are effective in communicating scarcity values among potential buyers and sellers, by providing farmers with an opportunity to lease or sell a portion of their water supply for a specific time interval or in perpetuity (Dudley, 1992; Rosegrant and Binswanger, 1994; Rosegrant and Meinzen-Dick, 1996; Dinar et al., 1997). Markets also encourage farmers to consider opportunity costs explicitly when they choose cropping patterns and irrigation methods (Dinar and Letey, 1991; Weinberg et al., 1993). Farmers with attractive market opportunities may choose to improve water management practices to make water available for sale or lease. Farm-level efforts to "convert" surface runoff or deep percolation into marketable water volume will reduce pressure on regional water-tables.

Land Assessments

Public water agencies in India, Pakistan, and other countries with major irrigation projects charge farmers for water-delivery services using area-based assessments intended to recover the costs of operation and maintenance (Puttaswamaiah, 1994, p. 187; Kemal et al., 1995; Tsur and Dinar, 1997). The charges are usually higher for crops with higher crop water requirements and in regions with higher costs of service. These programs are less costly to implement than volumetric water pricing (Small and Carruthers, 1991, p. 141), but do not provide an economic incentive to use water efficiently because the farm-level cost of additional water within a season is zero.

SUMMARY

Economic incentives and other policies that motivate farmers to improve water management may enhance resource use and sustainability in arid regions, and reduce the rate of increase in waterlogged and saline areas. Several engineering, administrative, and political issues will require attention in some countries to enable implementation of such policies, and transaction costs may not be trivial. Public investments may be required to improve irrigation systems to support better control and measurement of water deliveries before volumetric pricing or water marketing can be implemented successfully. The administrative costs of water delivery will likely increase when incentive programs are implemented and political support may be needed to gain approval for any changes in farm-level expectations regarding water supply when water rights are defined and traded.

The potential engineering and political costs of water-delivery system improvements often serve as binding constraints on policy enhancements, particularly in developing countries and in regions where water scarcity is not yet receiving national attention. However, in many arid countries, competition for land and water resources, and the value of output from irrigated agriculture, will continue to increase with rising populations and income levels. Therefore, it may be useful to begin improving water delivery systems and enhancing the policy environment in the near-term, while pressure on resources is not yet severe. This may enable public officials to implement economic incentives successfully in future, when water scarcity and the losses from waterlogging and salinization become ever more costly.

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REFERENCES

- Abdel-Dayem, S. 1997. Waterlogging and salinity, p. 99-116. In A.K. Biswas, (Ed.) *Water Resources: Environmental Planning, Management, and Development*. McGraw-Hill, New York.
- Abernethy, C.L., and J.W. Kijne. 1993. Managing the interactions of irrigation systems with their environments, p. 75-103. In *Ecologically Sound Resources Management in Irrigation*, German Association for Water Resources and Land Improvement, Verlag Paul Parey, Hamburg, Germany.
- Abrol, I.P., and J.L. Sehgal. 1994. Degraded lands and their rehabilitation in India, p. 129-144. In D.J. Greenland and I. Szabolcs (Ed.) *Soil Resilience and Sustainable Land Use*. CAB International, Wallingford, UK.
- Abrol, I.P., J.S.P. Yadav, and F.I. Massoud. 1988. Salt-affected soils and their management. *FAO Soils Bull.* 39. Food and Agriculture Organization, Rome, Italy.
- Afzal, M. 1996. Managing water resources for environmentally sustainable irrigated agriculture in Pakistan. *The Pakistan Devel. Rev.* 35(4): 977-988.
- Albertson, M.L., and H. Bouwer. 1992. Future of irrigation in balanced third world development. *Agric. Water Manage.* 21: 33-44.
- Amer, M.H. 1996. History of land drainage in Egypt, p. 61-130. *Proceedings of the Sixteenth Congress of ICID*, Cairo, History Seminar R. 4.
- Arnon, I. 1987. *Modernization of agriculture in developing countries: resources, potentials and problems*. Second Edition, John Wiley & Sons, New York.
- Barrow, C.J. 1991. *Land Degradation: Development and Breakdown of Terrestrial Environments*. Cambridge University Press, Cambridge, UK.
- Biswas, A.K. 1996. Water for the developing world in the 21st century: issues and implications. *ICID Journal*, 45(2): 1-12.
- Bouwer, H. 1994. Irrigation and global water outlook. *Agric. Water Manage.* 25: 221-231.
- Carruthers, I., M.W. Rosegrant, and D. Seckler. 1997. Irrigation and food security in the 21st century. *Irrigation and Drainage Systems*, 11: 83-101.
- Chand, R., and T. Haque. 1997. Sustainability of rice-wheat crop system in Indo-Gangetic region. *Economic and Political Weekly* 32(13), March 29, A26-A30.
- Chaudhry, M.A., and R.A. Young. 1990. Privatizing public tubewells in Pakistan: an appraisal of alternatives. *The Pakistan Development Review*, 29(1): 33-58.
- Chaudhry, M.J. 1990. The adoption of tubewell technology in Pakistan. *The Pakistan Development Review*, 29(3,4): 291-303.
- Chopra, K. 1989. Land degradation: dimensions and causalities. *Indian J. Agric. Econ.* 44(1): 45-54.
- Chopra, K. 1990. Agricultural development in Punjab: issues in resource use and sustainability. Vikas Publishing House Pvt. Ltd., New Delhi.
- Dev S.M., and B.L. Mungekar. 1996. Maharashtra's agricultural development: a blueprint. *Economic and Political Weekly* 31(13), March 30, A38 to A48.

- Dhawan, B.D. 1989. Water resource management in India: issues and dimensions. *Indian J. Agric. Econ.* 44(3): 233-241.
- Dinar, A., and J. Letey. 1991. Agricultural water marketing, allocative efficiency, and drainage reduction. *J. Environ. Econ. & Manage.* 20: 210-223.
- Dinar, A., and D. Zilberman. 1991. The economics of resource-conservation, pollution-reduction technology selection: the case of irrigation water. *Resources and Energy* 13: 323-348.
- Dinar, A., M.W. Rosegrant, and R. Meinzen-Dick. 1997. Water allocation mechanisms: principles and examples. *Policy Research Working Paper 1779*, World Bank, Washington, DC.
- Dregne, H.E. 1991. Arid land degradation: a result of mismanagement. *Geotimes* 36(6): 19-21.
- Dregne, H.E. 1995. Desertification control: a framework for action. *Environmental Monitoring and Assessment* 37: 111-122.
- Dudley, N.J. 1992. Water allocation by markets, common property and capacity sharing: companions or competitors?. *Natural Resources J.* 32(4): 757-778.
- Dyson, T. 1996. *Population and Food: Global Trends and Future Prospects*, Rutledge, London.
- Ellis, F. 1992. *Agricultural policies in developing countries*, Cambridge University Press, Cambridge.
- Falkenmark, M., and J. Lundqvist. 1998. Towards water security: political determination and human adaptation crucial. *Natural Resources Forum* 21(1): 37-51.
- Falkenmark, M., W. Klohn, J. Lundqvist, S. Postel, J. Rockstrom, D. Seckler, H. Shuval, and J. Wallace. 1998. Water scarcity as a key factor behind global food insecurity: round table discussion. *Ambio* 27(2): 148-154.
- Farrington, P., and R.B. Salama. 1996. Controlling dry-land salinity by planting trees in the best hydrogeological setting. *Land Degradation & Development*, 7: 183-204.
- Faruquee, R. 1996. Role of economic policies in protecting the environment: the experience of Pakistan. *The Pakistan Devel. Rev.* 35(4): 483-506.
- Ghassemi, F., A.J. Jakeman, and H.A. Nix. 1995. *Salinization of Land and Water Resources*. Center for Resource and Environmental Studies, Canberra, Australia.
- Greiner, R. 1997. Optimal farm management responses to emerging soil salinization in a dryland catchment in eastern Australia. *Land Degradation & Development*, 8: 281-303.
- Hillel, D. 1994. *Rivers of Eden: The Struggle for Water and the Quest for Peace in the Middle East*. Oxford University Press, Oxford.
- Hoffman, G.J. 1990. Leaching fraction and root zone salinity control, p. 237-261. In K.K. Tanji (Ed.) *Agricultural Salinity Assessment and Management*, American Society of Civil Engineers, New York.
- Jacobsen, T., and R.M. Adams. 1958. Salt and silt in ancient Mesopotamian agriculture. *Science*, 128: 1251-1258.
- Jensen, M.E., W.R. Rangeley, and P.J. Dieleman. 1990. Irrigation trends in world agriculture, p. 31-67. In B.A. Stewart, and D.R. Nielsen (Ed.) *Irrigation of Agricultural Crops*, Amer. Soc. Agron., Madison, Wisconsin.
- Kelleners, T.J., and M.R. Chaudhry. 1998. Drainage water salinity of tubewells and pipe drains: a case study from Pakistan. *Agric. Water Manage.* 37: 41-53.
- Kemal, A.R., F. Bilquees, and Z. Mahmood. 1995. Case study on the economic valuation of the salinization and waterlogging as a result of inappropriate irrigation in Pakistan. *Pakistan Instit. Devel. Econ.*, Islamabad.
- Kovda, V.A. 1983. Loss of productive land due to salinization. *Ambio*, 12(2): 91-93.
- Letey, J., A. Dinar, C. Woodring, and J.D. Oster. 1990. An economic analysis of irrigation systems. *Irrigation Science*, 11: 37-43.
- Madramootoo, C.A. 1997. Introduction, p. 1-9. In C.A. Madramootoo, W.R. Johnston and L.S. Willardson (Ed.) *Management of Agricultural Drainage Water Quality*, ICID and FAO, *Water Reports* 13, Rome.
- Mageed, Y.A. 1994. The central region: problems and perspectives, p. 101-119. In P. Rogers, and P. Lyndon (Ed.) *Water in the Arab World: Perspectives and Prognosis*. Harvard University Press, Cambridge, Massachusetts.
- Meinzen-Dick, R., and M. Mendoza. 1996. Alternative water allocation mechanisms: Indian and international experiences. *Economic and Political Weekly* 31(13), March 30, A25 to A30.
- Meinzen-Dick, R., and M.W. Rosegrant. 1997. Water as an economic good: incentives, institutions, and infrastructure, p. 312-320. In M. Kay, T. Franks, and L. Smith (Ed.) *Water: Economics, Management and Demand*, E & FN Spon., London.
- Mellor, J.W. 1996. Accelerating agricultural growth - Is irrigation institutional reform necessary? *The Pakistan Devel. Rev.* 35(4): 399-471.
- Moore, M. 1989. The fruits and fallacies of neoliberalism: the case of irrigation policy. *World Development*, 17(11): 1733-1750.
- Oster, J.D. 1984. Leaching for salinity control, p. 175-189. In I. Shainberg and J. Shalhevet (Ed.) *Soil Salinity Under Irrigation: Processes and Management*, Springer-Verlag, New York.
- Pinstrup-Andersen, P., and R. Pandya-Lorch. 1994. Poverty, agricultural intensification, and the environment. *The Pakistan Devel. Rev.* 33(4): 463-496.
- Prasad, K., and P.K. Rao. 1991. On irrigation water pricing in India. *Water Resources Development* 7(4): 274-280.
- Pretty, J.N. and P. Shah. 1997. Making soil and water conservation sustainable: from coercion and control to partnerships and participation. *Land Degradation & Development*, 8: 39-58.
- Puttaswamaiah, K. 1994. *Irrigation Projects in India:*

- Towards a New Policy. Indus Publishing Company, New Delhi.
- Qureshi, S.K., Hussain, Z., and Zeb-un-Nisa. 1994. An assessment of warabandi (irrigation rotation) in Pakistan: a preliminary analysis. *The Pakistan Devel. Rev.* 33(4): 845-855.
- Repetto, R., 1986. Skimming the water: rent-seeking and the performance of public irrigation systems. *Research Report 4*, World Resources Institute, Washington, DC.
- Rhoades, J.D., 1990. Soil salinity - causes and controls, p. 109-134. In A.S. Goodie (Ed.) *Techniques for Desert Reclamation*. John Wiley & Sons, New York.
- Rhoades, J.D., and J. Loveday. 1990. Salinity in irrigated agriculture, p. 1089-1142. In B.A. Stewart and D.R. Nielsen (Ed.) *Irrigation of Agricultural Crops*, Amer. Soc. Agron., Madison, Wisconsin.
- Rosegrant, M.W., and H.P. Binswanger, H.P. 1994. Markets in tradable water rights: potential for efficiency gains in developing country water resource allocation. *World Development*. 22(11): 1613-1625.
- Rosegrant, M.W., and R.S. Meinzen-Dick. 1996. Water resources in the Asia-Pacific region: managing scarcity. *Asian-Pacific Economic Literature*. 10(2): 32-53.
- Rosegrant, M.W., and C. Ringler. 1997. World food markets into the 21st century: environmental and resource constraints and policies. *The Australian J. Agric. Resource Economics* 41(3): 401-428.
- Rosegrant, M.W., and M.A. Sombilla. 1997. Critical issues suggested by trends in food, population, and the environment to the year 2020. *Amer. J. Agric. Econ.* 79: 1467-1470.
- Saleth, R.M. 1994. Towards a new water institution: economics, law, and policy. *Economic and Political Weekly* 29(39), Sept. 24, A147 to A155.
- Sampath, R.K. 1992. Issues in irrigation pricing in developing countries. *World Development*. 20(7): 967-977.
- Scott, S.F. 1993. Water and sustainable agricultural development, p. 19-50 In *Ecologically Sound Resources Management in Irrigation*. German Association for Water Resources and Land Improvement, Verlag Paul Parey, Hamburg, Germany.
- Small, L.E., and I. Carruthers. 1991. *Farmer-Financed Irrigation: The Economics of Reform*. Cambridge University Press, Cambridge.
- Smedema, L.K. 1990. Irrigation performance and waterlogging and salinity. *Irrigation and Drainage Systems*. 4: 367-374.
- Stone, I. 1984. *Canal Irrigation in British India: Perspectives on Technological Change in a Peasant Economy*, Cambridge University Press, Cambridge.
- Svendsen, M., and R. Meinzen-Dick. 1997. Irrigation management institutions in transition: a look back, a look forward. *Irrigation and Drainage Systems*. 11: 139-156.
- Szabolcs, I. 1987. The global problems of salt-affected soils. *Acta Agronomica Hungarica* 36(1-2): 159-172.
- Tsur, Y., and A. Dinar. 1997. The relative efficiency and implementation costs of alternative methods for pricing irrigation water. *The World Bank Economic Review* 11(2): 243-262.
- United Nations Environment Programme (UNEP). 1997. *World Atlas of Desertification*, Second Edition. John Wiley & Sons, New York.
- Weinberg, M., C.L. Kling, and J.E. Wilen. 1993. Water markets and water quality. *Amer. J. Agric. Econo.* 75: 278-291.
- Wichelns, D. 1991. Motivating reductions in drain water with block-rate prices for irrigation water. *Water Resources Bull.* 27(4): 585-592.
- Wichelns, D., L. Houston, and D. Cone. 1996. Economic incentives reduce irrigation deliveries and drain water volume. *Irrigation and Drainage Systems* 10: 131-141.
- Wolter, H., W., and A. Kandiah. 1997. Harnessing water to feed a hungry world. *ICID Journal* 46(1): 1-20.
- World Bank. 1992. *Development and the environment. World Development Report*. World Bank, Washington, DC.

Fruit Tree Orchards and Well Irrigation for Family Income in Dryland Farming Systems of Northern Syria

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ABSTRACT

In Syria, nearly all land suitable for rainfed agriculture is already under cultivation today and emphasis has been given to intensification of production and resource use. Farmers reduced the use of fallow in crop rotations, increased areas under irrigation through the digging of wells, and established fruit tree orchards. The barley-growing area of El Bab district, Aleppo Province, was chosen as the study area and interviews with 100 randomly selected farm families were conducted. Once dominated by traditional dryland farming based on integrated barley livestock systems, olive orchards and pump irrigation have changed the landscape of the area.

Surveyed farm families were grouped, according to characteristics of their resource bases and use, into three farming systems, namely the 'Irrigated', 'Resource Rich' and 'Resource Poor' systems, allowing analysis and comparison of the income structure and economic success among systems. The prospect of higher yields, more reliable harvests and the production of high-value crops have made the high investment and operating costs of irrigation economically attractive to farmers. Farmers bear the full risk of their investment in a situation where amounts and future availability of groundwater are uncertain.

The system appears to be unsustainable: diminishing groundwater reserves will mean higher drilling and pumping costs and failure of many existing wells. Economic incentives and technical assistance, made available to farmers for the establishment of tree plantations, encouraged their decision to convert cereal production area into tree orchards. Under the environmental conditions in the study area and current management practices of farmers, yield development and economic returns from these slow-maturing perennial crops have lagged behind farmer's expectations of higher future incomes.

As profitable irrigation expands to its limits, rainfed farming will remain the predominant land use, supplemented through off-farm income sources. The challenge for the existing farming systems requires research, and strengthened educational and financial institutions to develop sustainable alternatives to improve and secure family incomes and the livelihood of the farming community.

INTRODUCTION

Dryland farming areas throughout the Middle East and North Africa are characterised by low and erratic rainfall patterns. In addition, farmers are challenged to meet their families' needs under conditions of declining farm resource quantity and quality. With the existing inheritance practices, farm resources are subdivided among the sons, leaving the next generation with a smaller production base. An expansion of the production area is no longer possible, as nearly all land suitable for rainfed agriculture in Syria is already under cultivation.

To meet future food and feed demands of a fast-growing urban and rural population, emphasis is now put on intensification of production and the more efficient use of existing resources. In the process, the use of fallow in the crop rotation has been reduced substantially during the past decade, leading to a decrease in soil productivity. A more regular use with higher amounts of fertilizers is used in cereal production today. In their attempt to secure family income, farmers sought alternatives to the traditional barley livestock systems. Well irrigation and fruit tree orchards are examples of farmers' strategies to ensure higher and more stable income levels.

In order to limit groundwater extraction, no new licences are issued for the digging of irrigation wells. But the law is often not enforced and farmers are digging wells illegally, resulting in declining water tables as water extraction exceeds aquifer recharge. Without a digging licence, farmers are not eligible for loans from the Agricultural Bank. The prospect of higher yields, more reliable harvests and production of high value crops make the high investment and operating costs of irrigation acceptable to farmers. Farmers bear the full risk of the investment in well digging and irrigation equipment, given the uncertain amounts and periods of water extraction. Diminishing ground water reserves will increase drilling and pumping costs and have already lead to the failure of many existing wells with negative implications for the livelihood of the farm families.

The investment in fruit tree orchards by converting marginal cereal production areas can lead to increased future-farm income. Economic incentives and technical assistance were made available to farmers to establish tree orchards. This is a strategy of farmers to secure income for future generations had a visible impact on land use in the study area.

OBJECTIVE

To compare the impact of intensification of production and resource use on traditional rainfed systems and on high potential systems with access to irrigation in El Bab district. Farm resource allocation and use are examined in relation to economic performance and ability to provide sustainable income levels for the well being of the farming community.

METHODS

The 250-350 mm rainfall zone of the El Bab district in northern Syria was selected as the study area because of the predominance of traditional barley based farming systems with livestock integration (Fig. 1). Well irrigation is spreading in the area, which allowed a comparison of rainfed systems with high potential irrigated systems. In the study area, farmers had access to financial and technical support for the establishment of tree orchards, which allowed a study of the effects of this program on farm income and land use.

In a two-stage stratified sampling process, 20 villages were randomly selected from a list of villages in the study area; interviews with key village informants were conducted to gather village background information and to establish a list of farm households. In a second stage, a total of 100 farm households were selected from this list for a formal in depth survey. In addition, a survey of relevant institutions captured information on markets, supply channels, as well as credit institutions. The farms were grouped into farming systems, by using their resource base as classification variables. Descriptive and analytical statistics were used to analyse and compare the farming systems.

RESULTS

Three main farming systems were defined, with a high degree of homogeneity within the system, and a high level of heterogeneity among the systems. The three systems have the following characteristics (Table 1):

Table 1. Characteristics of the farming systems of El-Bab in northern Syria.

	Irrigated System (n = 43)	Rainfed System	
		Large (n = 24)	Small (n = 30)
Rainfed crops (ha)	13.2	17.6	5.9
Tree orchards (ha)	3.3	2.7	1.0
Off-farm income (\$)	1,058	574	1,993
Irrigated production (ha)	3.3	-	-
Flock size (head)	28	25	18
Household size	7.4	11	9.4

1. Rainfed, Small System

Resource poor farmers, with medium household sizes, small area of rainfed field crops and small area of permanent crops, high off-farm income, smaller flock sizes and no irrigation.

2. Rainfed, Large System

Resource rich farmers with medium household sizes, large areas of rainfed field crops and with permanent crops, less importance of off-farm income, larger flock sizes and no irrigation.

3. Irrigated System

Large household sizes with medium- to large-sized areas of land under rainfed field crops and permanent

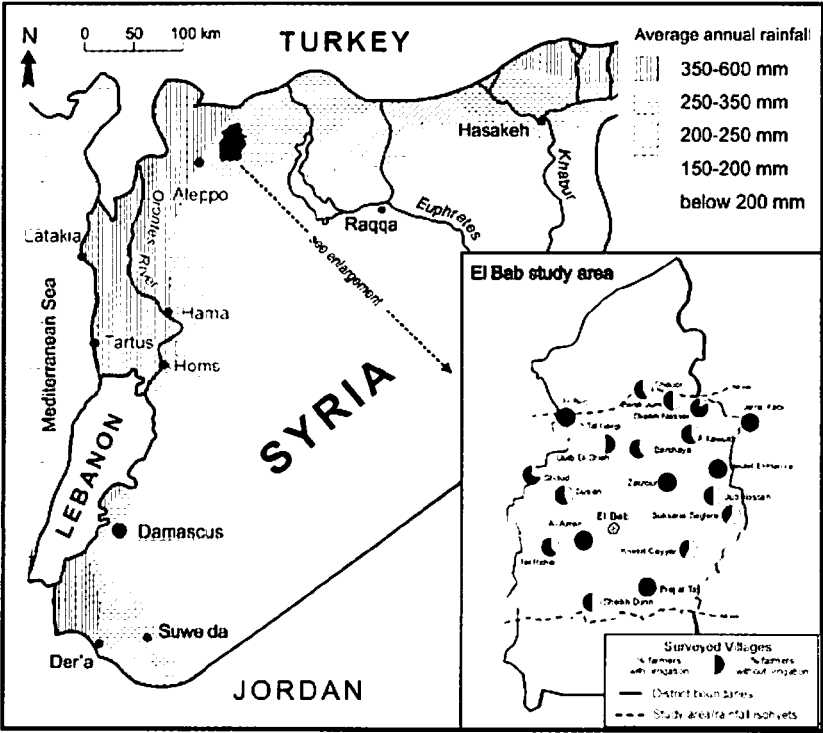


Fig. 1. The study area of El-Bab in northern Syria.

crops, irrigated production area, variable amounts of off-farm income and flock sizes.

Intensification - Farmer's Strategies to Meet Family Income Needs

Changes in land use are seen in comparing results of a 1984 study in the area (Tully, 1984) and estimates of the present study (Fig. 2). The use of fallow in the crop rotation was reduced by 30% over the 10 years. More regular fertilizer use in cereal production and higher amounts per hectare is believed to compensate for loss of soil fertility through cereal monoculture.

maturity and the pace of yield development are lagging behind farmer's expectations.

Environmental conditions and climate in the study area are not optimal for olive growing; calcareous and shallow soils, low air humidity and rainfall and occasional strong winter frosts hamper optimal development of the trees. While these conditions are difficult to change, the selection of better-adapted species could be a solution. In addition, management practices applied by the farmers are insufficient and need improvement. Problems include (a) very high plant densities, (b) insufficient irrigation, fertilizing, and pest control, and (c) unprofessional pruning.

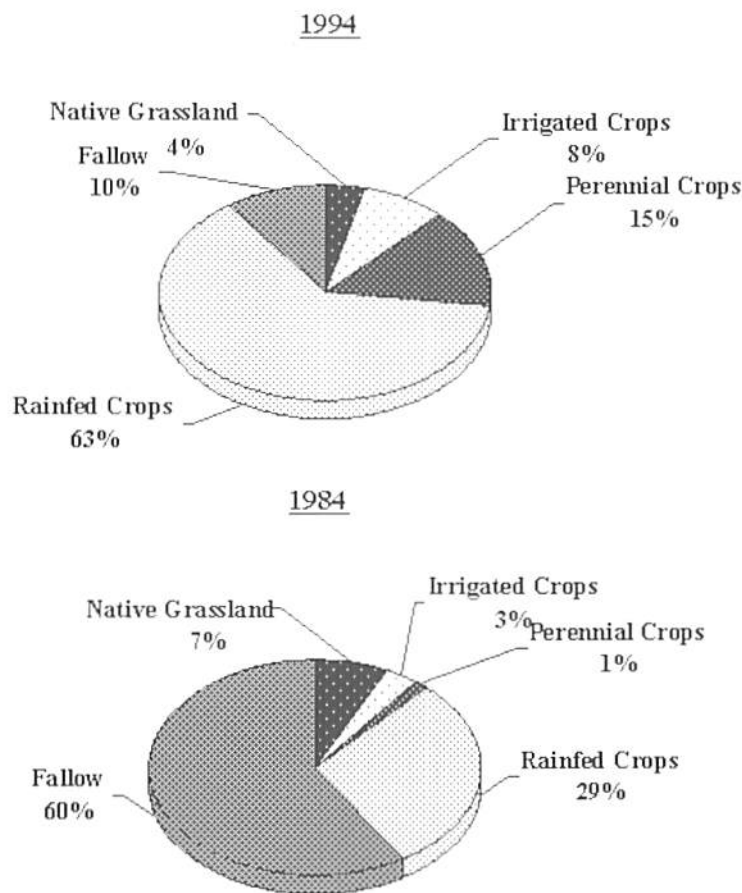


Fig. 2. Land use changes in El-Bab area (1984 - 1994).

Tree Orchards

More than one sixth of the area is now planted with tree orchards, representing an increase by 14% in ten years. In 1986, technical and financial assistance became available to farmers for planting trees. This included low interest loans, with a five-year grace period before repayment started and the leveling and clearing of the land. This presented an incentive for many farmers to convert marginal production areas, previously used for barley production, into tree orchards - mainly olive and pistachio. More than 70% of all tree orchards found in the study area today were established since 1986. Both the time needed to reach

The development of Gross Margin averages per hectare (defined as the value of production minus the cost of production averaged over time) of newly established olives was compared with that of barley crops previously grown on the land. The development shows that the cost of production of the perennial crops is greater than their production value for many years (Fig. 3). The investment has a positive effect only after fifteen years, when the average Gross Margin of olives surpasses the average Gross Margin of barley. This means that during 14 years, the farmer is giving up low, but positive, economic returns and instead is paying high input costs for the establishment of the trees.

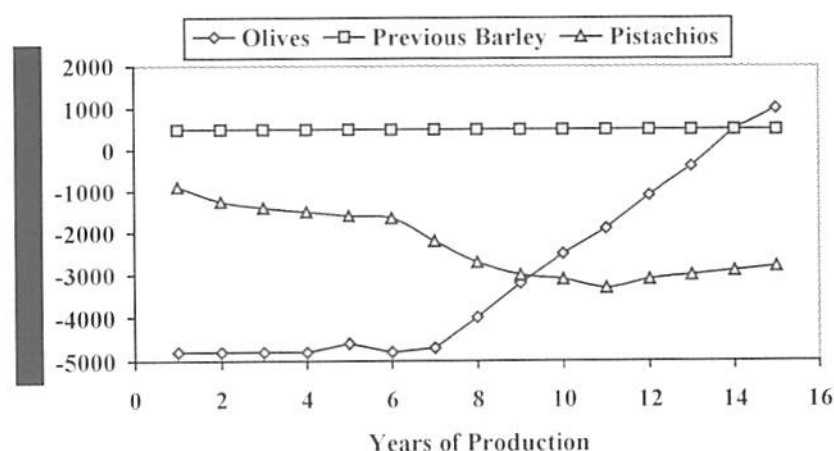


Fig. 3. Average gross margins for olive, pistachio and marginal barley in El-Bab area.

Well Irrigation

Over a period of 10 years, the area under irrigation in the study area increased fourfold. The sources of irrigation are privately owned wells, with an average depth of 66 m (SD 20.2). The predominant irrigation method is furrow and bed irrigation, known to be labor-intensive for having low water-use efficiency. More than 80% of all interviewed farmers have attempted to dig wells in the past. The success, expressed as the length of the productive period of irrigation wells and the amount of water and water recharge, is highly variable.

Of the digging attempts, 44% of wells are still productive today; the majority of them are less than 10 - years old. In 35% of cases, the wells dried up after less than 4 years, some of them produce only enough water today to irrigate the home garden (Table 2). The wells in the study area typically carry water only until the month of June until they fall dry during the summer. Irrigation water amounts vary greatly among wells (Table 3). The available number of irrigation days per well of the majority of farmers lies between 30 and 90 days; this in combination with the daily recharge rate of the well determines the choice of crops farmers can produce.

The irrigated cropping area is mainly used for the production of food crops, namely wheat, faba bean, and vegetables, of which the largest share is sold in the market (Fig. 4). Most of the irrigation water resources are allocated to the production of vegetables, which are clearly the most profitable (Fig. 5). The high water demand and irrigation frequency does not allow all farmers to grow them.

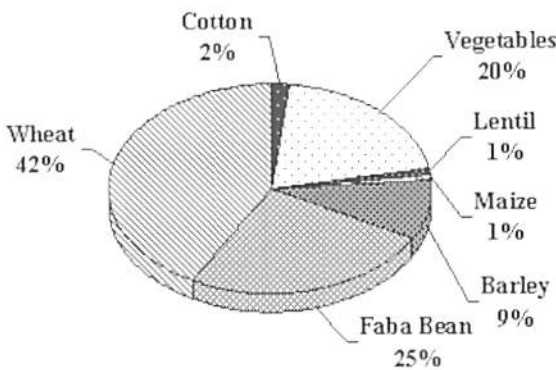


Fig. 4. Land use under irrigation in El Bab area, 1993/94.

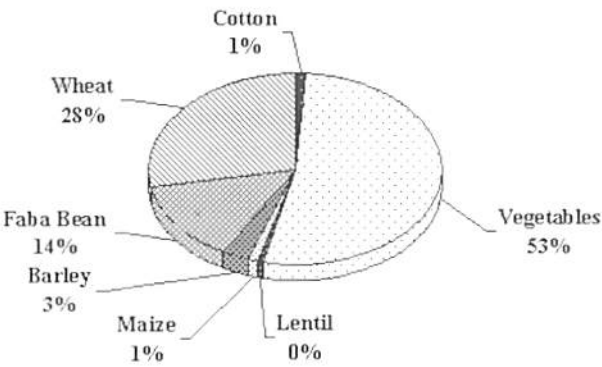


Fig. 5. Allocation of irrigation water resources by farmers in northern Syria.

Table 2. Results of well-digging attempts by farmers in El-Bab (1993/94).

	Well Digging Attempts (n = 97)
	-- % --
- Never attempted to dig a well	16
- The well is still productive today	44
- Well dried up after less than 4 years of use	26
- Well produces water only for home garden	9
- Never found water	5

Table 3. Water availability to farmers of the Irrigated system in El-Bab (1993/94).

	Irrigated System (n = 43)
	-- % --
- Less than 30 irrigation days	16
- 30 to 90 irrigation days	39
- 90 to 150 irrigation days	21
- 150 to 210 irrigation days	16
- More than 210 irrigation days	7
Average irrigation days per farm	110.2
LSD	64.5

Family Income Level and Composition

Family income is defined as the economic surplus used to satisfy family needs, calculated by subtracting farm expenses from farm revenues, plus the income received from off-farm activities. The income calculations were based on the agricultural year 1993/94, an average rain-fall year. Large differences existed between the income level of farmers in the Irrigated system compared to that of farmers in the Rainfed Large and Rainfed Small systems (Fig. 6). While similar in their average land

holding sizes, farmers in the Rainfed Large system achieved farm incomes of only one third compared to farmers with irrigation. In the Irrigated system, 57% of the farm income is produced on the 15% of their land, which is irrigated. Farm incomes in the Rainfed Small system appear to be insufficient to ensure the livelihood of many farm families, with off-farm income contributing more than 70% to family incomes. The importance of farm income from perennial crops is largest in the Rainfed Large system.

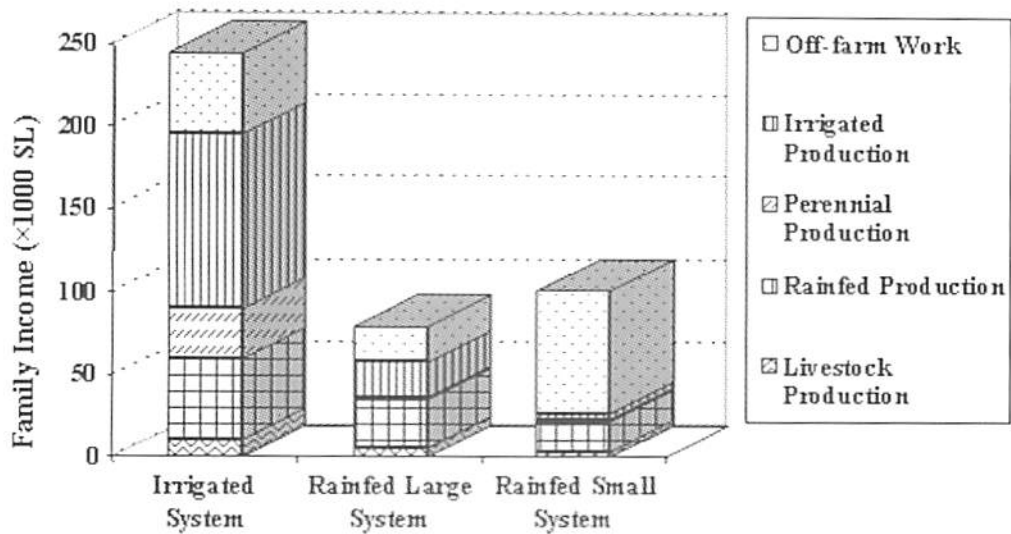


Fig. 6. Income - level and composition of families in Irrigated, Rainfed Large and Rainfed Small farming systems of El-Bab area, 1993/94.

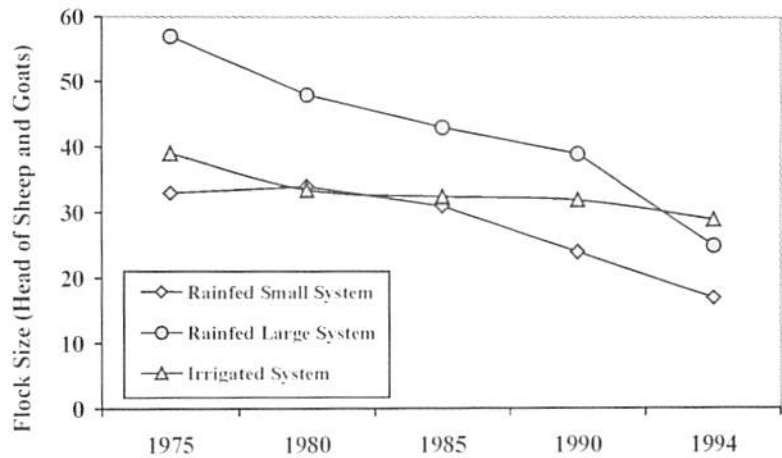


Fig. 7. Flock - size development recalled by farmers in the Irrigated, Rainfed Large and Rainfed Small systems of El-Bab area.

In the traditional, integrated barley/livestock systems, livestock used to contribute substantially to farm incomes. Based on recollections of farmers in the three farming systems, their average flock sizes decreased between 20% and 60% during the last 20 years. While total sheep numbers in the study area are reported to be stable or even increasing, individual flock sizes per farm are declining with inheritance practices of subdividing farm resources among the sons.

Animal production in the study area is subsistence-oriented and contributes less than 10% to family incomes in all three systems. Flocks are of great importance in providing a source of protein for the family's diet, and they can be used as disposable cash in times of need. Family income levels in the Rainfed Large and the Rainfed Small systems are often barely sufficient to cover household expenses. For these families, saving or investing of money is not possible, which reduces the families' ability to prepare for poor rainfall years and to invest in new technologies. The income level of farmers in the Irrigated system is at a much higher level, but incomes could drop substantially once the water resources are exhausted.

CONCLUSIONS

If water tables continue to decline and well irrigation reaches its limits, the number of poor farmers dependent on rainfed production will increase, causing them

to seek alternative employment and income sources. With growing competition for water and the growing demand for food and feed, the pressure for more efficient irrigation systems and water use.

Despite the environmental and climatic problems olive orchards are facing in the study area, there is room for improvement through a better selection of varieties and improved management of fruit trees, which will increase their productivity and potential income contribution through earlier maturity and higher yields. The increased fruit tree orchard area and spreading irrigation technology demonstrate that farmers adopt new technologies when they are convinced of their possible contribution to higher farm incomes. Through applied research, a well-trained and informed extension service as well as more flexible financial support would help farmers to select technologies, which can improve income and family well being in the future.

REFERENCE

Tully, D. 1984. Land use and farmer strategies in El-Bab. The feasibility of forage legumes in place of fallow. 68p. ICARDA, Farming Systems Program, Aleppo, Syria.

Rural Development in Dry Areas: Turkey's Gap Project

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ABSTRACT

The Southeastern Anatolia Project (GAP) is one of the largest and the most comprehensive regional development projects not only in Turkey but also in the world in terms of the physical structure involved, the area covered, and the objectives that it seeks to achieve. The Project has been transformed into an integrated regional development scheme spanning many sectors with the introduction of the GAP Master Plan. In addition to dams, hydroelectric power plants and irrigation systems, investments which complement each other for regional development in areas of agriculture, industry, rural and urban infrastructure, transportation, education, health and culture have been incorporated in the Project in an integrated manner.

The GAP Region has a very important place for agricultural production thanks to its natural sources and geographic situation. Agricultural sector is still the main economic sector in the Region according to statistical data and as a life-style. There are 3,923 villages and 4,840 hamlets in the GAP Region and the 35% of the total population is rural population. The GAP Region has 3.1 million (M)/ha agricultural lands. It covers about 10% of cultivable agricultural land of Turkey. Rainfed agriculture is predominant in the Region, crops diversification is limited, and productivity is low. The value of total agricultural output of the GAP Region is estimated as equivalent to US \$120 M, and the contribution of the GAP Region to the agricultural GNP is about 10% in 1997. As agriculture is by far the dominant sector in the economy of the Region and rural development is one of the most important issue of the GAP. The project will lead to fundamental changes in these areas, as "development" is not only a matter of economic growth, but also a process of upgrading the living standards of individuals and society.

As a direct result of the GAP investments, the living standards of many inhabitants have already started to increase. With progressive implementation, more and more people will become direct beneficiaries of the Project. In the process of realization, GAP has already achieved some important results from the completed and ongoing projects. The objectives of those projects are training of farmers, creating possibilities to ensure such developments as the elimination of regional disparities, enhancement of the income level of the people, reduction of unemployment, removing the income differentiation between farmers in dryland and irrigated land by introducing new fields of income generating activities.

SOUTHEASTERN ANATOLIA PROJECT (GAP)

Area and Population

The GAP Project area lies in southeastern Turkey, covering nine provinces, corresponding to approximately 10% of the country's total population as well as its surface area. The Project area includes watersheds of the lower Euphrates and Tigris Rivers and the upper Mesopotamian plains. The total surface area is 75,358 km², of which 42.2% is cultivated (36% rainfed), 33.3% pastures, and 20.5% forest and bush. Average gradient over 94% of the total surface area is less than 12%, which is the threshold of cultivability. Salinity and alkalinity problems are minimal, and most of the soil has good drainage conditions. Wind erosion is minimal, but water erosion in places could be moderate to strong.

The population of the region in the 1997 Census was 6.1 M, of which 36% are rural. Annual population growth was about 3.7%, which was above the national average (2.54%). Although fertility rate is higher in rural areas, population is increasing in urban centers more rapidly due to high migration rates.

Economy

A comparison of the gross regional product (GRP) of the region with that of Turkey clearly indicates the level of its underdevelopment. The Region accounted for 4% of the GDP. Agriculture is by far the dominant production sector, accounting for nearly 40% of GRP. The value of total agricultural output of the GAP Region is estimated as equivalent to US \$120 M and the contribution of the GAP Region to the agricultural GNP is about 10% in 1997. Rainfed agriculture is predominant in the region, crops diversification is limited, and productivity is low.

Nearly 70% of the economically active population is engaged in agriculture, but it only generates about 40% of total added value. Similarly, the animal stock is large, but productivity is low. Traditional production methods still predominate, but agricultural modernization has started.

The Project

The GAP is a large-scale multi-sectorial regional development project aiming to remove a socio-economical "gap" between the project area and rest of country. The GAP Project was initially planned to irrigate land and generate electricity by building 22 dams and 19 hydroelectric power plants over the Tigris and Euphrates Rivers. Besides the hydroelectric power plants and

irrigation scheme on the two rivers, all development sector are later involved in the GAP including agriculture, livestock, fishery, manufacturing, commerce mining, tourism etc.

When the GAP is completed, 28% of total water potential of Turkey will be brought under control and 1.7 M ha of land will be irrigated. In addition, 28 M kWh electricity energy will be generated annually. According to projection, upon the completion of the GAP Turkey's national income will be 12% higher than it would have been otherwise. It is estimated that as a result of project impact during the first decade of 21st Century, Turkey will produce enough food to feed the 80 M people; 3.3 M extra job will be created. Feed and agricultural by-product produce in the region will be enough to feed the animal population in the Region. Surplus food and feed produced in the region is intended for export the WANA countries. The high potential generated in both agriculture and industry by the GAP will increase the income level of the Region fivefold and generate employment opportunities for 3.5 M people living in the Region.

In the Region, a comprehensive investment program is under way. The GAP total estimated investment cost is US \$32 billion of which 13.7 billion has been already spent, which is equal to 42.8% realization. The GAP will also lay the foundation for international cooperation as well as it will directly benefit our neighbors in a number of ways.

MASTER PLAN

The GAP Master Plan, prepared and put in to operation in 1989, defining the Region's potential, and identifying the bottlenecks, set the development goals objective and strategies. A three-face development program was initiated and action plan was established based on master plan proposals, taking into account interactions between the sectors, population projection and spatial development forecast. According to Master Plan, the regional development objectives are to:

- Raise the income levels in the GAP Region by improving the economic structure to narrow the income disparity between the Region and other regions.
- Increase the productivity and employment opportunities in rural areas.
- Enhance the assimilative capacity of larger cities in the Region.
- Contribute to the national objectives such as economic growth; export promotion and social stability by efficient utilization of the Region's resources.

Macro-level planning and management, coordination, monitoring, evaluation and implementation related to project implementation are carried out by the Southeastern Anatolia Project Regional Development Administration, which was established in 1989.

Agricultural Development Strategies

Agricultural development objectives in GAP Region are to raise the income levels in rural areas by enhancing agricultural productivity and diversifying farming activities to; provide sufficient inputs to agro-processing industries; increase employment opportunities to minimize the drift of people out of the rural areas; and to contribute to the production of exportable surpluses (Anon., 1990). To realize these agricultural development objectives, agricultural development strategies have also been determined in Master Plan. These are given below.

Agricultural Policies

1. Provide irrigation facilities which are effective in overcoming adverse agro-ecological conditions.
2. Promote farm mechanization in proper combination with the application of fertilizer, agro-chemicals, and irrigation water.
3. Distribute better inputs timely and in sufficient quality and quantity.
4. Improve land tenure systems.
5. Improve pricing and marketing to give incentives for farmers.

Irrigation

1. Identify and promote strategic crops in view of marketability and agro-ecological conditions.
2. Encourage high crop intensity by establishing crop cycles and adjusting water charges.
3. Organize farmers in irrigated areas for on-farm water management and extension.

Livestock

1. Improve husbandry productivity by improving the local sheep, goat and cattle breeds through artificial and natural insemination and improving feeding by pasture management, and forage and feed concentrate production.
2. Improve the physical infrastructure to promote commercial livestock production.

Fishery and Forestry

1. Utilize dam lakes to promote inland fishery.
2. Provide a package of support services for aquaculture including hatchery, fingerling production, training and research, processing, marketing and pricing.
3. Conduct intensive afforestation within the designated forest areas and areas around the reservoirs and to encourage on-farm tree planting.
4. According to these agricultural development strategies, many projects have been carried out by GAP-RDA, and also there other agricultural researches, which were carried out by the other institutes, as can be seen in the following part.

Agricultural Sector: Present State

The food demand is dramatically increasing due to the rapidly population growth in the world. 800 M people face nutritional and food deficit problems. Increasing urbanization and industrialization have a strong pressure on cultivable land and those lands are getting less and less. This is why the pressure on natural resources is also increasing.

In order to overcome these problems, we do not have too many options. We must either widen the cultivable land or get maximum yield per unit land. As it is known very well that one of the way to widen the cultivable land is to shorten the forest area, which is not desirable, but we have other option that is to increase the yield from per unit land and animal by means of agricultural research and extension. Considering the agricultural production potential of GAP Region, it is obvious that there is a need to follow a strategy which based on sustainable use of natural resources due to its future vital role in food security regarding its location.

Topography Climate and Land Use

The topography of GAP Region can be subdivided into two main units, the uplands, and the plains. The uplands extend southwards from the southeastern Taurus Mountains. They consist of high, deeply incised mountains around the perimeter of the GAP Region; mountains blocks, dissected plains, and lava uplands are the characteristics. The plains occurred to the south of the Region and extend through Syria and Iraq. These mainly lie between 400,000-550,000 m above sea level.

The climate of the Region is characterized by dry, hot summers and mild to cold, wet winter. Mean annual rainfall decreases from over 1,200 mm in the north to 311 mm in the south. Mean monthly rainfall is very low during June and September and reaches a maximum in December and January, with a high degree of inter-annual and intra-annual variability. There is a strong difference between north and south. Frost, especially in the north, occurs from the end of November to February or March. Mean annual evapotranspiration rates are 1164 mm in north GAP and 1257 mm in south GAP, with highest mean monthly rates in July 211 mm in the north GAP and 224 mm in the south GAP.

GAP Region's total surface area is 75,000 km² of which 42.2% is arable land (36% rainfed), 33.3% range, and 20.5% forest, and bush. Average gradient over 94% of total surface area is less than 12%. GAP Region has 3.2 M ha agricultural lands. It covers about 10% of cultivable agricultural land of Turkey. In the Euphrates and Tigris basins, the area brought under irrigation has reached 183,080 ha in 1998. About 11% of GAP's irrigation projects have been completed. When all the projects in the GAP will have been completed, more than half of the agricultural land, 1.7 M ha, can be irrigated. This amount is about 20% of the irrigable agricultural land of Turkey (Anon., 1996).

Population and Employment in Agriculture

There is evidence of human settlements in the GAP Region since Neolithic age (7000-5000 BC). However, settlement begun in the earnest during the old Bronze Age (2500-1900 BC) with the Proto-Hittites. Since then, numerous civilizations lived in the area, including the Assyrians, Sumerians, Persians, Seleucids, Romans, Arabs, Seljuk Turks, and Ottomans. According to the 1997 Population Census, the GAP Region accounts for 9.75% of the population of the country with 6,129,041 habitants. It is estimated that the population of the region will reach 9.2 M in 2005.

With the increases of agricultural output, the demand for inputs increases, resulting in additional employment and higher returns. The demand for employment in agriculture the GAP region projected to increases by 160% after completing the whole Project, as the agricultural production that highly depends on labor more than mechanization.

There is a high rate of urbanization in the Region. The ratio of the urban population to the total population has increased rapidly. While the urbanization ratio was 47.6% in 1985 and reached 56% in 1990 (Anon., 1997a), it was 64% in 1997. Of the 6.2 M people in GAP, 645% live in the country and 36% in villages; corresponding figures for Turkey's 63 M people are 65%, and 35%.

As the technology of the agricultural mechanization level is low, agricultural activities depend highly on labor. This is why the agricultural sector has also an importance in order to contribution to employment. The rate of the population, 12-year old and over is Adiyaman (79%), Diyarbakir (69%), Gaziantep (50%), Mardin (74%), Siirt (72%), Sanliurfa (71), Batman (70%), Sirnak (68%), and GAP (67%).

Agricultural Income

The value of total agricultural output of the GAP Region is estimated as equivalent to US \$120 M for the year 1997. Considering that this value was about US \$31.5 M before irrigation and that the area already under irrigation constitutes a rather small part in the projected 1.7 M ha ultimately to be brought under irrigation, the economic contribution to be realized with the completion of the project seems tremendous indeed (Anon., 1998).

The contribution of the GAP Region to the agricultural GNP is 9.76% in 1996. The agricultural income rates of the provinces in the GAP Region Adiyaman (6.7%), Diyarbakir (23%), Gaziantep (15%), Mardin (10%), Siirt (3%), Sanliurfa (27%), Batman (4.2%), Sirnak (3.6%), and Kilis (6.8%).

Agricultural Production

The main important agricultural crops' sown area and production are given in Table 1. The production of lentil was started to produce as a second crop in 1980's. Turkey was the first among the lentil-producing countries. Starting from 1990 onwards, Turkey's lentil

production started to decrease. In 1997, lentil was produced in 409,123 ha area at the GAP Region, and total production was 403,093 tons. There are three main provinces for lentil production at the GAP Region; Sanliurfa (30%), Diyarbakir (30%) and Mardin (15%).

In 1996, cotton was produced in 265,228 ha and total production was about 300,808 tons at the GAP Region, 32% of Turkey's total production of cotton is in the GAP Region, while 50% of the total cotton production of the GAP Region, belongs to Sanliurfa. The other important provinces for cotton production are Diyarbakir (21.6%) and Mardin (9%).

Pistachio is one of the important crops for the Region. In 1997, the total number of pistachio trees at the GAP Region was 37,859,681, i.e., 86% of the total in Turkey. The main provinces for pistachio are Sanliurfa (61%) and Gaziantep (21%).

Wheat, which has a wide usage due to the traditional nutrition culture and habits of the GAP Region, has become an economically important crop in the last decades. The total production of the Region was 1,788,438 tons in 1997. The important provinces for pepper at the GAP Region are Sanliurfa (34%), and Diyarbakir (25%).

In 1997, maize was produced in 6,602 ha of land at the GAP Region and total production of the Region was 28,914 tons. The important provinces for maize production at the GAP Region are Sanliurfa (22.8%), Gaziantep (50%), Adiyaman (22%) and Diyarbakir (4%).

Animal production sector also has a potential, which should be improved, in the GAP Region. The present number of animals of the Region is given in the Table 3.

By the year 2010, the value of agricultural production in Turkey will increase five-fold. Nearly half of the increase in value of production will come from increases in quantity of production and little more than half comes from agricultural products, due to higher domestic demand and favorable international market conditions (Anon., 1992). Value of production in the GAP Region and Turkey are given in the Table 4.

The value of crop production in the GAP Region was 1.4 billion TL in 1988 and constituted 11% of total agricultural crop value in Turkey. In 2010 with the full realization of GAP, the value of crop production in the GAP Region is expected to increase by 4.6 times to 6.5 billion TL constituting 18% of the total value of crop production of Turkish agriculture. Over 60% of the increase in the value of GAP crop production will come from production increases and remaining 40% from price increases. Therefore, over next two decades GAP Region will account for nearly 20% of the increase in total Turkish value of crop production.

Table 1. Selected Crops' sown area and production (1997).

Crops	Area Sown ----ha----	Production ----ton----	Crops	Area Sown ----ha----	Production ----ton----
Wheat	1,148,088	1,788,438			
Barley	631,639	1,023,056	Tobacco	49,445	61,568
Corn	6,602	28,914	Potatoes	505	8,568
Millet	634	554	Onion	6,868	134,322
Rice	2,216	4,402	Garlic	1,344	10,942
Sunflower	7,877	7,581	Dry beans	3,656	1,903
Cotton	265,228	300,808	Lentil	409,123	403,093
Sugar beet	2,019	64,747	Vegetables	98,988	1,818,184

Table 2. Crop production in GAP Region and Turkey (1997).

Crops	GAP -----ton-----	Turkey -----ton-----	GAP in Turkey -----%-----	Crops	GAP -----ton-----	Turkey -----ton-----	GAP in Turkey -----%-----
Wheat	1,788,438	18,650,000	9.6	Cotton	277,397	831,672	33.3
Corn	28,914	2,080,000	1.3	Tobacco	61,568	286,414	21.5
Rice	4,402	165,000	2.6	Potatoes	8,568	5,100,000	0.2
Sunflower	7,581	900,000	0.8	Lentil	403,093	410,000	98.3
Soybean	311	40,000	0.8				

Table 3. Number of animals in the GAP Region (1997).

<u>Province</u>	<u>Sheep</u>	<u>Cattle</u>	<u>Hens</u>
	-----1000-----		
Adiyaman	266	88	81
Gaziantep	330	40	656
Diyarbakir	794	207	825
Mardin	294	51	327
Siirt	189	21	132
Sanliurfa	1,430	117	933
Batman	282	33	186
Sirnak	256	30	77
Kilis	68	3	108
GAP	3,909	590	3,524
Turkey	30,238	11,185	166,272
GAP in Turkey (%)	12.93	5.28	2.12

Table 4. Value of Agricultural Production in the GAP Region and Turkey.

<u>Year</u>	<u>Value of Production¹</u>			<u>Volume of Production²</u>		
	<u>Turkey Total</u>	<u>Turkey Crop</u>	<u>GAP Crop</u>	<u>Turkey Total</u>	<u>Turkey Crop</u>	<u>GAP Crop</u>
1988	16.43	12.56	1.40	16.43	12.56	1.40
1995	25.80	17.37	2.16	20.14	14.46	1.87
2000	36.78	22.81	3.08	24.30	16.99	2.44
2005	51.58	29.53	4.72	28.97	19.85	3.42
2010	75.84	40.31	6.49	33.80	22.68	4.03

	<u>Indices of Value</u>			<u>Indices of Volume</u>		
	<u>Turkey Total</u>	<u>Turkey Crop</u>	<u>GAP Crop</u>	<u>Turkey Total</u>	<u>Turkey Crop</u>	<u>GAP Crop</u>
1988	100	100	100	100	100	100
1995	157	138	154	115	115	134
200	224	182	220	135	135	174
2005	314	235	337	158	158	244
2010	462	321	464	181	181	288

¹(billion TL). ²(1988 prices-billion TL).

The agricultural production in the GAP Region is expected to register significant structural changes in the next two decades. With completion of the irrigation projects, the region is expected to move from a region dependent on the agricultural production of the rest of Turkey in 1988 to a region which is self sufficient in most products, and an exporter to the rest of Turkey in many products including corn, barley, chickpea, lentil, groundnut, soybean, cotton and fruits (Anon., 1992).

Agricultural Research Approach for GAP Region

The importance of agricultural research is strongly emphasized in the GAP Master Plan due to its considerable contribution to the yield increase in rural areas through income increase. As 1.7 M ha will be irrigated after completion the whole irrigation scheme, the farmers who are familiar with rainfed farming will have to change their attitude and farming methods. This means that the new crops will take place in agricultural production in the GAP Region. With the entrance of new

crops to the GAP Region, the farmers will be forced to use new technologies. Naturally, the new technologies will be tested before application. This requires agricultural research. In this context, the new crops appropriate to irrigated conditions and climate should be identified and advised accordingly. As mentioned earlier, this requires a series of agricultural research and time.

On the other hand, the agricultural research for rainfed areas is also very important as well as research for irrigated farming because the farmers in the rainfed areas especially need high quality seeds in order to increase their yield. The income disparities between irrigated and rainfed areas must be reduced by agricultural research activities for the rainfed areas. A total of 448 research projects have been implemented during 1966-1996 period in the GAP Region. These projects cover the following subjects; aquaculture, irrigation, ornament, agricultural economy, soil, plant protection, planting-yield-adaptation, fertilizing, livestock, breeding, mechanization, meteorology, vegetation, extension, environment, planting-harvest-processing, irrigation-yield, agricultural housing.

Ongoing Agricultural Sector Projects

At the present, there are several projects that are implemented in agricultural sector to ensure sustainable agricultural and rural development, income generation and productivity, farmers' training and implementation of new technologies. The principal project titles are:

- Regulation and Management of Water in Irrigation Canals and Methods and Technologies for Saving Water.
- Management, Operation and Maintenance of Irrigation Systems in the GAP Region.
- Agricultural Research and Development Project Package-Phase II.
- The Study on Agricultural Mechanization Needs in the GAP Region-Phase II.
- A forestation and Erosion Control.
- Introduction of New Irrigation Methods and Techniques.
- Sanliurfa-Harran Plains On-Farm and Village Development Project.
- Improving the Welfare of the People Living in Rainfed Agricultural Areas.
- Participatory Rural Development Project.
- Batman Small Ruminant Development Project.
- Sirnak Small Ruminant Contract Farming Project.
- Establishment of an Agricultural Research Center within GAP Framework.
- Sustainable Production of Forage, Feed and Small Ruminants in Selected Villages of the GAP Region.
- Improving Seed Production, Adaptation of New Cereal and Food Legume Varieties through Farmers' Participation.

The Agricultural Extension Approach

There are approximately 270,000 farms and 3.2 M ha of cultivable land of which 1.7 M ha will be irrigated in the GAP Region. The farmers who have irrigable land will have to learn many applications and technologies, which are introduced by the existing extension service. The farmers are not the only learners, but also the extension agents. Besides, the new farming techniques require purchasing power to be used by farmers.

The principal role of extension service is to transfer up-to-date, applicable and target-oriented information to farmers in an efficient way as possible. Although there are various extension systems, the common ground of all is, or should be, the transfer of necessary technology and information. As long as this is secured and farmers benefit from the extension service, it does not matter which system is used.

Since the GAP Region covers very large area, it is possible to see different farming methods, which are based on mostly cultural and traditional values. This is why it would be advisable to apply tailor-made extension methods and systems according to socio-cultural structure. This is defined as diversification of extension

systems. This can only be ensured provided that farmers' participation in extension programs at every stage, from decision-making to implementation as well as financial contribution. Hence, there can be different extension systems, which are acceptable by farmers, and which are flexible, dynamic, and applicable for different cases even in the same region.

It is obvious that the existing extension system in the GAP Region should be strengthened. For this reason, GAP-RDA has been implementing some supportive projects. These projects are mainly supporting and encouraging the farmers to involve them in the decision-making process. This is particularly seen in water management structures.

FOOD AND FEED PROSPECTS IN THE WANA REGION

West Asia /North Africa Region (WANA) extends from Morocco in the west to Pakistan and Afghanistan in the east, and from Turkey in the north to Ethiopia and Yemen in the south. In the region, there are 24 independent states.

WANA is the center of origin of wheat, barley, food and feed legumes, fat-tailed sheep, goats, and Arabian horse. It is characterized by high population growth, which is expected to reach 1 billion by the year 2020. Low and erratic rainfall, limited areas of arable land, continuously degrading range land, severely limited water resources, and existence of several economically important animal diseases such as rinderpest, foot-and-mouth disease, and brucellosis. These negative characteristics are highlighting the need for a sustainable agricultural development, a priority issue in the overall development strategy of the governments of the region.

Two recent studies (Somel, 1986; Nordblom and Shomo, 1997) by ICARDA's scientists clearly show, in the year 2000 and 2020, as either regional aggregates or countrywide, great amount of demand deficit and, with the exception of Turkey, a continuous decrease in self-sufficiency ratio for main agricultural commodities in the Region. For example, the grain gap, in 1995 was 35 M tons. If the rate of production growth can be sustained at 2% per year to the year 2020, (which is a remote possibility), the WANA grain gap will increase to 82 M t (El-Beltagy, 1997).

These findings clearly underline the formidable challenges waiting policy-makers and scientists of the region. The challenges will be to (i) sustain production growth while sustaining the natural-resource base, (ii) improve purchasing power of poor and middle class families, (iii) develop appropriate technologies for increasing land productivity, (iv) improve farm management practices, (v) conserve potentially useful genetic materials.

All these challenges, defined above, could only be successfully met through the concomitant development of four complementary efforts: generation of appropriate research strategies, development of appropriate technologies, strengthening of institutions and human

resource base, and regional and international cooperation for bringing resources and critical mass of research skill together.

CONCLUSION

Human-based development is the main aspect of the southeastern Anatolia Project. The natural resources are the pushing power of the project. It is extremely crucial to obtain sustainable benefits by optimal use of water and soil resources according to sustainable farming principles.

REFERENCES

- Anonymous. 1990. T.R.P.M. SPO. The Southeastern Anatolia Project Master Plan Report.
- Anonymous. 1992. T.R.P.M. GAP-RDA. Agricultural Commodities Marketing Survey Planning of Crop Pattern and Integration of Marketing and Crop Pattern Studies.
- Anonymous. 1993. T.R.P.M. GAP-RDA. GAP Regional Transportation and Infrastructure Development Study.
- Anonymous. 1996. T.R.P.M. GAP-RDA. Importance of GAP in Turkish and World Agriculture.
- Anonymous. 1997a. T.R.P.M. GAP-RDA. Social Action Plan.
- Anonymous. 1997b. T.R. SSI, GAP Province Statistics, 1950-1996.
- Anonymous. 1998. T.R.P.M. GAP-RDA. Latest State in Southeastern Anatolia Project July 1998.
- Somel, K. 1986. Food and Agriculture toward 2000 in WANA Region, ICARDA.
- Nordblom, T.L., and F. Shomo. 1995. Food and Feed Prospects to 2020 in the WANA. ICARDA, *Social Sci. Paper* No.2.
- El-Beltagy, A. 1997. West Asia and North Africa: A Regional Vision. ICARDA, Aleppo, Syria.

ÇATOM: New Model for Integrating Women in Development in the Southeastern Anatolia Project

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ABSTRACT

Republic of Turkey Prime Ministry Southeastern Anatolia Project Regional Development Administration (GAP-RDA) has identified and started a project since 1991 to improve the status of women in the GAP region. In the framework of this project, Multi-Purpose Community Centers (ÇATOMs) in which the training programs for women and young girls on literacy, health, family planning, maternal and child health, nutrition, home economy, income-generating activities have been implemented, and social and culture activities have been organized, and established in squatter settlement and central villages since 1995. Participatory, holistic, and integrated approaches are the basic policy of all ÇATOMs. The contexts of the basic activities carried out in the center are being determined by the participation of the target groups; their participation and contribution are essential in the applications. In this paper, the process of project implementation and the outcomes of the project are presented.

INTRODUCTION

Today, many specialists working in development fields share the view that development plans, programs and projects still neglect the role and importance of women. Yet, it is widely known that women, today and in the past alike, take equal or even heavier burdens and responsibilities than men in almost every field of family and community life though the weight of burdens and responsibilities may vary with respect to the level of development and structure of culture.

It was first in the 1970s that the position of women in the process of development found a firm place in the agenda. Today, the concept *women and development* covers such headings as women's role in the process of development and participation to work force; their status in terms of access to modern institutions (i.e., extension, training, credit, health, social services, etc.); possibilities of enhancing their control on the outcomes of their own labor and daily lives; which add up to the question of massive participation to the process of development.

In the 1980s, during which equalitarian policies determined project approaches, projects, plans, and implementation were all under the influence of the outcomes of struggles waged in various fields, including gender. The basic problem is defined as gender imbalance, which is assumed to be originating from both

gender structuring within the family and from the nature of relations established with the market in the process of development. In this context, the approaches of gender-balanced development aim at the creation of institutions and processes which will empower women for participation, mobility, and initiative taking (Ertürk, 1995). All these developments were reflected in Turkey as well.

The place and functions of women in the process of development were considered, in 1991, as an important parameter by GAP as an integrated and human centered regional development project. At the initial stage, there were investigations and surveys to describe the tendencies, ideas, problems, and social relations of women in the region, which ended up with a model developed to make them active actors in development. This is the model of multi-purpose community centers (ÇATOM).

WHAT IS SOUTHEASTERN ANATOLIA PROJECT?

In the southeastern part of Turkey, the area covered by the administrative provinces of Adıyaman, Batman, Gaziantep, Kilis, Mardin, Siirt, Van, Şırnak, and Diyarbakır is defined as the "GAP Region". The Southeastern Anatolia Project, or GAP in short, is a multi-sectoral and integrated regional development effort based on the principle of sustainability. Aiming at the full scale socio-economic development of the region, the Project involves the construction of dams, hydraulic power plants and irrigation schemes on and around the rivers Euphrates and Tigris, as well as investments in the fields of rural and urban infrastructure, agriculture, transportation, industry, health, education, housing, tourism and various other sectors. The Project consists of 13 sub-projects, seven of which are related to the Euphrates Basin and six to the Tigris. As such, the Project envisages the construction of 22 dams and 19 hydraulic power plants on both the Euphrates Tigris and their tributaries.

The ultimate goal of the Project is to minimize, in the medium term, development disparities existing between this specific region and other regions of the country, and eliminate such disparities altogether in the long term by raising the income level and living standards of the people of the Region. The basic strategy adopted for the achievement of this goal is the development of land, water and human resources of the region.

Social Dimension of GAP

All development projects entail conscious and planned interventions to existing social structures. Thus, they

have modifying and transforming effects on society. This is much more valid for the GAP as an integrated regional development project. It is natural, as it is the case for all development projects that the GAP will bring about some changes in the social structure of the region. Thus, the success of the Project in terms of attaining its original targets requires a penetrating knowledge and information on the existing social structure. This is essential for the design and implementation of sustainable development projects which are adopted and participated by people.

Considering this fact, the GAP Administration commissioned, in 1992 to 1994, a series of social studies to guide development efforts, identify the basic principles of development, mobilize community participation and to identify the ways of mitigating disparities and imbalances by integration of different sections of the society (i.e., women, nomadic tribes, the urban poor, youngsters, street children, small farmers and landless peasants) to the process of development.

These studies were conducted by non-governmental organizations and academics in line with the codes and principles of scientific objective research. Under these surveys, there were face-to-face interviews and questionnaires involving about 10,000 people (both sexes, young people, dwellers of rural and urban settlements and *gecekondul*). In light of the findings of these surveys, the *GAP Social Action Plan* was prepared to form a general framework for Project activities aiming at sustainable, equitable, and participatory social development.

Women's Status in the Social Relations Network

Women in Rural Areas

Taking a look at the region specific social development indicators, one can easily observe that the women of the region lag far behind the standards of a modern society. The women of the region are under the negative impacts of both traditional social stratification and gender imbalances, where their roles and status are determined socially. This situation becomes more apparent in the rural area. In the rural parts of the Region, women participate much lesser to decision-making and household management, benefit less from basic health and education services, face difficulty in having access to sources of income, and also reap the benefits of modern technology far behind men. Lack of land or having only a small plot, prevalence of small family enterprises, and high fertility further increases the work burden of women. In addition to routine farming works, other domestic activities of women include conserving food for winter, making bread (takes 2 hours a day), fetching water (fetching drinking water is a troublesome chore, especially in remote mountain villages, taking about 3 to 4 hours a day), washing laundry, fetching firewood, and attending children.

Education level among rural women is very low. The rate of literacy among rural women is about 25%. The low level of education decreases the accessibility of women to public social services and participation to public domain. As the findings of the women survey (1994) show, women get married at too early at age (17). In fact, 37% of females get married under age 15; early marriage naturally increases the number of children. The average number of children per married women is 5.1. Women's participation to decision-making is extremely limited. For example, only 12.4% of married women had made marriage on their own will. The existing status of women in the region is of course not only the outcome of their personal characteristics but come the result of their socio-cultural environment.

Women in Urban Areas

Although the communities in the region have already stepped up into the process of modernization, some traditional structures still persist and influence daily life. In this overall structure, women are particularly affected by gender imbalances. While rural women have an active role in production, it is not the case for urban women, for reasons such as low level of education and skills and somewhat adverse market conditions. However, the changing economic and social structure of the Region and the processes of industrialization and urbanization brought along by the GAP create non-agricultural employment opportunities for women.

In the urban settlements of the region and in *gecekondul* (urban poor neighborhood), women and young girls in particular are employed in some marginal works which are of contingent nature such as hand weaving, embroidery, machine knitting, tailoring, etc. In other words, women living in urban poor neighborhoods are engaged in low status and labor-intensive works. Women's working out of home and contributing to household income are generally accepted by men who gradually develop affirmative behavior on this issue. The level of education among urban women is relatively higher than rural women. The rate of literacy is about 56%.

In spite of the fact that there is trend toward democratic participation to decision-making in family in urban areas, the hierarchical structure of decision-making is still dominant (71%). As far as spending related to household matters is concerned, women's role is considerable in both decision-making and practice. However, the main economic and financial decisions are at the discretion of men.

According to the GAP women's survey (1994), more than a half of urban women (64%) got married at the age interval 15-19. The average age at first marriage is 17.5. For the majority of women (71%), the decision on marriage was taken by considering their opinion as well. As it is the case in rural areas too, the first years of urban marriage gives too many children. This is because a male child in particular is extremely important for families. The average number of children per urban family is 3.5.

Why Women are Important in Development?

In the region where the GAP is introducing social change and thus social mobility, there are also significant changes in the status and role of women and men in intra-family relations. Surveys in the region indicate that there is an accelerated transition from extended (18%) to nuclear family (65%). It is widely recognized that the nuclear family in developed and developing societies is divorced of a wide network of kinship ties which leads to the rationalization of the behavior of nuclear family members and a change in the traditional roles of men and women.

Within the framework of gender roles, women in each specific communities or area have peculiar patterns of relationship with men, with the other members of the community, and with each other. These peculiarities are culturally determined. Further, communities assign some functions and roles to each individual. There are considerable discrepancies in what communities assign as roles and functions and what individuals perceive as their roles and functions. Thus, gender roles are specifically related to culture and values.

The weight of gender discrimination and women's position at the back stage prevents their move to a status where they can also control and manage resources beyond production *per se*. Nevertheless, one should not infer from this reality that women contribute less than men to the welfare and well being of their families, communities, and countries. Observations that gender discrimination increasingly plays against women, especially in the developing countries have made the issue of the role and function of women in development a more urgent one (Saltyk, 1998): Women and men do not equitably reap the benefits of development, women form the majority in the universal ranks of the "poorest of the poor", and the share of women in the total number of poor rapidly rise, leading to the "feminization of poverty".

One can speak of two rationalities for addressing gender issues, specifically in development programs. The first one is obvious. If women, constituting the half of the population, are neglected, a potential will be left idle and it will be impossible to fully reach the targets of development. The second one is, as revealed by various surveys, related to the fact that any investment in women has more immediate effects on the welfare of children and families.

ÇATOM: INTEGRATING WOMEN IN DEVELOPMENT

Women-focused "Multi-Purpose Community Centers" is one of the participatory and integrated schemes of the GAP which originated from a search for alternatives in gender balanced development and social-cultural change under the light of the findings of the survey "*Women's Status in the GAP Region and Their Integration to the Process of Development*". ÇATOM were phased in, starting from November 1995. They

are, as the name suggests, community-based Centers established in the urban poor neighborhoods inhabited mostly by those who have migrated from rural areas, and rural settlements of a somewhat central location where women are marginalized. In ÇATOM, where activities are tailored in an integrated, participatory, and sustainable approach, the direct target groups of programs are women and young girls of age 14 to 50. At these Centers, where flexible and modular programs are adopted, the overall aim is to raise the status of women, to contribute to gender balanced and sustainable human development, and to develop relevant and replicable models geared to these aims. The following are what ÇATOM is doing or planning to do in line:

1. While used to be "invisible", women are made "visible" (*Resolution of the 1985 UN Conference for the Elimination of Discrimination Against Women*). Furthermore, the ÇATOM programs particularly "favor" women and are in this sense engaged in "positive discrimination."
2. Support is given for the more effective and comprehensive extension of health, and education services which are among the fundamental tasks of the State.
3. ÇATOM helps create an environment of healthier and fruitful dialogue between the most needy sections of the society and the State and voluntary organizations, thus consolidating the foundations of a human-centered, peaceful and democratic society.
4. ÇATOM are established by grassroots movements and with local support and managed by local women and young girls who have potential for pioneering and learning. In this sense ÇATOM are schools which train the future female development specialists.

The programs and projects implemented at ÇATOM as instruments of intervention target the following in order to:

- Raise the rate of literacy.
- Build basic information and awareness on health issues.
- Generate income by building productive skills.
- Teach the ways of balanced nutrition and home economics.
- Supply practical information on childcare and training.
- Develop skills which can generate income.
- Make them (women and young girls) aware of their own problems and those of their community.
- Enhance their capacity to express themselves.
- Enhance their self-confidence by encouraging organized and collective action.
- Improve their access to public services.

As can be understood from the topics listed above, all activities under the ÇATOM are planned and carried out in their integrity, including the dimensions of education, health, guidance, production, and organization.

Operation and Organization of ÇATOM

The activities of ÇATOM are planned and carried out in cooperation with relevant governmental and non-governmental organizations and with the participation of target groups. Programs are tailored by considering specific local conditions and needs of target groups.

Each ÇATOM is managed by high-school graduated local young girls and women who are subject to periodic training. They are in charge of conducting surveys to derive more information about their communities, guiding women, planning programs, and monitoring implementation. Each ÇATOM also has a ÇATOM Committee consisting of three to five persons elected from ÇATOM's participants by the participants themselves. The Committee is also present in the management of ÇATOM on behalf of all participants. This scheme is expected to contribute to managerial-capacity building among local women.

ÇATOM basically adopts flexible and modular programs. Activities are carried out under three general headings: social programs, income-generating programs, and health programs. Each participant has a chance to attend all three programs, and in fact, they are encouraged to do so. It should be added that there are also social and cultural activities accompanying these programs. In addition, there are mobile health cabins working under ÇATOM. These mobile units are used to outreach those who have difficulty with access to health services and health training. As of mid-1999, there are 21 active ÇATOMs in the region. Their coverage is about 25,000 females.

ÇATOM Social Impact Assessment

The GAP Administration and the Development Foundation of Turkey (TKV) has conducted a social impact assessment study (SIA) from August to October in 1998, covering eight ÇATOM which were active for at least one year (ÇATOMs in the central districts, neighborhoods, and villages of Panyurfa, Mardin, Siirt, and Batman). This study concentrated on qualitative impact rather than quantitative outputs.

Techniques Used

Data to form the basis of SIA were obtained by using *participatory and rapid appraisal techniques*. Face-to-face communication, large meetings, visits to relevant governmental organizations, focus group meetings, brainstorming, were used. Interviews covered the following groups:

- Present ÇATOM attendants.
- Those who have completed their programs.
- Families of ÇATOM participants.
- Nearby shopkeepers. Young men and other persons or groups.
- Neighborhood leaders and village headmen in settlements where the ÇATOM are active.
- The ÇATOM field personnel.

- Trainers of social and income-generating programs and health personnel conducting health programs and mobile health services.
- Governmental organizations such as provincial and district governorate and province-district directorates which extend technical, financial, and administrative and expertise support in the conduct of programs (i.e., in education, health, agriculture and social services).

Objectives and Expectations

The basic aim of SIA include the review of the validity of approaches and methods of ÇATOM programs; identification of positive and negative effects of ÇATOM activities on various parties (i.e., individuals, families, communities, governmental and non-governmental organizations); and collection of relevant information and data for the development of future programs. To attain this objective, SIA focused on the following topics and questions:

- To what extent the central activities could respond to the expectations and priorities of the target group?
- In which programs the target group was relatively more interested?
- Did programs lead to a change in the behavior and attitudes of participants and of other family and community members through participants?
- To what extent information gained in ÇATOM activities was used in daily practical life?
- What kind of impact did the existence of ÇATOM create on participants, trainers, communities, service units, and governmental organizations?
- In places where ÇATOM are active, was there a relative rise in local demand for public services? Did other organizations adopt ÇATOM as a model?
- Were the expectations of the target group and existing financial, material and human resources properly considered while starting ÇATOM and preparing its programs?
- Did various groups take part in the processes of programming and decision-making as expected?
- Are the management and organization of the ÇATOM as efficient as planned or expected?
- To what extent the government support was available and in which areas?

Impact on Stakeholders

Of the eight ÇATOM covered by the assessment study, six are at provincial Centers, one is at a district center and one is in a village. The majority of their target groups consist of resource poor women and young girls. At places where ÇATOM are establish, there is relatively more difficult access to health and education services. In urban settlements where there are ÇATOM, target groups either cannot use modern urban facilities

or do so only to a limited extent. The basic reasons are as follows:

Difficulties accompanying living conditions; in other words, very scarce time available after daily chores and child care.

Social pressure and tight control over young women and girls emanating from traditional relationship patterns and paternalistic family structures.

Timidness of women in particular, caused by difficult adaptation to urban life mainly stemming from lack of self confidence and illiteracy; hesitancy in getting to touch with modern urban institutions and facilities.

Impact on Participants

The impact of ÇATOM on their participants can be outlined under the following headings as depicted from observations and interviews conducted during the SIA.

Desires and Expectations

They raise hopes, and young girls in particularly strikingly express their wish to get educated, hold a profession, and gain their economic freedom.

Going out of Home

Young women and girls spend time out of their homes, and they want to be at ÇATOM to relieve themselves from the pressures of their communities.

Interaction and Communication

There is more suitable environment for interaction and communication; there is a growing network of social relationship among females of varying cultural backgrounds, and emergence of an environment of interaction between the participants and trainers.

Awareness About the Outer World

They become more aware of what is going on outside their immediate environments, learning different and new thing bring them in touch with outer world, and they get a chance to meet and contact people from other villages or neighborhoods.

Utilization of Urban Facilities

They have improved and easier access to urban services and institutions.

Building Self-confidence

Participants begin to build self-confidence, identify their problems and to ask for services, they can express themselves better and defend their rights, and they are more attentive and tidy about themselves and their immediate environments.

Building Awareness

Building awareness may sometimes lead to frustration, and awareness makes them more sensitive to family violence.

Family Relations

Self-confidence brings along a rise in status within family, and there is growing affection and tolerance within family.

Information-Skills/Income-Employment

Information obtained at ÇATOM is transferred into

daily life practices, though not much advanced, skills to use machinery, to get in touch with new technologies and to learn new things make them happier, and though limited for the time being, ÇATOM attendance gain some income and employment.

Impacts on Families

During interviews with families, the following headings were considered with respect to the impact of ÇATOM on families.

Participation

Intensity of household chores reduces attendance to ÇATOM, women prefer to send their daughters to ÇATOM rather than going there, and men prefer their daughters attend ÇATOM programs rather than their wives.

Behavior and Attitude

Behavior and attitude of young girls towards education change positively, and there is growing solidarity between young girls and their mothers.

Status

Other grow trust in ÇATOM attendants, their status in the family is enhanced.

Family Relations

ÇATOM attendance may cause family tensions. Young girls desire for change may generate unrest/dissatisfaction. Outer pressures affect families, and there is improvement in family relations. Young girls are proud of what they have learned

Outlook to ÇATOM

Families regard ÇATOM as Centers for counseling and guidance, and an environment of mutual trust is growing.

Impact on Field Personnel

The field personnel attend regular training programs organized jointly by the GAP Administration and TKV. They are also encouraged to take part in seminars, visits, study tours, etc. They gain information and experience through training programs and field practices and steps are being taken to train these people as *local development agents*.

The field personnel of ÇATOM have thus far took part in periodic training programs in Ankara, Panlyurfa, Siirt, Ad'yaman, Diyarbak'r, and Batman. These training programs covered such specific topics as "women and development", "reporting", "project development and planning", "participatory approaches", "ÇATOM philosophy", and "communication and getting information on communities". Information and concepts introduced in training activities are gradually internalized by participants, and this internalization finds reflection in daily talks, behavior, and reports. Monthly monitoring records of ÇATOM are kept and reported by the field personnel.

The field personnel are also invited to meetings and seminars organized by various national and international organizations. They strengthen their relationship with

the local people, governmental organizations and local non-governmental organizations in neighborhoods and villages where the ÇATOM are active on the occasion of various ceremonies, exhibitions, etc.

Non-governmental and international organizations visiting the field have always appreciated the quality and commitment of the field personnel in terms of their approach to the issues of development. ÇATOM activities have contributed to the accumulated experience, information, and skills of the field personnel which made them more capable of discussing matters with the people and developing relevant suggestions. In short, the field personnel played a very positive role in establishing a bridge between the GAP and local people.

Impacts on Trainers

The following are some common points in the assessment of the impact of ÇATOM on trainers:

- Trainers who find an opportunity to work in an informal environment state that they have joined with high expectations and that they are satisfied to conduct their work in an atmosphere of mutual understanding and trust. The change-taking place gives motivation to trainers. The enthusiasm of participants mobilizes them.
- The specific problems of young women and girls may generate psychological problems of serious dimensions as well as physiological ones. Those who participate in ÇATOM's health training programs consult to doctors or nurses on their special health problems and ask for their help.
- Trainers, too, build self-confidence and an extrovert personality mainly as a result of flexible and modular programs.
- About a half of the trainers, take part for the first time at the planning and implementation stages of a project.
- The use by trainers of such communication techniques as calling participants by their names, showing interest in their personal problems and house-visits improve their relationship with the target group and improve the quality of programs.
- The ÇATOM could find their way to grassroots. If there are more ÇATOM and if they are supported, this will mitigate the service burden of governmental organizations, particularly in the field of health.
- The project was successful in raising the rates of literacy.
- Expected success could not be reached in income-generating programs.
- Such activities as drama shows, sightseeing tours, concerts, and celebrations on special days have contributed to social integration among various groups.
- Supply of such materials or inputs as cloth, stationery, etc. To very poor participants in some programs contributed to the success of the program concerned.
- Existence of a female physician and a health scheme were important factors in attracting people to ÇATOM and enhancing participation.
- It was a positive point too to extend health training and services to surrounding neighborhoods and villages through mobile health cabins.

General Impact

The ÇATOM have become the center of attention and helped build awareness of the problems of women. The ÇATOM are frequently visited by governmental, non-governmental, international, and private organizations, and their activities find ample place in the local and national media.

As such, the ÇATOM may generate effects which are not originally planned or envisaged. For example, the very existence of ÇATOM has had an impact on some voluntary women's organizations and humanitarian aid foundations, motivating them to consider the question "*How can we collaborate and in which areas?*" The 8th of March World Women Day (1997) was celebrated in the Sađlýk village of Panlýýurfa in a very lively atmosphere with the participation of the local people and visitors. In 1998, again on the occasion of the World Women Day, a festival was organized in Dargeçit jointly by the Mother Culture Cooperative, TKV, Governorate, and the GAP Administration. Items produced by women were exhibited at the ÇATOM building in Ankara and in Panilurfa. The photo exhibition by AFSAD "*GAP and Women*" was visited by many.

The field personnel of ÇATOM were invited to meetings organized by various governmental, non-governmental, and international organizations. These invitations may be taken as an indicator of importance assigned by others to ÇATOM in terms of seeking alternative solutions to the problems of women and making women more visible.

Overall Assessment of ÇATOM: Findings

What follows is the summary of the basic findings of the assessment made on individual ÇATOM units.

Impact on Governmental Organizations and Agencies

During the SIA study, there were contacts with Governmental organizations to evaluate their findings and suggestions. In this context, a general assessment was made as to the findings and evaluation of these organizations and agencies in regard to each ÇATOM. The following are the results of this assessment:

- The ÇATOM is a well thought out and relevant project. Important benefits are expected, if conducted properly.
- The target group of the ÇATOM consists of poor and illiterate women with a lot of children.

Target People and Participation

- The ÇATOM have reached the poor sections constituting the bottom layers of the social pyramid.
- While young girls form a majority in programs in general, literacy and health programs have also reached middle-aged married women.
- Visits and training activities covering the families of ÇATOM participants and continuous visits to ÇATOM by families and ex-participants contribute to the legitimacy of this institution and thus encourage further participation.

Social Programs

- Programs and literacy courses in particular helped participants build confidence, express themselves better, and become more sociable.
- Health training and cutting-sewing courses have had important impact. Some participants transferred their new information to other family members and channeled them to health institutions.

Income Generating Programs

- Monetary returns from income generating activities were not satisfactory and there was low rate of participation to such programs mainly for this reason.
- However, the continuation of skill development programs by taking order from outside and marketing of ÇATOM products by calling at shops are significant events in terms of making women more outward looking.
- The performance was not satisfactory in terms of developing programs which considered local conditions and marketability of items produced.

Polyclinic and Mobile Health Services

- Delivery of polyclinic services by a female doctor and a nurse in ÇATOM was a factor facilitating the acceptance of ÇATOM. However, difficulties in finding medical personnel for ÇATOM reduced the efficiency of health services.
- Urban poor neighborhoods and rural areas were served by the mobile health unit, and people in rural areas were taken to health Centers when necessary.

The Model

- The ÇATOM acted as an intermediary for the poor sections of the population who had difficulty in having access to social services. New organizational alternatives and more humane approaches were displayed during these efforts
- A flexible structure devoid of red tape and warm human relations enhance people's interest in ÇATOM's programs and contributed to the success of programs
- The ÇATOM have now assumed the character of

"women's houses", where they further their communication and solidarity in a conducive social atmosphere. This is quite a significant dynamic in terms of social change.

- Participants are affected by the environment surrounding them; they are now more ready and willing to change themselves in social, cultural, and economic terms.

Organization

- First steps have been taken to involve participants in the management of CATOM affairs and to establish CATOM committees which will contribute to local capacity building.

General Impact

- Frequent visits to ÇATOM by local, national, and international organizations, and the space that the ÇATOM have enjoyed in the media, have contributed to raising awareness about the problems of the region.
- With ÇATOM, there is growing interest in the problems of the rural people in particular.
- Gender issues and the role of women in development are being discussed more in the public.
- Also, the problems of women living in urban poor neighborhoods are discussed more widely.
- There was success in making use of the mass media and grounds were laid for cooperation with non-governmental organizations.
- Poor women living in rural areas and urban poor neighborhoods were invited to various meetings and seminars to give them the floor to speak out their problems.
- Women's organizations and voluntary groups have started to visit the region and seek solutions to various problems.
- With the activities of the ÇATOM, it was understood better that the training of women is a need in terms of human rights and also a factor which contributed to economic and social development.

CONCLUSIONS

The female, who is always identified with respect to or in connection with a man, faces greater difficulties than men in her efforts for building her personality and becoming an individual. In the GAP Region, where gender-based social status discrepancies are more pronounced, the female faces these problems even more.

The GAP leads to a change in the status and place of women, in both family and community, along with overall changes in economic, social, and cultural spheres. The possibility of giving a positive character to these changes depends upon the adoption and materialization of three basic principles in the development and implementation of projects related to women. These are *participation*, *sustainability*, and *integration*.

The ÇATOM model was developed in this context to improve the status of women and ensure their integration with the process of development. *The ÇATOM turned out to be Centers of dynamism in the rural or urban settlements where they exist.* It may not be sound to evaluate this model in terms of the sheer numbers of females who benefit from training or how much they earn, but *the model has been adopted by the people.* In this model, women are present in a group which is totally different from what they have used to know and they build confidence in themselves as a part of a totally different network of communication formed by other participants and trainers.

The SIA for the ÇATOM has revealed some important qualitative changes which are difficult to put in quantified terms. According to the results of the SIA, the ÇATOM is becoming *a center of attraction, with a flexible and informal approach*, and women start to seek solution to many of their problems through ÇATOM units. They become aware that they are in fact free individuals and start to change what is given with their enhanced awareness. In other words, their inner motivations are rising. As important all these is the fact that the approach of other organizations change as well. This gives the possibility of strengthening the relationship between formal organizations and institutions and the people at large.

The ÇATOM implementations have shown that integrated and participatory development models will contribute to sustainability of development programs, and empower local women. It has been learnt from this model that cooperation and coordination among various organization, improvement, and usage of local capacity, holistic approach, and participation of stakeholders to

planning and implementation, increase the effectiveness of projects to empower women.

REFERENCES

- Ertürk, Y. 1995. Gender differentiation and equality in sustainable development. Seminar on Sustainable Development and Southeastern Anatolia Project", 27-29 March 1995, İvanlıyurfa (unpublished).
- GAP Regional Development Administration (GAP - RDA). 1993. Trends of Social Change in the GAP Region, Chamber of Agricultural Engineers, Ankara.
- GAP Regional Development Administration (GAP - RDA). 1994. Status of Women in the GAP Region and Their Integration to the Process of Development, Development Foundation of Turkey (TKV), Ankara.
- GAP Regional Development Administration (GAP - RDA). 1994a. Population Movements in the GAP Region, Department of Sociology, METU, Ankara.
- GAP Regional Development Administration (GAP - RDA). 1994b. Employment and Re-Settlement in Areas to Remain Under the Dam Lakes of the GAP Region, Sociology Association, Ankara.
- GAP Regional Development Administration (GAP - RDA). 1994c. Employment and Re-Settlement in Areas to Remain UGAP - RDA, 1995. The GAP Social Action Plan.
- GAP Regional Development Administration (GAP - RDA). 1999. ÇATOM Social Impact Assessment, GAP - RDA/TKV, Ankara (in print).
- Saltik, A. 1998. Notes from the training seminar "Participation and Women in Development" to the ÇATOM field personnel. Batman, Turkey.

Geo-Statistical Analysis and GIS in Measuring the Sustainability in El-Hammam Area, Egypt

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ABSTRACT

One of the most important indicators that illustrate the success of the sustainability in the newly reclaimed lands in Egypt is the increase in stabilization. In this study, a set of villages represents a small part of Nuhariya region and known as El Hammam zone will be monitored as one cluster. This study depends on the use of GIS for the correlation between the geo-statistical analysis and the analytical approaches. The effective soil depth, EC, available moisture content, and altitude data of the different villages have been used to determine their impact on community stability, agricultural production, and economic social status as indicators of sustainability. Our analysis of the above-mentioned aspects, with emphasis on their availability and efficiency, will be used to interpret the rate of stability in the different villages and identify factors promoting or suppressing the sustainability of these communities. The decision-makers at local and regional levels can use these geo-information products in planning sustainable land management and sustainable development.

INTRODUCTION

Egypt most essential target by the beginning of the 21st century is to achieve its dream of leaving the narrow Valley and moving towards the wider Egypt, especially after the population in the Nile Valley has reached its peak. By the beginning of the 20th century, the cultivated area was 4.7 million (M) feddan (Feddan = 4200 m²); the inhabited area was 6.6 M feddan, and Egypt's population was 11.2 M people. Hence, the individual's share of the land was 0.4 feddan by the middle of this century, the cultivated area was 5.2 M feddan, and the inhabited area was 7.3 M fed. Egypt's population was 19 M people, and hence, the individual's share of the cultivated land became 0.3 feddan and from the inhabited area reached 0.4 feddan. By the end of this century, the cultivated area reached 7.8 M fed, the inhabited area reached 12.5 M fed, and the population reached 62 M people. Hence, the individual's share from the cultivated land lessened to 0.13 fed from the inhabited area reached 0.2 feddan.

On one hand, there is continuous increase in the cultivated land and the inhabited area; on the other hand, the individual's share is also continuously decreasing. Accordingly, moving expanding to the desert from the Old Valley is not merely a choice, but it is an essential condition for life to go on for the present

and future generations. The Government's current objectives are directed towards establishing new urban and rural communities in which the Egyptian investors, universities, and the institutes' graduates can reside. Such an objective represents a very essential and courageous solution to the development movement in Egypt.

El Hammam area is of about 34,502 feddan. It represents one of the newly reclaimed areas in the west of the Nile Delta. It is divided into two zones each of six villages distributed over 5457 settlers as part of national project for graduates' allocation, (Fig. 1). In this current study, the effective soil depth, EC, available moisture content and altitude data of the different villages have been used to determine their impact on community stability, while the agricultural production and economic social status as well were used as indicators of sustainability. The available moisture content is expressed as drought classes after, Erian et al., (1997), since the area is in torric climate and under intervals of irrigation.

MATERIALS AND METHODS

The effective soil depths, EC, drought, and altitude data of 526 points were observed from the field in a grid system with spacing of 1000 meters. The integrated land and watershed management system ILWIS developed in ITC, (Version 2.2), has been used as the main software for this study. The system provides its users with state-of-the-art data gathering, data input, data storage, data manipulation, analysis, and data output capability by integrating conventional GIS.

Ancillary Information

The following maps were used to fulfill this purpose:

- The topographic maps of the area sheets NH35-K5b "Alam Musaylikh", NH35L-5d "El Hammam", NH35-L6a "Alam al Jataa", NH35L-6b "Jabal Khashm al Qaud", NH35L-6c "Burj al Arab", NH35L-6d "Iking Maryut", scale 1:50,000 produced by the Egyptian General Survey Authority (1992).
- The geological map of Egypt, scale 1: 2,000,000 produced by the Ministry of Industry and Mineral Resources (1981).
- The soil map of the area, after Erian et al., (1999).
- The uncultivated land unit within El Hammam area, after Erian et al., (1999). This produced from the maximum likelihood classification (MLH) on the false color composite obtained for the TM bands 5, 4, and 3.

Methodology

The rating values used, after were Erian et al., (1991 and 1997). The ILWIS (2.2), ordinary Kriging algorithm, using of the semivariogram parameters after Stein (1998), has been used as the main technique for geo-statistical analysis. The geo-statistical analysis is a two-step-procedure involving the calculation of the experimental semivariogram and fitting a model, and interpolation to study the spatial variability of soil properties. The flow chart of the recommended framework to fulfill the objective of the study as modified after, Erian et al., (1999).

RESULTS AND DISCUSSION

Field Observations

Two types of data about the effective soil depth, EC, available moisture content, and altitude were investigated with a total of 526 observations. The first was the observed data from the field in a grid system with spacing distance of 1000 meters representing the different mapping units based on aerial photo-interpretation. The second type used the information from the satellite image and spectral classification map to add some observations to the edges of the area. The location of the observation points is presented in Fig. 2.

Interpolating using Ordinary Kriging

Semivariograms were calculated and variogram models were fitted using nonlinear regression. The best variogram model for the study area. The effective depths EC, available moisture content, and altitude of 526 observations were interpolated separately using the ordinary Kriging. The result of the interpolated map was compared with the uncultivated area of the spectral classification, after Erian et al.,(1999), for acceptability.

The classification of the interpolated maps were rated in five classes, (after Erian, 1991). The total areas of the rated land quality classes are shown in Table 1.

Crossing

The crossing technique was applied in the following order to the rated maps. Effective soil depth, EC, drought, and altitude using ILWIS (2.2), GIS capabilities, and presented in Table 2. According to Erian et al., (1999), the produced capability map scale is suitable for the village level survey interpretation. The resulting scale is a function to the minimum mappable area of the produced map. Elbersen (1985), identified that if the minimum mappable area is of about 1.56 ha (= 3.7 feddan), the publication scale can reach 1: 25.000 representing the 2nd order, which corresponds to the detailed soil survey level. Such a map could be successfully used for the soil survey interpretation on the village level.

The resulted units of the were grouped into three main groups where the Group 1 represents the soils with the minimum limitations (Class 1 and 2), Group 2 represents the marginal level for limitations (Class 3) and the last group represents the severe limitations (Class 4 and 5) as shown in Table 3. The resulting map were crossed with the villages' map.

Sustainability

The information about the settling, poverty, illiteracy, population density, availability of active community development association, income of other activities rather than agriculture, and wheat production is presented in Table 5 after SIDES (1999). This information has been rated after Erian (1996) and (1997) and the could be summarized as follows:

The total annual income per person in the studied area is below the poverty line. The settlement percentage is less than 32% in all villages, except village Mostafa Ismail which reached 65%. The wheat production in comparison with the highest production of the area is less than 60% in most villages. Also, it corresponds to the critical limitation of the area. The proportion of illiterate people is exceeding 24%. The majority

Table 1. Area calculated for four variables in El Hammam Zones.

Variable	Classes	Area Feddan	Variable	Classes	Area Feddan
Effective soil depths (cm)	Rock out crop (D5)	3494	Altitude (meters)	C1: < 50m (C1)	19,118
	Shallow soils (D4)	5705		C2: 50 - 52.5 m (C2)	5761
	Moderate deep soil (D3)	7947		C3: 52.5 - 55 m (C3)	2737
	Deep soils (D2)	10,382		C4: 55 - 57.5 m (C4)	2029
	Very Deep S. (D1)	6974		C5: 57.5 - 60 m (C5)	1705
	Total	34,502		C6: > 60 m (C6)	3152
				Total	34,502
Moisture available water content (mm)	C1: > 160 mm (M1)	291	EC Value (dS/m)	Non S. Soil (S1)	-
	C2: 120 - 160 mm (M2)	5820		Slightly S. Soil (S2)	752
	C3: 80 - 120 mm (M3)	8935		Moderate S. S (S3)	15,170
	C4: 40 - 80 mm (M2)	9676		Strong S.S. (S4)	18,572
	C5: < 40 mm (M5)	9780		Very St. S .S (S5)	8
	Total	34,502		Total	34,502

are feminine illiterates. The general illiteracy percentages correspond to the general figures of illiteracy in Egypt. The study of the income of other activities rather than agriculture could illustrate the economic stability. In most villages, it is less than 35% and only on Villages 23 and 22, it reached about 45%. The benefits of the Community Development Associations activities are in a very low level due to the fragile social institutional activities. In general, all villages could be considered in critical status and closely related to the critical soil limitation of the area.

REFERENCES

- Elbersen, G.W.W. 1985. Soil Survey Methodology and Specification. ITC lecture note, K5 (SOL 27), Enschede, The Netherlands.
- Egyptian General Survey Authority. 1992. The topographic maps sheets NH35-K5b "Alam Musaylikh", NH35L-5d "El Hammam", NH35-L6a "Alam al Jataa", NH35L-6b "Jabal Khashm al Qaud", NH35L-6c "Burj al Arab", NH35L-6d "Iking Maryut", and Scale 1: 50,000.

Table 2. The results of grouping of limitation levels.

Code No.	Grouping D, C, M, S	Area Feddan	% Feddan	Code No.	Grouping D, C, M, S	Area Feddan	% Feddan
1	C1	484	1.40	15	C3, S	3224	9.36
2	C2, S	4593	13.33	16	C3, M	2451	7.12
3	C2, M	134	0.39	17	C3, M, S	5524	16.04
4	C2, M, S	3367	9.77	18	C3, A	1337	3.88
5	C2, A	3	0.01	19	C3, A, S	936	2.72
6	C2, A, S	31	0.09	20	C3, A, M	585	1.70
7	C2, A, M	111	0.32	21	C3, A, M, S	1642	4.77
8	C2, A, M, S	656	1.91	22	C3, D	9	0.03
9	C2, D	0	0.00	23	C3, D, S	30	0.09
10	C2, D, S	65	0.19	24	C3, D, M	1788	5.19
11	C2, D, M	0	0.00	25	C3, D, M, S	4842	14.06
12	C2, D, M, S	193	0.56	26	C3, D, A	9	0.03
13	C2, D, A, S	0	0.00	27	C3, D, A, S	0	0
14	C2,D, A.M.S	6	0.02	28	C3, D, A, M	118	0.34
				29	C3, D, A.M.S	2308	6.70
Sub-Total		9,643	28			24803	72.03
Total						34,446	100

Table 3. Sustainability Indicators at El Hammam Area

<u>Village</u>		<u>Critical</u> <u>Area</u> ¹	<u>Settling</u>	<u>Density</u>	<u>Illiteracy %</u>		<u>Total</u>	<u>Per</u>	<u>Wheat</u>	<u>Non-</u>	<u>CDAs</u> ³
<u>Code</u>	<u>Name</u>		<u>%</u>	<u>Person</u>	<u>Male</u>	<u>Female</u>		<u>Capita</u>	<u>Production</u>	<u>Farm</u>	<u>Benefits</u>
				/km ²				<u>Income</u>		<u>Income</u>	
Zone I								<u>/person</u>	<u>%</u>		
23	Abou El Anbya Ibrahim	24	11	2540	28	50	38	1068	83	45	14
24	Sayedna Younis	15	32	3225	17	44	29	800	56	20	16
25	Sayedna Edris	2	15	440	9	40	24	649	83	25	0
26	Sayedna Hood	8	13	950	32	52	42	805	83	35	2
27	Sayedna Shouaeb	62	16	1695	21	49	33	841	94	14	5
28	Amr Ibn El Aas	95	18	715	19	36	26	879	56	26	2
29	Tarek Ibn Zeyad	98	5	545	45	70	57	774	33	27	0
Zone II											
22	Sayedna Salaah	51	4	613	23	53	38	598	56	44	3
30	El Takmoul	91	9	834	16	39	27	846	56	24	1
31	Abou Zahra	98	20	1234	18	51	33	653	28	14	1
32	Abdel Basset	96	12	900	24	51	37	794	56	22	0
33	Mostafa Ismail	99	65	704	25	54	37	819	56	25	2

¹This area represents "Class 3" which is shown in Table (3), ²Poverty line = \$1/day/ person = L.E. 1241/person/year, N.B. 1* 365 days* 3.4 (the value of one dollar in L.E.) = 1241. ³The benefits of the Community Development Associations (CDAs)

- Erian, W.F., F. Hanna, and C.R. Valenzuela. 1991. Digital Image Processing and Land Evaluation of the Sugar Beet Zone, Nubariya District, Egypt-II Potential Land-use. *J. Agric. Sci., Mansoura Univ.* 16 (8): 1901-1912.
- Erian, W.F. 1996. GIS monitoring for physical and socio-economic factors affecting the sustainability of newly formed rural communities in desert areas Egypt. The Fifth International Conference on Desert Development, August 12-17, organized by the International Center for Arid and Semiarid Land Studies, Office of International Affairs, Texas Tech University, Lubbock, Texas, USA.
- Erian, W.F. 1997. The use of the sustainable development multi-indicators for evaluating the stabilization in some new rural communities in desert areas of Egypt. The International Conference on Geo-Information for Sustainable Land Management, 17-21 August. Organized by ITC, Enschede, and The Netherlands.
- Erian, W.F. 1997. The use of GIS to combine soil map with the suggested irrigation scheduling in the sugar beet zone, Nubariya, Egypt. The International Conference on Earth Observation and Environmental Information (EOEI97), 13-16 October Alexandria, Egypt.
- Erian, W.F., and R.K. Yacoub. 1999. The use of GIS to combine analytical and synthetic approaches for obtaining efficient & effective soil survey interpretation. The Sixth International Conference on the Development of Dry Lands, August 22-27, organized by the International Desert Development Commission, in cooperation with ICARDA, Cairo, Egypt.
- Ministry of Industry and Mineral Resources, 1981. The geological map of Egypt. Cairo, Egypt.
- SIDES, 1999. Workshop: Towards Sustainable Development For the New Rural Communities: Information Management for Development. Organized by the Sustainable Integrated Development and Environment Sector - Caritas Egypt, 28-30 June.
- Soil Survey Staff, 1997. *Soil Survey Manual*, USDA, Handbook 18, Washington DC. USA.
- Stein, A. 1998. Spatial statistics for soils and the environment, soil survey course, ITC, *lecture note*, Enschede, The Netherlands.

XI. Renewable Energy

Energy Transport Characteristics in Greenhouses Using an Earth-Tube Heat Exchanger

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ABSTRACT

The present research work was carried out to investigate the potential of using deep soil as a new and renewable source of heating and cooling of ambient air for protected agriculture. An instrumented earth-tube heat exchanger was constructed, installed, and operated as a single-pass, heat exchanger. Airflow and peripheral deep soil temperatures were measured at the inlet, center, and outlet end of the earth-tube heat exchanger. Energy exchange rates were computed and related to concurrent temperatures of heat exchanger operation.

The obtained results revealed that the 2.0-m peripheral deep soil temperature remained sufficiently high and low for effective heating and cooling modes. The energy exchange characteristics of the earth-tube heat exchanger were essentially weather-driven, and the magnitudes of energy production were basically inverse functions of inlet air-flow temperature. During winter season, the peripheral tube wall temperature of 20°C remained sufficiently high for effective heating mode operation. The seasonal average thermal efficiency and heat exchange rate of earth-tube heat exchanger were 83% and 3.63 kWh/day, respectively. During summer season, the peripheral tube wall temperature of 22.1°C remained sufficiently low for effective cooling operation. The seasonal average thermal efficiency and heat exchange rate of the earth-tube heat exchanger were 87.4% and 2.29 kWh/day, respectively.

INTRODUCTION

Greenhouse producers have used various types of energy sources such as electricity, coal, oil, solar energy, and many other energy sources to heat and maintain an optimum inside-environment for growth. Due to the steadily increasing costs of fossil fuels and their uncertain availability, considerable attention has been given to earth temperature as an alternative source of energy for heating and cooling the greenhouses.

Scott et al. (1965) used a 134-m length of corrugated steel pipe (0.457-m diameter), buried to an average depth of 2.4 m at that time, to investigate the capability of an earth-tube system and to determine its feasibility for use in commercial livestock housing. They concluded that it was not economically suitable for use at that time for the specific location. Walker et al. (1976)

employed coal-mine air to control temperature and humidity in greenhouse and reported moderately successful results.

Walker and Buxton (1977) reported the use of a buried pipe through which air was circulated to heat and cool a greenhouse. This proved inadequate for winter heat requirements except for the most southern region of the United States. However, in summer this system could effectively limit high temperatures in a greenhouse located in any area of the U.S. Ewen et al. (1980) stated that the air which was conditioned with deep-soil temperatures could reduce the heating requirements of a greenhouse if used as a thermal buffer. For summer greenhouse operation, they found that the control of temperature rise due to insulation could be obtained through direct use of soil-conditioned air. Cooling a greenhouse by this method was often superior to conventional means.

A finite element formulation was used by Puri (1986) to theoretically examine different parameters of an earth-tube system when operated intermittently. From this study, a few conclusions were formulated on performance. A counter-flow underground heat exchanger for poultry housing was installed and studied by Diener et al. (1990), which revealed 42% of heating energy savings. Bernier et al. (1991a) computed the performance of a wet-soil heat exchanger storage system in a commercial type greenhouse. The stored heat was recovered by convection at the soil surface and by forced ventilation through the exchanger pipes.

A research work about the wet-soil heat exchanger system was carried out by Beriner et al. (1991b) to evaluate the contribution of solar energy to the total heat requirement, which indicated an approximate energy saving of 33% from the system and a payback period from one to five years. Baxter (1992), in a basic study of earth-tube thermal performance for heating ambient air during winter season, revealed that the thermal capacity of the deep soil was sufficient to maintain effective performance of the earth-tube system for heating-mode periods for at least 4 weeks during winter and perhaps longer. Since the earth-tube system has possibilities for use as a dual-purpose system, characteristics of cooling mode operation and energy exchange performance were also investigated by Baxter (1994).

The objective of the present research was to investigate the performance of heating and cooling modes for

continuous operation of an earth-tube heat exchanger as an alternative energy source and energy conservation approach during a progressive winter and summer periods in order to provide and maintain an optimum environment growth inside the greenhouses.

EXPERIMENTAL FACILITIES AND DESIGN

An instrumented earth-tube and fan system was designed, constructed, and operated as a single-pass, heat exchanger at the Rice Mechanization Center (RMC) of Agricultural Engineering Research Institute (AEnRI), in Meet El-Dyba, Kafr El-Sheikh Governorate. It is made from 1-mm thick, galvanized iron sheet welded by Oxygen-Stalin welding. The gross dimensions of the earth-tube system were 50-m long and 0.14-m diameter, with a net curvature surface area of approximately 22 m².

The earth-tube system buried below the surface grade line at a depth of 2.0 m in clay soil to the center-line of the pipe. Inlet and outlet risers were installed at Locations A and C. To provide air-flow through the earth-tube system, a high pressure two suction fans (single speed, direct driven, 3.2 cm water-static pressure, 122 Watt and 1200 m³/hr capacity) were placed on the two outlet branches of the riser tube above the end of earth-tube system. The average air-flow volume was 0.568 m³/s. The system was operated as a single-pass heat exchanger, and the outlet air-flow was utilized to provide and maintain an optimum environment growth inside the two experimental greenhouses. These suction fans were automatically operated using a differential thermostat. They were switched ON and OFF depending upon the optimum ambient air temperature requirements.

For the duration of the whole year of 1995, the temperatures distribution in the earth at different depths of 0.0, 0.5, 1.0, 1.5, and 2.0 m were measured and recorded to determine the specific depth of soil at which the relative temperature remains stable for heating and cooling modes performance. Five thermocouples (copper-constantan) were placed vertically in the soil at different depths starting at zero m deep and continuing at 0.5-m intervals to a depth of 2.0 m. Three vertical columns of thermocouples were located laterally at 5 m to measure and record the deep soil temperatures in three sections of the earth and five different depths of the soil. For obtaining ambient air temperature data, a thermocouple and fan assembly was mounted 2 m above the horizontal surface of the ground.

The daily average hourly thermal efficiencies and energy exchange rates of the earth-tube heat exchanger may be controlled by three factors; inlet air-flow temperature, outlet air-flow temperature, and tube-wall temperature which developed along the earth-tube's length due to the air-flow passing through the system. Seven thermocouples were installed laterally at each of the three longitudinal locations (A, B, and C) as shown in Fig. 1. To measure the air-flow temperatures at the

two-outlet branches end of earth-tube system, two thermocouples were used. All the terminals of thermocouples (24 during the experimental work) were connected with a temperature recorder (model Digistrip II from KYE Instrument Company, USA). A multi-input process monitor was used to record and print data on a special paper. The data were updated by a scan of all sensors every 5 minutes, and the means of 12 scans were recorded every hour using a data-logger system.

The thermal efficiencies of earth-tube heat exchanger for cooling (η_c) and heating (η_h) modes were computed using the following equations (Holman, 1986):

$$\eta_c = \frac{T_{ai} - T_{ao}}{T_{ai} - T_{po}} \times 100\% \dots\dots\dots (1),$$

$$\eta_h = \frac{T_{ao} - T_{ai}}{T_{po} - T_{ai}} \times 100\% \dots\dots\dots (2),$$

Where:

- T_{ai} = inlet air-flow temperature at inlet location, °C;
- T_{ao} = outlet air-flow temperature at outlet location,
- C; T_{po} = earth-tube wall temperature at outlet location, C.

The volumetric air-flow rates (m³/h) were converted into mass air-flow rates (kg/s). Energy exchange rates (Q_{exr}) were calculated according to ASHRAE (1985) as:

$$Q_{exr} = m C_p (T_{ao} - T_{ai}), \text{ watt} \dots\dots\dots (3)$$

Where:

- M=mass flow rate of air-flow, kg/s; Cp=specific heat of air-flow, J/kg/°C.

For the duration of the experimental work, random humidity measurements revealed that there was no change of moisture content of the air-flow through the earth-tube system, thus energy exchanges were treated as sensible heat (sensible heating process) as recommended by several researchers (Bradshaw, 1985; Esmay and Dixon, 1986; Barre et al., 1989).

RESULTS AND DISCUSSION

For the duration of 1995, the temperature gradients in the earth at different depths of 0.0, 0.5, 1.0, 1.5, 2.0 m, and maximum and minimum ambient air temperatures were measured and recorded in order to determine the depth at which the relative temperature remains sufficiently constant. The obtained data showed that the 2.0 m peripheral deep soil temperature on the average remained constant at 20.2°C during the 6 month period of the winter season when the seasonal average minimum ambient air temperature was 10.72°C, giving an average potential difference of 9.48°C. Whilst it remained constant at 21.0°C during the rest period of

the year when the seasonal average maximum ambient air temperature was 27.4°C that gave an average potential difference of 6.4°C.

This peripheral deep soil temperature (at 2.0 m) was essentially stable due to the large thermal capacity of the soil-water mass. The primary inversion of the vertical temperature gradient of soil near the surface of the earth occurred in spring. The seasonal change inverted all temperatures of the vertical soil gradient at five depths. During the winter months, the shallow depths had the coldest temperatures and the deeper depths had the warmest temperature. However, during May, the deep soil temperature magnitudes at all depths were inverted and soil temperature at depth 0.0 m became the warmest soil temperature and deep soil temperature at 2.0 m depth became the coldest. During November the fall inversion of deep soil temperatures again reversed these vertical soil temperature magnitudes in sequential order.

These two reversals of the deep soil temperatures occurred, depending upon the intensity of solar radiation flux incident on the top surface of the earth and the ambient air temperature. To assess the specific depth of soil at which the relative temperature remains constant for effective heating and cooling mode operations. The deep soil temperature (T_{ds}) was plotted against different depths of soil (D_s). A quadratic regression analysis (polynomial equation) was developed and indicated a highly significant relationship between these parameters. The polynomial equations of the best fit were:

Heating mode (winter):

$$T_{ds} = 17.728 + 1.933 \times 10^{-2} (D_s) - 3.338 \times 10^{-5} (D_s)^2$$

Cooling mode (summer):

$$T_{ds} = 25.761 - 3.742 \times 10^{-2} (D_s) + 6.292 \times 10^{-5} (D_s)^2$$

The deep soil temperature of 20.2°C remained constant throughout the whole year at depth of 2.3 m. However, it was very difficult to locate the earth-tube at that depth due to the watertable. The monthly average daily inlet air-flow temperature, outlet air-flow temperature, peripheral temperature of the earth-tube system, thermal efficiency of the earth-tube system, and

energy exchange rate throughout the winter season of 1996-'97 and 1997-'98 (Table 1). The thermal efficiency of earth-tube system was continuously variable during the whole period of heating mode depending upon the temperature difference between outlet air-flow and inlet air-flow, and temperature difference between peripheral earth-tube system and inlet air-flow. The greatest average thermal efficiency of the earth-tube system (86.9%) occurred on January with an average inlet air-flow temperature of 11.7°C, while the lowest average thermal efficiency of the earth-tube system (75.0%) occurred on November with an average of inlet air-flow temperature of 16.3°C.

Another important parameter related to overall thermal performance of earth-tube system is the stability of the thermal mass of the deep soil at depth of 2.0 m. The inlet air-flow temperature decreased gradually with time of the day from nearly 4.0 p.m. to a value lower than the optimum night temperature (18°C) and remained under this level until it reached a minimum value of 8.5°C at early morning (6.0 a.m.). However, the inlet air-flow temperature, after passing through the earth-tube system, increased to a magnitude higher than the optimum night temperature inside the greenhouse and remained above this level of temperature throughout the majority of the recorded days (72% of the recorded days), making an effective heating mode operation.

An interesting characteristic of earth-tube temperature operation and peripheral deep soil temperature response indicated that the wall surface temperature of earth-tube system slightly increased during daylight, particularly at and around noon to a magnitude higher than the 2.0-m deep soil temperature and remained above this level until nearly 4.0 p.m. This can be attributed to the increase of the intensity of solar radiation and ambient air temperature during those times. Solar radiation flux incident enhanced to produce a relatively high peak of ambient air temperature during the afternoon hours achieved on 28% of the recorded days. This high ambient air temperature produced a cooling period at those times. The warm ambient air temperatures were greater enough to elevate the peripheral deep soil temperature at inlet location for the next days.

Table 1. Operating temperatures of the earth-tube heat exchanger, overall thermal efficiency (η_h) and energy exchange rate (Q_{exr}) throughout the winter of 1996-'97 and 1997-'98.

Month	Inlet Airflow Temperature T_{ai}	Outlet Airflow Temperature T_{ao}	Earth-tube Wall Temperature T_{po}	Thermal Efficiency η_h	Energy Exchange Rate Q_{exr}
		Temperature	Temperature		
		-----°C-----	-----°C-----	---%---	-kWh/day-
November	16.30	19.21	20.18	75.00	2.046
December	13.17	18.92	20.09	83.09	4.042
January	11.72	18.80	19.87	86.87	4.977
February	13.73	18.65	19.70	82.41	3.459
Mean	13.73	18.90	19.96	82.99	3.634

These intermittent times of higher inlet air-flow temperatures which gave rise to cooling mode operation, provided a thermal recharge effect for the peripheral deep soil along the tube's perimeter. This supplemental heat input should provide high performance during subsequent cold times throughout the day. Consequently, this rapid thermal recharge characteristic occurred during warm ambient air temperature times that provided a potential approach for improving energy yields of the system. The obtained data throughout this month indicates the probable use of a solar air heater and an earth-tube system can be operated in tandem to provide greater and more effective energy yields.

The thermal efficiency decreased gradually with time of the day from nearly 6.0 a.m. until it reached a minimum magnitude at nearly 2.0 p.m. It then increased gradually till it approached a maximum value at 6.0 a.m. As the inlet air-flow temperature is decreased lower than the tube surface temperature, the thermal capacity of inlet air-flow is increased, and the actual heat gain is thus increased making the thermal performance more efficient.

The low ambient air temperature for the four winter months ranged from 10.5°C to 7.4°C. These low ambient air temperature conditions provided a high heat exchange rate for the specific earth-tube heat exchanger and surrounding thermal mass of the deep soil. The greatest value of heating energy exchange (4.98 kWh/day) occurred on January when the monthly average daily inlet air-flow temperature (11.72°C) was quite low, whilst the lowest heating energy exchange rate (2.05 kWh/day) was recognized on November with an average inlet air-flow temperature of 16.30°C.

As shown in Table 1, there were some differences in energy exchange rates for the four winter months. These differences were attributed to the influence of the prevailing atmospheric conditions. The greatest value of monthly average hourly energy exchange rate (5.62 kW) for November performed at and around 6.0 am, when the inlet air-flow temperature and wall surface temperature of earth-tube system were on the average 10.90°C and 19.88°C, respectively.

The operating temperatures of the earth-tube system provided a heating effect of 8.16°C, while the lowest value of heat exchange rate (0.172 kW) produced at and around 4.0 p.m., when the inlet air-flow and wall surface temperatures were on the average 20.70°C and 21.20°C respectively. Consequently, the earth tube system provided only a heating effect of 0.50°C. During this month, the hourly changeover from heating mode to cooling mode began to occur at noon and afternoon. This month had a broad range of ambient air temperatures from around 9.20°C to a comparatively high value of 24.10°C. The greatest cooling energy exchange rate (heat energy lost) for the November month (0.985 kW), which was the first time cooling energy exchanges have exceeded heating energy for many hours of the month operation.

The energy exchange rates during December gradually increased from 4.0 p.m. (2.780 kW) until it reached a maximum value (7.638 kW) at early morning (6.0 a.m.). The hourly change-over from heating mode to the cooling mode began to occur at and around 2.0 p.m., when the inlet air-flow temperature at that time increased to a magnitude (21.47°C) higher than the peripheral deep soil (19.72°C) adjacent to the tube's perimeter and remained above this level till nearly 3.0 p.m. More than 80% of possible sunshine hours, which helped to produce a relatively high peak of ambient air temperature at the afternoon, occurred on many days throughout this month. The warm ambient air at 2.0 p.m. was great enough to elevate the tube-wall temperature for the next hours, and the outlet peripheral deep soil temperature also increased slightly by this ambient air.

Due to the hourly average inlet air-flow temperatures throughout January being low enough, the greatest hourly average energy exchange rate (5.439 kW) achieved. The energy exchange rate increased gradually from after 2.0 p.m. (1.397 kW) until it reached the maximum magnitude (8.237 kW), normally at early morning (6.0 a.m.). This month had a broad range of ambient air temperatures from around 6.70°C at early morning to a comparatively high value of 18.60°C in the afternoon.

Thus, there was no cooling energy exchange occurred at any time throughout the month of January. Because, the previous month (December) had provided an adequate thermal recharge effect (heat input) for the peripheral deep soil adjacent to the earth-tube's perimeter, the peripheral deep soil temperature was continuously higher than the inlet air-flow temperature and remained above this temperature throughout the month of January.

The hourly average energy exchange rate during February also increased gradually from 4.0 p.m. (2.766 kW) till it approached the maximum value (7.590 kW) at early morning. This month had also a broad range of ambient air temperatures from around 8.30°C at early morning to a comparatively high magnitude of 21.80°C in the afternoon. More than 90% of bright possible sunshine hours, which helped to produce a relatively high peak of ambient air temperature at noon and afternoon, were recognized on so many days throughout the month of February.

The seasonal average hourly heating energy exchange rate of an earth-tube system is related to the inlet air-flow temperature for the winter season. This figure shows that the energy exchange characteristics of the earth-tube system were essentially weather-driven and the magnitudes of heating energy production were basically inverse functions of inlet air-flow temperature.

The monthly average daily temperatures of inlet air-flow, outlet air-flow, earth-tube wall, thermal efficiency of earth-tube heat exchanger, and energy exchange rate for the months of April, May, June, and July of 1997

are summarized in Table 2. It shows that the thermal efficiencies of the earth-tube system were continuously variable during the whole period of cooling mode operation depending on the inlet air-flow temperatures. Thus, the lowest value of thermal efficiency occurred during April when the monthly average daily air-flow temperature was 22.16°C. The daily average cooling degree-days (cooling effect) was 1.02°C-days, while the greatest magnitude of thermal efficiency achieved during July when the inlet air-flow temperature was on the average 28.78°C. During this month, the daily average cooling degree-days were 5.05°C-days. Comparatively, the earth-tube efficiency for each period of cooling mode operation was higher than earth-tube efficiency for the respective periods of heating mode operation.

produced short periods of heating mode performance as discussed later.

This interesting characteristic of earth-tube temperature operation and deep soil temperature response revealed that the approach of cool fall temperatures causes earth-tube performance to automatically switch from cooling-mode operation during daylight to heating mode operation during the night. These low ambient air temperatures demonstrated a responsive thermal charge of the peripheral deep soil adjacent to the wall surface of earth-tube system. The thermal efficiency of earth-tube system was increased sequentially from the early morning low inlet air-flow temperature to a peak around mid-afternoon when normally the maximum daily ambient air temperature occurred, after which the

Table 2. Operating temperatures of the earth-tube heat exchanger, overall thermal efficiency (η_c), and energy exchange rate (Q_{exr}) throughout the summer of 1997.

Month	Inlet Airflow Temperature	Outlet Airflow Temperature	Earth-tube Wall Temperature	Thermal Efficiency	Energy Exchange Rate
	T_{ai}	T_{ao}	T_{po}	η_h	Q_{exr}
	-----°C-----			---%---	-kWh/day-
April	22.16	21.14	20.90	80.95	0.717
May	24.51	21.87	21.39	84.62	1.856
June	27.58	23.28	22.69	87.93	3.023
July	28.78	23.73	23.19	90.34	3.550
Mean	25.76	22.51	22.04	87.37	2.287

The most probable reason for greater earth-tube thermal efficiency during cooling mode operation was the more consistent daily ambient air temperature during the summer season than those during the winter season. Two major characteristics of the system may be contributing to effective earth-tube thermal performance: one was the good thermal conductivity of the earth-tube metal and its attributes at both the external and internal interfaces with the deep soil and air-flow respectively. The other was the stability of the thermal capacity of the deep soil at depth 2.0 m.

These factors produced excellent heat exchange rate and earth-tube thermal efficiency for both cooling mode and heating-mode operations. The pertinent temperature affects thermal performance of the earth-tube for the specific periods. It indicates that the inlet air-flow temperature gradually increased with time of the day from 6.0 a.m. to a magnitude higher than the optimum temperature for the protected agriculture during daylight (25°C) and remained above this level until it reached the maximum value at 2.0 p.m. It then decreased gradually to a magnitude higher than the optimum night temperature (18°C) and remained above this level till it approached the minimum value at early morning. Because the data plotted in this figure represented the seasonal average hourly operation temperatures included the low early morning temperature of inlet air-flow during April. These cool mornings

thermal efficiency decreased until the low ambient air temperature was reached again. Thus, the effectiveness ratings of earth-tube system during cooling mode operation were greater for high ambient air temperature periods. This is an inherent and desirable characteristic of earth-tube performance, particularly during the hottest periods.

The thermal exchange rate (input energy) of the earth-tube heat exchanger during the cooling mode operation was measured and computed throughout the summer month. To be successful as a heat exchanger system, it must produce a relatively high level of thermal exchange rate during summer season, when high ambient air temperatures occur frequently. As can be observed in Table 2, the greatest magnitude of cooling energy exchange performed on July when the monthly average daily inlet air-flow temperature was quite high.

During this month, the maximum ambient air temperature was 33.50°C, which created an excellent potential for cooling-mode operation, while the lowest value of cooling energy exchange rate occurred on April with an average inlet air-flow temperature of 22.16°C. Cooling energy exchange rate was closely related to daily maximum ambient air temperature and cooling degree-day. The monthly average daily degree-days for the four months (April, May, June, and July) were 1.02, 2.64, 4.30, and 5.03°C-days, respectively.

Another weather factor related to energy yield were the low early morning ambient air temperatures that occurred between midnight to early morning (7.0 a.m.) throughout the month of April. These eight hours of cold mornings produced short periods of heating-mode operation. Consequently, the earth-tube performance was automatically switched from cooling mode operation during the daylight to heating mode operation during the night. For this month, the maximum hourly average cooling energy exchange rate was 3.374 kW. Energy yields would have been higher if the ambient air temperatures and other weather conditions had been more favorable for cooling mode performance.

The hourly cooling energy exchange rate during May increased from the early morning low air temperature to a peak around mid-afternoon when normally the maximum ambient air temperature occurred. The maximum hourly input energy rate (4.098 kW) normally performed at 2.0 p.m. when the inlet air-flow temperature at that time was 30.30°C. After the maximum inlet air-flow temperature occurred, the input energy rate decreased till it reached a lowest magnitude (0.035 kW) when the morning low air-flow temperature was reached again. No heating energy exchange occurred at early morning throughout the last 20 days of this month. However, there were 70 hours (early morning low air-flow temperatures) occurred through the first ten days of this month produced short periods of heating mode operation. Due to this reason, the monthly average hourly input energy rates from after mid-night to early morning were low.

Because the month of June had a broad range of ambient air temperatures from 23.20°C (at 6.0 a.m.) to a comparatively high value of 31.20°C (at 2.0 p.m.), the lowest and greatest hourly average input energy rates were 1.195 and 4.401 kW at those times, respectively. No heating mode operation occurred at any time throughout June, because the peripheral deep soil temperature along the earth-tube's perimeter was continuously lower than the inlet air-flow temperature and remained under this level through this month.

The input energy rates for the month of July were greater than those of the previous months (April, May, and June), which resulted from the high inlet air-flow temperatures. This month had maximum and minimum inlet air-flow temperatures on the average of 33.50°C and 24.90°C respectively, which created an excellent potential for cooling mode operation. Thus, the greatest and lowest hourly average input energy rates were 5.096 and 2.109 kW which performed at 2.0 p.m. and 6.0 a.m. respectively. Also, there was no heating energy exchange occurred at any time throughout this month, because the inlet air-flow temperature was continuously higher than the peripheral deep soil temperature adjacent to the earth-tube's perimeter and remained above this temperature throughout this month. From all the previous discussions, the cooling energy exchange characteristics of the earth-tube heat exchanger were weather-driven and the magnitudes of cooling energy

production were basically inverse functions of inlet air-flow temperature.

CONCLUSIONS

The obtained results of this research work during winter and summer seasons can be summarized and concluded by the following points:

1. The thermal capacity of the deep soil was sufficient to provide and maintain effective performance of the earth-tube system for heating and cooling-mode operations throughout the winter and summer seasons. Consequently, a *promising potential for earth-tube system thermal performance was achieved*. The energy exchange rates of the system were essentially weather-driven and the values of energy production were mainly inverse functions of inlet air-flow temperatures. During winter, the seasonal average thermal efficiency and heat exchange rate of earth-tube heat exchanger were 82.99% and 3.634 kWh/day, respectively.
2. During summer, the peripheral tube-wall temperature of 22.04°C remained sufficiently low for effective cooling-mode operation. The effectiveness ratings of the earth-tube system were greater for high inlet air-flow temperature periods. This is an inherent and desirable characteristic of earth-tube system performance. The seasonal average thermal efficiency and cooling heat exchange rate of earth-tube heat exchanger were 87.37% and 2.287 kWh/day, respectively.

REFERENCES

- ASHRAE, 1985. Handbook of fundamentals; Amer. Soc. Heating, Refrigerating and Air Conditioning Eng, Inc. Atlanta, GA.
- Barre, H.J., L.L. Sammet, and G.L. Nelson. 1989. Environmental and functional engineering of agricultural buildings. Van Nostrand Reinhold Co.
- Baxter, D.O. 1992. Energy exchanges and related temperatures of an earth-tube heat exchanger in the heating mode. *Trans. ASAE* 35(1): 275-284.
- Baxter, D.O. 1994. Energy exchanges and related temperatures of an earth-tube heat exchanger in the cooling mode. *Trans. ASAE* 37(1): 257-267.
- Bernier, H., G.S.V. Raghaven, and J. Paris. 1991a. Evaluation of a soil heat exchanger-storage system for a greenhouse. Part I, System performance. *Canadian Agric. Eng.* 33(1): 93-98.
- Bernier, H., G.S.V. Raghaven, and J. Paris. 1991b. Evaluation of a soil heat exchanger-storage system for a greenhouse. Part II, System performance. *Canadian Agric. Eng.* 33(1): 99-104.
- Bradshaw, V. 1985. Building control system. John Wiley & Sons, New York.
- Diener, R.G., M.L. Moseley, R.A. Peterson, W.T. Jones, and M.L. Pentrack. 1990. Construction of an underground heat exchanger for broiler housing with preliminary results. *Appl. Eng. Agric.* 6(1): 82-86.

- Esmay, M.L., and J.N. Dixon. 1986. Environmental control for agricultural buildings. The AVI PUB Publ. Co. Inc. Westport, CT.
- Ewen, L.S., J.N. Walker, and J.W. Buxton. 1980. Environmental in a greenhouse thermally buffered with ground-conditioned air. *Trans. ASAE*. 23(4): 985-993.
- Holman, J.P. 1986. Heat transfer. 10th Ed., McGraw-Hill International Book Co., London. 570 p.
- Puri, V.M. 1986. Feasibility and performance curves for intermittent earth-tube heat exchanger. *Trans. ASAE*. 29(2): 526-532.
- Scott, N.R., R.A. Parsons, and T.A. Koehler. 1965. Analysis and performance of an earth air heat exchanger. ASAE Paper No. 65-840. Cited by Baxter (1994).
- Walker, J.N., W.O. Peterson, G.A. Duncan, and D.T. Anastasia. 1976. Temperature and humidity in a greenhouse ventilated with coal mine air. *Trans. ASAE*. 19(2): 311-317.
- Walker, J.N., and J.W. Buxton. 1977. Can circulating air through buried pipe be used to heat and cool greenhouses. *J. Amer. Soc. Hort. Sci.* 102(5): 626-629.

A Solar Energy-Driven System for Crop Cultivation Using Saline Water

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ABSTRACT

In arid and semi-arid areas adjacent to sea and in regions with underground storage of saline water, desalinization can furnish an adequate source of water for agricultural and other domestic development. Establishment of a desalinization system for agricultural purposes should account for the cost and the efficient use of available water by the plant. In this study, establishment of a desalinization system for plant cultivation was investigated.

The system basically was composed of a *solar still and cultivation pot*. The solar still consisted of a pool with a mix of saline water and sand, from which water evaporates during the daytime when temperature increases. The evaporated water condenses in the cooler cultivation pot, where the roots of the plant absorb it directly. The effects of transparent plastic film covering of the pool and mulching of the soil surface in the pot using transparent plastic film or aluminum film were investigated, as well as the mechanism of water desalinization.

The temperature of saline water and sand mix in the pool covered with a transparent plastic film was higher than that in the non-covered pool by 8°C during the daytime and about 3°C during the night. This higher temperature produced more water condensed in the cultivation pot of the pool with plastic cover, which was about six times that produced by the non-covered pool. During the daytime, the mulching of the soil surface with transparent plastic film resulted in soil temperature higher by about 6°C than mulching with aluminum film. During the night-time, the aluminum mulching produced soil temperature higher by only 1°C than the plastic mulching. Hence, the water condensed in the cultivation pot increased under the plastic film mulching by about 3-fold as compared by that under aluminum mulching.

The results showed that the system performs better when the temperature of the cultivation pot is lower than that of the pool, especially during the night-time. Cultivation of *Brassica sp.* was accomplished from seed to harvest using this desalinization system, in which the transparent plastic film used to cover the pool and mulching the soil surface in the pot.

INTRODUCTION

Arid lands, in which evapotranspiration exceeds precipitation, occupy 47% of the land on the earth (Inanaga, 1998). In these lands, 20% of the global population lives and the agriculture and livestock-raising industry are widely present, but are jeopardized by the scarcity in water for agriculture and daily life. Some of these arid and semi-arid lands are located in areas adjacent to the sea and/or in regions with sufficient underground storage of saline water. Hence, the potential generation of fresh water for agriculture and domestic needs is anticipated and promising. Therefore, desalinization of water has been tried and practiced using various methods, such as *electrodialysis*, *reverse osmosis membrane*, *refrigeration*, and *distillation*, etc. Most of these methods are characterized by the high assembly and running cost (Sotoyama, 1992; Goto, 1996). Therefore, there is an urgent need to minimize these costs (Kubota et al., 1987).

Recently, development of economical desalinization systems has counted upon solar energy technology that is not applied to the running cost. The development of solar energy distillation system (solar still) was an excellent example (Ishikawa et al., 1996). Although this system has very low productivity for desalinized water, its cost is low, with simple structure and easy operation. Hence, when desalinized water using the solar still is used for agricultural production, avoidance of water loss during irrigation should be managed. This can be achieved by supplying the water directly to the plant; yet, there is no system in which the solar still and cultivation system is combined. A system that combines the solar still and pots for plant cultivation under saline soil was experimentally established (Inanaga, 1991, 1994).

In this study establishment of a desalinization system for plant cultivation was investigated. The system basically comprised a solar still and a cultivation pot. The solar still involved a pool with a mix of saline water and sand, from which water evaporates during the daytime when temperature increases. The evaporated water condenses in the cooler cultivation pot, where the roots of the plant absorb it directly. The system is described in this paper and its principle outlined.

MATERIALS AND METHODS

The solar energy-driving system was placed in glasshouse. A plastic container (115-cm W x 70-cm D x 19.5-cm H) were filled with 200 kg sand and 55 L salt-water, and from outside was buried horizontally in

the sand ground up to 16 cm from the bottom. During the experiment period, salt water containing 3% NaCl was applied to keep NaCl concentration in the media the same as the concentration of seawater or even more.

To evaluate effects of transparent plastic film cover of the pool covered and uncovered pools with the film were prepared. A cultivation pot made of translucent plastic was used, and its bottom was removed and covered with plastic net. A 2-cm thick gravel (0.5 cm in diameter) was paved over the plastic net and 0.5-cm thick rock wool was placed on the gravel; over it was 15-cm placed a thick dried vermiculite layer. Water content was measured by weight. Seeds of "pak-choi" were sowed into the pot 11 days after the preparation of the system. Pak-choi germinated 3 days after sowing (11 days after preparing the system). True leaf developed 5 days after germination.

To evaluate the effect of mulching materials on the cultivation pot for water condensation, the soil surface in the pot was mulched using transparent plastic film or aluminum film. The pool was covered with film made from polyvinyl chloride. Temperature in the cultivation and the pool was measured by a copper-constant thermocouple every hour during the day and night. The temperature of the cultivation pot was measured at its center, at 1-cm depth from surface of the soil, and that of the pool was measured directly under the center of the pot. All data are presented as the mean of three replications.

RESULTS

The temperature of the covered pool remained higher than that of the uncovered pool during the day and night. The cover of the pool has no any effects on the temperature of the cultivation pot. The temperature of the cultivation pot was always higher than that of the pool in daytime and the contrary true in the nighttime. The difference of temperature between the pool and the pot in the uncovered pool was higher than that in the covered pool during the daytime, and lower during the nighttime. Rate of water condensation in the cultivation pot for the covered pool was higher than that for the uncovered pool.

Changes of temperatures of the pools covered with polyvinyl chloride film and aluminum film from 36 to 38 days after preparing the system varied with the materials. Temperature of the pool covered with polyvinyl chloride film was higher than that covered with aluminum film during daytime and lower during nighttime. The difference in temperature between that of the pool and that of the cultivation pot was higher all day in the cultivation pot covered with polyvinyl chloride film than that covered with aluminum film. The rate of water condensation on the cultivation pot covered with polyvinyl chloride film was higher than that covered with aluminum film.

Change of water contents in the planting pot occurred when both the pool and the planting pot were

covered with polyvinyl chloride film. The temperature of the cultivation pot was higher than that of the pool on and after 10:00, and lower on and after 15:00 or 16:00 hours. On the other hand, the moisture contents of the soil in the cultivation pot always increased from 14:00 to 9:00 in the next morning, and always decreased from 9:00 to 14:00 hours. The difference in temperature between the pool and temperature of the cultivation pot was highly negative by correlating with rate of water condensation on the cultivation pot ($r = -0.80$). Thus, the difference of temperature between the cultivation pot and the pool has been the key factor for generation and condensation of water in this system.

DISCUSSION

It is demonstrated that the solar energy-driving system successfully desalinated saline water, which was used for cultivation of plants. Also, the difference of temperature between the cultivation pot and the pool has been shown to be the key factor in this system.

It was clear that the system depended on the heat energy that combines factors such as *reflection*, *permeability*, and *accumulation of solar energy* by sand and *cover or mulching film* when the solar energy was used. The heat energy is important for evaporation of water from saltwater, whereby the water condenses from water vapor to be used by the plant. Nevertheless, the pak-choi which was grown in this system was poor in comparison with plants which grown in field or hydroponics. Thus, in order to increase the moisture condensation and collection, there are needs for some improvement on absorption and accumulation of solar energy in the pool, and on suppression of increasing temperature and cooling on the planting pot. It is necessary that the pool cover materials should have high permeability of solar energy in one-way direction (from outside to inside and not from inside to outside).

Future research should have focal point on developing a pool cover, which has this characteristic of one-way solar permeability. On the other hand, for the cultivation pot, it is necessary that the materials of the mulching should maintain the temperature as low as possible in the pot during the day and night. Also, to facilitate cooling of the cultivation pot, its important to install a radiation plate and a vent hole. The sizes of the cultivation pot and the pool, as well as the fertilization methods, need to be examined. *This system can be also tested for recycling wastewater and sewage for different uses.*

REFERENCES

- Goto, T. 1996. Present status and future aspects of seawater desalination technology. *Bull. Soc. Sea Water Sci.* (Japan), 50(4): 211-215 (in Japanese)
- Goto, T., and Y. Nakajima 1979. Present status of desalination by solar energy. *Bull. Soc. Sea Water Sci.* (Japan), 33(3): 154-164 (in Japanese)
- Inanaga, S. 1991. Improvement of sloping beds of row

- for crop establishment in saline lowland in Cangzhou Prefecture, China. p. 143-148. *Proceedings of International Symposium on "Impacts of Salinization and Acidification on Terrestrial Ecosystem and its Rehabilitation"*. Tokyo, Japan.
- Inanaga, S. 1994. High ridge cultivation and salt content in soil. p. 107-111. *Proceedings of China-Japan joint Symposium on "Impacts of Salinization and Acidification on Terrestrial Ecosystem and its Rehabilitation in East Asia"*. Beijing, China.
- Inanaga, S. 1998. Agriculture and stock raising, and desertification in semi-arid land in Asia. In K. Takeuchi and M. Tanaka (Ed.) Sustainable utilization of bio-resources. *Earth Environmental Study*, Iwanami shoten (Japan), 6: 97-122.
- Ishikawa, M., K. Otsuki, and M. Kamitika. 1996. An experimental study of a desalination system using solar energy and temperature difference between soil and air. *Green Age* 10: 7-13.
- Kubota, S., O. Kuroda, and S. Takahashi. 1987. Seawater desalination systems powered by solar energy. *Bull. Soc. Sea Water Sci.* (Japan), 41(3): 123-141 (in Japanese)
- Toyama, S. 1988. Review on desalting distillator. *Bull. Soc. Sea Water Sci.* (Japan), 41(6): 305-313 (in Japanese).

Features of Wind Conditions over Egypt

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ABSTRACT

Hourly data of wind speed and direction in the period 1981-1995 at 23 surface meteorological stations have been used to depict climatic features of wind over Egypt. Distribution of mean wind speed, mean wind vector, persistence, and available highest power density of wind energy were investigated. Mean annual wind speed ranged from 2 to 7.5 m/s with maximum values at coastal areas at Port Said, Hurghada, Rasbenass, and Elowainat. Centers of minimum speeds have been found at Siwa Oasis, at El-Arish, and at Luxor. Magnitude of annual wind vector followed a similar pattern but with a lower order of magnitude.

Persistence ratios ranged from 70 to 25%, with high values at coastal areas of the Red Sea, Middle Egypt, and around Lake Nasser up to the Elowainat region. Lower persistence was found over the Delta, around El-Arish, and around the Siwa Oasis. For this reason, wind blows from a steady direction (300°-330° from north) over most northern parts of Egypt and blows from southwest to northeast at southern boundaries of Egypt. Over the Delta and around Siwa Oasis, it has a variable direction. By computing power density of wind at all stations, it has been found that promising areas of wind energy are located at Port Said, Hurghada, Rasbenass, and around Lake Nasser. At some places, maximum available wind energy at 50 meters above ground level reached 2300 watt.m⁻². A linear model was established to get a forecast of extreme wind speed at any station. Harmonic analysis of wind speed for two stations showed that seasonal and semi-annual oscillation plays an important role in wind speed variation.

INTRODUCTION

The features of the climate of Egypt have been described in many publications, among them the work of Griffiths and Soliman (1972), who found maximum annual wind speed of order 5.6 m.s⁻¹ on the coastal areas, either on Red Sea or on north coast of the Mediterranean. In the Delta and interior areas, the speed decreases gradually towards the Western Desert, where it ranges from 3.4 to 1.7 m.s⁻¹. Elliott et al. (1987) estimated distribution of annual average wind power over Egypt, and classified wind speeds into three categories; energy density ranged from 200 to 400 watt.m⁻², with higher values over coastal areas and west of Lake Nasser.

Mortensen and Said (1996) issued a wind atlas of Gulf of Suez; they have modeled wind data over the Gulf of Suez in the period 1991-'95 using WASP program package issued by RISØ Danish laboratory (Mortensen et al., 1998). They gave a description of the Gulf wind climate and possible wind energy available in this area. They found that the Hurghada area is a promising resource of wind energy. However, the short period of the study and its limitation to the Gulf of Suez does not give a complete picture about wind energy available over the whole area of Egypt.

Distribution of mean wind vector as well as persistence is important factors to describe wind climate over Egypt. The persistence ratio may give an idea about the prevailing wind at a specified area. It is calculated as the ratio between modulus of resultant wind vector to the mean wind speed at the same location and in the same period; it ranges from 0 to 1. When its value is near 1, the wind blows from the same direction all the time and vice versa. Its distribution is useful in airport planning and environmental studies.

The wind climate of extreme wind speed is often characterized by the so-called "n-year return wind". This gives the 10-minute mean wind speed, which on average will be exceeded once in the period of n years. To estimate extreme wind speeds with a longer return periods, double exponential Gumbel distribution is used here. The procedure for estimation of Cook (1985) and Jensen et al. (1992) would be also used here. To get a monthly forecast of mean wind speed, harmonic analysis will be used here at some stations.

DATA AND METHODOLOGY

Wind data of speeds and directions at the daily times 00, 03, 06, 09, 12, 15, 18, 21 Universal Time (UT) in the period 1981-'95 have been used in this study. To represent all different locations in Egypt, 23 surface meteorological stations of the Egyptian Meteorological Authority (EMA) Network have been introduced in the study (Fig. 1). The stations have been chosen such that records are continuous and missing data are minimized. According to WMO regulations of measuring wind, wind anemometer height at all stations is about 10 meters above ground level. No correction was made, and we regard the data are homogeneous.

To estimate persistence at a given station, the method of Panofsky and Brier (1958) has been used. So, if S_{kj} is the value of wind speed (regardless of direction), V_k is the wind vector at observation of index k and at station of index j, then the persistence P_j is determined from the relation:

$$P_j = \frac{n \left| \sum_{i=1}^n I_{ij}^* \right|}{\sum_{i=1}^n S_{ij}} \quad : j = 1, 2, \dots, 23 \dots \dots \dots (1)$$

Where:
n is the number of observations in the whole period.
To get the best linear model for extreme wind speeds, an algorithm was made and programmed. If S_j were extreme wind speed in the month of index j, and S_j were arranged in acceding order, the assigned probability X_j could be determined from:

$$X_j = \frac{j}{N+1} \quad : j = 1, 2, \dots, N \dots \dots \dots (2)$$

Where:
N is the number of observation of extreme winds (one per month).
A regression line between S_j and $-\ln(-\ln(X_j))$ is obtained. After that the two constants α & β of regression model are determined. According to Jensen et al. (1992), extreme speed S_2 at return period T_2 can be determined from a known extreme speed S_1 at return time T_1 from the relation:

$$S_2 = S_1 + \alpha \ln \left(\frac{T_2}{T_1} \right) \dots \dots \dots (3)$$

To compute power density P_j from wind, scale parameter A_j , and shape parameter K_j of Weibull (1951) distribution of wind speeds at each station has been estimated. Also, corresponding available power density P_j at 50 meters (m) at station of index j has been computed (However there are many methods for estimate A_j , K_j). The method that has been used here is of Troen and Petersen (1989). After estimating A_j and K_j , power density P_j has been computed from:

$$P_j = \frac{\rho}{2} A_j^3 \Gamma \left(1 + \frac{3}{K_j} \right) \dots \dots \dots (4)$$

Where:
 ρ is air density and Γ is the Gamma function that can be determined from the integration:

$$\Gamma \left(1 + \frac{3}{K_j} \right) = \int_0^\infty z^{\frac{3}{K_j}} e^{-z} dz \dots \dots \dots (5)$$

To estimate Weibull parameters A_j and K_j at 50 m above ground level, wind speeds $U(50)$ are estimated from their corresponding speeds $U(10)$ at 10 m from ground level from logarithmic law:

$$U(50) = U(10) \frac{\ln(50) - \ln(z_0)}{\ln(10) - \ln(z_0)} \dots \dots \dots (6)$$

Where:
 z_0 is the surface roughness. It has to be noted that Equation 6 is strictly only valid for a steady state, horizontally homogeneous surface layers where the static stability is very close to neutral. Also we could find the highest wind speed U_m from Equation 7 below which is given by (Niels et al., 1997). The highest power density P_{max} could be estimated from Equation 8 below:

$$U_m = A_j \left(\frac{K_j + 2}{K_j} \right)^{\frac{1}{K_j}} \dots \dots \dots (7)$$

$$P_{max} = \frac{\rho}{2} U_m^3 \dots \dots \dots (8)$$

RESULTS

Annual distribution of mean wind speed ranges from 2.0 to 7.5 m.s⁻¹. Areas of maximum speeds are located at Gulf of Suez, Port Said, Rasbenass, and around Lake Nasser. Areas of minimum speed are located at Del, El-Arish, Luxor, and in the Western Desert of Egypt around Siwa Oasis.

Annual distribution of annual resultant wind vector, like the distribution of mean wind speed, but with less order of magnitude, vector ranges from 0.6 to 4.8 m.s⁻¹. Areas of maximum resultants are located at the Gulf of Suez, Port Said, Rasbenass, and around Lake Nasser. Areas of minimum resultants are located at Delta, El-Arish, Luxor, and in Western Desert of Egypt around Siwa Oasis. By applying Equation 1, annual distribution of persistence P_j ranges from 25% to 70%. Maximum persistence is located around Minya, Hurghada, Rasbenass, and zonal belt around Lake Nasser.

On the other hand, low persistence is found over Delta, El-Arish, Luxor, and the Western Desert. This leads one to conclude that areas of high persistence such as that of south valley and around Lake Nasser are suitable to erect airports for steady wind direction in them. Besides, new towns planned in these areas could have better environmental impact when the designer takes into account the persistence distribution in these areas.

Direction of the annual resultant of wind vector shows that wind blows from steady direction (300°-

330° from north) over most northern parts of Egypt and blows from southwest to southeast (260°-060° from north) at southern boundaries of Egypt. Over Delta and around Siwa Oasis, it has a variable direction. Again, this makes it be easy to plan new towns in Egypt and get a better environmental impact when designer takes this results into account in the future.

From diurnal variation of wind speed in winter and summer at Port Said and Rasbenass, it is clear that the wind speeds are maximum from 9 UT and at Port Said in winter and 16 UT in summer. The high wind speed in summer may be due to the large contrast between land and sea surface temperature in summer than in winter. At Rasbenass, maximum wind speeds take place at 12 UT in both winter and summer. Besides, the variations of diurnal speed coincide in both seasons. This may be due to the location of Rasbenass that is not affected by pressure weather system invading south Europe.

Distribution of mean energy density and the maximum available energy density at 50 m above ground, one could see that mean energy density over Egypt at 50 m above ground level ranges from 100 to 1200 watt.m⁻², maximum available energy density ranges from 400 to 2300 watt.m⁻². Areas located around Hurghada, Port Said, Rashness, and around Lake Nasser up to El-Ouwaynat are promising places where wind farms can be erected there. Around El-Arish, Luxor, and Siwa Oasis, the expected power from wind may not be economic where its value is less than 200 watt.m⁻².

Wind vector in different seasons are westerly over the north coast of Egypt during the winter months, their speed ranges from 1.3 to 2.3 m.s⁻¹ (Table 1). Although the direction of resultant wind vectors is northwest in spring, summer and autumn, its magnitude increases in spring and autumn, where it ranges from 1.2 to 4.6 m.s⁻¹. However, highest wind speed over the north coast of Egypt takes place during summer months, ranging from 1.4 to 4.7 m.s⁻¹.

The direction of wind is southwest over Cairo City during winter. Its speed ranges from 0.4 to 1 m.s⁻¹. In summer, spring, and autumn, it is northerly to northeast and its speed ranges from .6 to 3.4 m.s⁻¹. The magnitude of wind vectors culminates in summer, where its speed ranges from 3.1 to 3.4 m.s⁻¹. Over the Suez Gulf, it is southwest to northwest and its magnitude ranges from 1 to 2 m.s⁻¹ in winter. In spring and autumn, it is northwest to northeast, and its magnitude ranges from 0.5 to 4 m.s⁻¹. In summer months, the resultant wind vectors are northwest to north, and its magnitude ranges from 1.7 to 4.3 m.s⁻¹. Over north Sinai, the resultant wind vector is westerly, and its magnitude ranges from 2.1 to 5.3 m.s⁻¹. In spring and autumn months, its direction is northwest to northeast and its magnitude ranges from 0.9 to 8.7 m.s⁻¹. The highest resultant wind vector occurs in summer where its direction is northwest to northeast and its magnitude ranges from 2.2 to 8.8 m.s⁻¹.

Over Middle Egypt and Upper Egypt, directions are northwest. In winter, changes to northeast in southern parts of Upper Egypt and its magnitude ranges from 0.6 to 4.7 m.s⁻¹. The highest magnitude occurs in autumn and summer over Upper Egypt, where its speed ranges from 0.4 to 5 m.s⁻¹. Along the coast of the Red Sea, resultant wind vectors are northwest during all months of the year, and their magnitudes are the highest ones among all other parts of Egypt, where their magnitudes range from 3.3 to 8.4 m.s⁻¹.

By applying procedures stated before and data series of extreme wind speeds at Hurghada station, it was found that the constant a in Equation 3 equals to 1.531. By applying the resultant model and taking $U_1 = 26.3$ m.s⁻¹ (the last term in the modified series), the forecasted wind speed after 20 years might be 26.7 m.s⁻¹. Harmonic analysis of series of monthly wind speeds at Siwa and Hurghada indicates that seasonal variation at Siwa station and semi-annual at coastal station variation plays an important role in wind speed variation at these two locations. By combining the harmonic of high variance, a forecast can be estimated.

CONCLUSIONS

From the above results one can conclude that maximum wind speeds, magnitude of wind vectors, and persistence are found mainly at coastal areas of Egypt and in the vicinity around Lake Nasser. In other parts of Egypt these variables are less order of magnitude. The direction of major wind at coastal areas and north of Egypt is mainly from northwest to northeast direction. Farther south of Egypt, it comes from the southwest to northeast direction. In most sites nearby or at coastal areas, the wind speed reaches a maximum in summer season. This may be due to the effect of high contrast between sea surface temperature and that of land in summer.

The forecasted extreme wind speed is close to the measure one. This may refer to the existence of stable weather conditions at most times of the year. Also, the *forecasted monthly wind speed by harmonic analysis is close to measured one*. It was found that mean energy density from wind at 50 m above ground level ranged from 100 to 1200 watt.m⁻². In the same time, maximum available energy density ranged from 200 to 2300 watt.m⁻². *There are many promising areas in Egypt in which wind farms can be erected*. These areas are located at Rasbenass, Hurghada, Port Said, and around Lake Nasser up to Elowainat.

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REFERENCES

- Cook, N.J. 1985. The designer's guide to wind loading of building structures. Part 1. Background, damages survey, wind data, and structural classification. Butterworths, London.
- Elliott, D.L., D.S. Renne, and K. Bassyouni. 1987. Energy resource assessment of Egypt. *Proceedings of the sixth "ASME Wind Energy Symposium"*, Dallas, Texas, 3: 215-216.
- Griffiths, J.F., and K. Soliman. 1972. The Northern Sahara Climate, *World Survey of Climatology*. Elsevier, Amsterdam. 10: 75-132.
- Justus, C.G., Hargraves, Amir Mikhail, and Denise Graber. 1977. Methods for estimating wind speed distributions. *J. AP. Met.* 17: 350-353.
- Jensen, N.O., Mann, and L. Kristensen. 1992. Aspects of the natural wind of relevance to large bridges, aerodynamics of large bridges. Balkema, Rotterdam, p. 25-32.
- Mortensen, N.G., and U.S. Said. 1996. Climatological tables and graphs for wind atlas stations, wind atlas for the Gulf of Suez. RISØ National Laboratory, Roskilde, Denmark, September 1996, 94-112.
- _____, L. Landberg, I. Troen, and E.I. Petersen. 1998. Wind atlas analysis and application program (WASP), Vol. 1. RISØ National Laboratory, Roskilde, Denmark.
- _____, L. Landberg, I. Troen, and E.I. Petersen. 1997. Wind atlas analysis and application program (WASP), Vol. 30. RISØ National Laboratory, Roskilde, Denmark.
- Panofsky, H.A., and G.W. Brier. 1958. Frequency of vectors, some applications of statistics to meteorology. The Pennsylvania State University, University Press, p. 13-24.
- Weibull, W. 1951. A statistical distribution function of wide applicability. *J. App. Mech.* 18: 293-297.

II. Application of New Technology

Strategies for Technology Transfer in India's Drylands

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ABSTRACT

Agriculture, including animal husbandry, is the mainstay of the economy in the Indian arid zone. Dryland agriculture is a real challenge for farm scientists and extension workers because it is risk-prone and the farmers are mostly resource-poor. Transfer of technology strategy for such farmers and farming has to be different from that with irrigated, resource-rich, and progressive farmers. Farm scientists and extension workers need to ponder over this and evolve an appropriate technology transfer strategy based on local needs and field experiences. This is an appropriate time to involve farmers, along with researchers and extension workers, in the generation, assessment, refinement, and transfer of technology at a faster rate.

In India, there are five technology transfer systems in vogue: (i) First-line Extension Education System being adopted by educational and research organizations, (ii) National Agricultural Extension Service (NAES)/ Training and Visit (T&V) System, (iii) Special Extension Programs on specific crops/problems, (iv) Rural Development Program, and (v) Extension efforts of the Non-Government Organizations (NGOs). The concerned Central/State Government Ministries have the main mandate for transfer of technology for Systems 2, 3, and 4 referred to above.

The first-line Extension Education System serves as a window through which extension agencies as well as farmers come in contact with the latest agricultural technologies. Their main objectives are to: (i) promptly demonstrate the latest agricultural technologies to farmers and extension workers, with a view to reducing the time-lag between the technology generation and its adoption; (ii) test and verify technologies under farmers' socioeconomic conditions, getting the first-hand specific feedback; (iii) providing training and communication support to the concerned State Departments/ Non-Governmental Organization; and (iv) develop extension models to be adopted by the general extension system for large-scale multiplication.

Some of the first-line extension education projects include: National Demonstrations Program, Operational Research Project (ORP), Lab-to-Land Project, Farm Science Centres (Krishi Vigyan Kendra), Institute Village Linkage Program (IVLP), and Technology Evaluation and Impact-Assessment Project.

INTRODUCTION

Agriculture, including animal husbandry, is the main stay of the economy in the drylands of India. The rainfall in the dryland areas is highly uneven and erratic. *Dryland farming is risk-prone, and the farmers are mostly resource-poor.* To reduce risk, dryland farmers diversify their farming systems. Dryland agriculture has been badly neglected compared with irrigated farming. Although India has achieved outstanding agricultural progress in its more favorable, irrigated regions, there has been little effect of "green revolution" technologies in dryland areas. This is a real challenge for the farm scientists as well as the extension professionals. This is an opportune time to highlight suitable strategies for generation, assessment, refinement, and transfer of technology for dryland areas. Transfer of technology strategy for dryland farmers/farming has to be different from those of irrigated, resource-rich, and progressive farmers.

India has a long history of extension work. Non-Government Organizations (NGOs)/voluntary agencies were first to initiate such action as early as the 1920s, i.e., Gandhian Experiment in Rural Reconstruction (1920), Sriniketan Project (1921), Marthandom Project (1921), Gurgaon Project (1927), Rural Reconstruction Movement (1932), and Indian Village Upliftment Scheme (1945). Later, Government institutions also took some initiatives in this direction, i.e., "Grow More Food" Campaigns (1942), Etawa Pilot Project (1948), Nilokheri Project (1947), and Sarvodaya Program (1948) (Prasad and Reddy, 1991). These efforts were *limited, sporadic, and lacked scientific planning* and an appropriate approach as a long-term development strategy.

The Community Development Program, launched in 1952, was the first organized national effort towards total rural reconstruction. This was followed by National Extension Service (1953), Panchayati Raj (1959), Intensive Agricultural District Program (IADP) in 1960, Intensive Agricultural Area Program (IAAP) in 1964, High-Yielding Variety Program (HYVP) in 1966, and Training and Visit (T&V) Program in 1974 (Prasad and Reddy, 1991).

At present, five-extension education/ transfer of technology systems are in vogue in India, each having its own mandate, approach and thrust. These systems are: (1) First-line Extension Education System, (2) National Agricultural Extension Service (NAES)/ Training and Visit (T&V) System, (3) Special Extension Program on Specific Crops, (4) Rural Development Program, and (5) Extension efforts of the Non-Government Organizations (NGOs).

The Ministry of Agriculture, Government of India, has the main mandate for transfer of technology. It has under its jurisdiction three Extension Programs (2, 3 and 4 out of the five systems referred to above). The First-line Extension Education System of the Indian Center for Agricultural Research (ICAR) is basically an institutional extension role, a catalytic role, and a supportive or complementary role to accelerate the pace of technology transfer. It serves as a window of educational and research institutions through which the extension agencies as well as the farmers can grasp the latest agricultural technologies.

Some of the extension efforts initiated since 1960s, including those on dryland agriculture, are the National Demonstrations Program since 1965, Operational Research Projects (ORP) since 1970s, Lab-to-Land Project launched in 1979, Farm Science Centres since 1974, National Agricultural Research Program (NARP), Institute-Village Linkage Program (IVLP), and National Agricultural Technology Project (NATP).

In the past, technology transfer in agriculture has been a "top-down" approach. As such, the information is transferred stepwise through publications, meetings, and some advisory and farm experimentation from researchers to field specialists, and then, with the aid of extension workers, to leading or innovative farmers and later to other farmers. The "top-down" strategy of technology transfer has brought a tremendous improvement in irrigated situations. However, this approach could not succeed on dryland areas where farmers practise complex, diverse, and risk-prone farming systems. For dryland areas, a "bottom-up" approach, where farmers are involved from planning stage, would be ideal strategy. The "participatory approach" with the basic elements of self-reliance and equity has demonstrated its capacity to improve lives and production systems of resource-poor farmers in dryland areas.

Now, the first-line transfer of technology programs are mainly being operated through Farm Science Centres (FSC/KVK) and NATP (Technology Assessment and Refinement - TAR) programs. In both programs, the "bottom-up" approach is being adopted. The FSC/KVK are the grass roots-level technology transfer and vocational training institutions designed for bridging the gap between the available technologies at one end and their application for increased production on the other. Initially, the mandate of FSC/KVK was only to impart training to farmers, farmwomen, and rural youth in agriculture and allied fields. Now, the mandate of FSC/KVK has been revised as vocational need-based training for self-employment, training on production technologies to farmers, farmwomen and grass roots-level extension workers, "on-farm" testing of new technologies, and front-line demonstrations. The transfer of technology programs such as National Demonstrations, Operational Research Projects, Lab-to-Land Project, have been transferred to FSC/KVK (Shukla et al., 1994). The FSC/KVK are designed to impart the latest knowledge to the farmers/farm women

through work experience by employing the principles of "Teaching by Doing" and "Learning by Doing".

The National Agricultural Technology Project (NATP) is designed to bring in needed reforms towards technology generation, assessment, and refinement before being disseminated to stakeholders. The project is also designed to introduce new models for technology dissemination with emphasis on institutionalizing research and extension linkage at the grass roots level. The NATP Programs are demand-driven, location-specific, multi-disciplinary and in program-mode; the planning processes are "bottom-up". The following transfer of technology Programs are being taken up under NATP (Kaul and Mittal, 1998):

1. **Technology Assessment and Refinement (TAR).** New technologies developed on research stations are tested by the scientists on farmers' fields to assess and refine them before transfer for large-scale adoption.
2. **Agricultural Technology Management Agency (ATMA).** To strengthen research-extension-farmer linkages and to provide an effective mechanism for co-ordination and management of activities of different agencies at the district level and below.
3. **Agricultural Technology Information Center (ATIC).** To make information, technologies, knowledge, planting materials, seeds, and consultancy, available to end-users through a single window system by research organizations.

Training of extension personnel, farmers, farmwomen, and rural youth has been the main component of different technology transfer strategies. The training has an added importance in dryland agriculture because of its highly diversified and risk-prone nature. It therefore requires more managerial skills on the part of farmers which could be brought to an improved level through proper training. Moreover, training of farmers, farm women and rural youth on a continuing basis is required in view of the fast changing agricultural technology and the increasing sophistication of farming systems.

There are several multi-tiered training institutions in the country for catering to the training needs of farmers and extension personnel. The training institutions at various levels and their target groups have been summarized below:

A. *National*

Country-wide network of ICAR Research Institutes, Project Directorates, National Research Centers and Trainers' Training Centers (Senior and middle management personnel), and National Institute for Rural Development and National Center for Management of Agricultural Extension (MANAGE).

B. *Regional*

Extension Education Institutes, State Agricultural Universities and Crop Directorates, Type of Participants: (Middle Management).

C. State

State Agricultural Universities, (Middle and lower management), State Agricultural Training Institutes, ICAR Research Institutes, (Farmers/Farm Women/Rural Youth), ICAR Project Directorates, ICAR National Research Centers.

D. District

Krishi Vigyan Kendra/Farm Science Centers (Lower management Farmers/Farmwomen/Rural Youth), Farmers' Training Centers, Regional Research and Sub Stations, Extension Training Centers, Gram Sevak Training Centers/VEW Training Centers, Agricultural Schools.

Primarily, two institutions, i.e., Farmers' Training Centres (FTC) and Krishi Vigyan Kendras (KVK)/ Farm Science Centres (FSC) are catering for the training requirements of farmers, farm women and rural youth. ICAR Institutes and State Agricultural Universities also impart training to farmers to a limited extent. The MANAGE, Extension Education Institutes, ICAR Institutes and State Agricultural Universities impart training to senior and middle level extension personnel and to the trainers of FTC and KVK/ FSC to refresh their knowledge.

A number of training approaches are possible and also available, though at varying levels of operation. These training approaches involve at least two of the six principal participants in training, scientists, subject-matter specialists, extension workers, farmers, NGO, and commercial organizations/ input agencies. Therefore, five models of training can be prepared as given below and all are used in dryland farming in India:

1. **Scientists - Farmers Model:** In this approach, the scientists directly train the farmers. There is no intermediary. This model has the advantage that the training is imparted by scientists themselves who are the repositories of scientific solution to farmers' problems and the latest technology. As a result, the training messages have the least possibility of distortion. Also, the farmers' problems can be provided with on-the-spot solution. However, due to paucity of time at their disposal, their main concern being

research and education, can cover only a small number of farmers.

2. **Scientists-Subject Matter Specialists-Farmers Model:** In this model, an intermediary, i.e., subject matter specialist (SMS) is introduced between the scientists-farmers linkage for training. Thus, scientists are required to train SMS who, in turn, are required to train the farmers.
3. **Scientists-Subject Matter Specialists-Extension Workers-Farmers Model:** This model introduces two intermediaries between the scientists-farmers linkage, i.e., SMS and extension workers. This model represents the training and visit system (T&V) of agricultural extension; SMS are trained by the scientists every month at State Agricultural Universities Regional Research Stations. They in turn impart training to extension workers every fortnight, and the extension workers then impart training to contact farmers regularly.
4. **NGOs - Farmers Model:** In this model, the NGOs directly train the farmers. NGO workers undertake training at ICAR Institutes/State Agricultural Universities and then they impart training to the farmers.
5. **Commercial Organizations/ Input Agencies - Farmers Model:** In this model, a commercial organizations/input agencies impart trainings to farmers in products of their commercial interest.

REFERENCES

- Kaul, G.L., and J.P. Mittal. 1998. National Agricultural Technology Project - *Main Document*, ICAR, New Delhi, India.
- Prasad, C., and H.N.B. Reddy. 1991. Extension strategy for minimizing risk in rainfed agriculture, pp. 1-25. In C. Prasad and J.P. Das (Ed.) *Extension Strategies for Rainfed Agriculture*, Indian Society of Extension Education, New Delhi, India.
- Shukla, A.N., G.G. Reddy, and N.K. Sanghi. 1994. Intervention of Krishi Vigyan Kendra (Farm Science Center) in Transfer of Technology, Sri Aurobindo Institute of Rural Development, Gaddipalli, A.P., India.

Future Trends of Technology Transfer for Egyptian Agriculture

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ABSTRACT

The successful application of technology transfer (TT) in the field of agricultural engineering has had dramatic effects in agricultural growth and development in Egypt. These effects are being felt throughout universities, government, and private and public industrial sectors. This work has been going on for more than three decades. The application of TT has changed the way that scientists exchange research knowledge, techniques, and ideas. In the past, public sector research in most developing countries was predominantly supported by governments, which mandated that public sector institutions freely serve society. Therefore, technologies generated by this sector were freely exchanged for research and development purposes without entering into any kind of commercial agreements. With the advent of new technologies, this trend is now changing. The Ministry of Agriculture has strategic plans to enhance TT through awareness-creation, human resource development, institutional development, information access, elimination of technology transfer barriers, and developing and following private sector rules in technology transfer.

INTRODUCTION

Technology transfer is moving technology from one area to another; it starts within the universities, research institutes, organization, among countries, and nowadays across continents within very short time periods through electronic networks. Technology can be transferred as applied academic research, information, knowledge, technical support, actual technology, and training. The actual cost of transferring in most cases in the past was free, especially to developing countries, but in the new world of paying for new technologies, transferring is achieved by licensing and selling according to specific terms and conditions agreed upon by both parties. In this case, a written agreement or a license is required. Meanwhile, between academic universities or research institutions, materials can be transferred for research purposes.

The necessity of TT has become increasingly important for developing countries, especially with the widening of the technology gap with leading countries. Drastic examples of the gap are reflected in advanced electronics in instrumentation and communication, biotechnology and genetic engineering, geographic information systems (GIS), and information technology. Efforts in TT have so far been needed, and will increasingly be so in the future.

Why Technology Transfer?

Technology usually is developed locally to solve local problems; however, the same technology may have applications in other places. In order for another place to be able to use the technology, it is necessary to provide a means of getting the technology to the area where it can be used. The technology must be transferred to other areas, societies in those areas also benefit. There are multiple benefits of technology transfer: *social, political, economical, and environmental*. Technology transfer not only means moving the actual technology, but also includes information, training, support mechanisms, and policies. Putting these prerequisites together requires integrated efforts and approach. The integrated approach to technology transfer includes the following areas:

Awareness Creation

Proper awareness of technology transfer issues must be created nationally among the *general public, policy-makers, scientists, and administrators*. Several ways and approaches are used to create this awareness, such as workshops, conferences, seminars, personal contacts, international and national exhibitions, information exchange through global communications, joint projects, and Non-Government Organizations (NGOs). Many international programs are involved in this process.

Human Resource Development

In order to access and manage technologies, well-trained people are needed. These people must be well versed in policy, technical and commercialization issues. Furthermore, those involved must also work together as a team so that communication is enhanced. Leadership and organizational skills of technology transfer managers, scientists, and industrial personnel are essential.

Training programs are essential for human skills development. Usually, training activities are mostly implemented at national training centers and run by professional instructors or carried out abroad at specialized facilities through collaborative training projects.

Egypt is considered a leading country in The Middle East and Africa for training activities. Most of professional staff in agriculture receives training in Egyptian training facilities.

Institutional Development

Technology transfer management is extreme importance in developed countries. Therefore, they exchange and commercialize their own technologies, potentially

generating revenues for further research and development globally. To meet these management levels in developing countries requires long-term efforts to link public and private institutions. The U.S.A and other developed countries have gone through similar experiences and have adjusted their policies and institutional framework accordingly. This provided the basis for public and private sectors' Intellectual Property Rights (IPR) protection and technology transfer practices. Taking advantage of these changes, public sector institutions have reacted quickly and strengthened their IPR protection and technology transfer framework through the creation of formal offices at universities and research Institutions.

The Egyptian Government issued the first law and established innovation protection office in Cairo on patents, design and industrial models (No. 132, 1949) and its modification by law No. 47 (1981). The main features of this law are the protection of new industrially exploitable inventions, new methods or processes of manufacture, and new application of methods or processes already known. Recently, the Egyptian Government established a contact office to strengthen relations among concerned institutions nationally and internationally.

Information and Communication Facilities

Information is an integral part of the technology package. Without appropriate information, technology is of little use. Meanwhile the parties involved in technology transfer must communicate with each other. Finding the right person to facilitate this communication is essential. With the advancement of computer and satellite technologies, Internet communications are becoming extremely popular, and all of these serve as a source of information. There are several methods of spreading information. During the last two decades, technology transfer has been implemented rapidly in the agricultural sector. Central administration of extension plays an important role in providing information by the following:

- Enhance partnership relations between universities and industry to disseminate new discoveries from the laboratory to the market for the benefit of society.
- New discoveries from universities and research institutes have been transferred to help farmers and private companies.
- Improve agricultural publications such as agricultural journals, leaflets, brochures, and extension posters.
- Increase number of agricultural programs through Egyptian TV channels and radio stations.
- Today, extension at village, district, and governorate level spreads information during field days, field demonstrations, and farmers meetings.
- Extension departments should encourage farmers and investors in "old" and "new" lands to

participate in and visit exhibitions which enable visitors to update their knowledge and become acquainted with new technologies.

- Several programs of on-the-job training have been held in different subjects.

Technology Transfer Barriers

- Lack of communications among concerned institutions.
- Shortage of applied research due to weak links and poor relations between private sector and research institutes.
- In some cases, the government spreads free information.
- Government considers technology transfer activities as mandate duties.
- Lack of confidence between industry and academic institutions for problems' solution.
- Some industrialists believe Government should get solutions for all existing problems.
- Shortage of research funds allocated for agricultural community development.
- Absence of extension staff in universities; therefore, most research is theoretical rather than practical.

Private Sector Role in Technology Transfer

- Private companies should establish specialized NGOs, either in agriculture or in an industry, to identify common problems and transfer problems to concerned universities or research institutes under specific agreements.
- Private sectors should allocate funds for research and development for better products.
- Strengthen linkages between companies, universities and research institutes for technology transfer agreement negotiations for technologies coming to the concerned research institutes, and those going from concerned research institutions to beneficiaries.
- The private sector should carry out information dissemination.
- Agricultural journals should be increased, as should the number of specialized fairs.
- A number of agricultural service companies have been established during the last two decades and should be increased to generate new technologies and introduce updated information.
- Creating an environment for commercialization of usable products.
- Universities and research institutes should work closely with private companies to develop appropriate in-country workshops and technical training programs.

Impacts on the Global Community and Future Directions

We live in a global market place. Countries are increasingly trying to work together to access each other's technologies. New technologies play an important role in enhancing the productivity of the agricultural sector to feed the world's growing populations. Their access requires countries and institutions to have appropriate national and institutional policies to manage the technologies - especially in intellectual property rights and biosafety. In addition, the countries must meet global treaty requirements (e.g., GATT/ WTO, Convention on Biological Diversity, and Union International pour la Protection des Obtentions Végétales (UPOV)). Many developing countries have taken positive steps and began developing capacity and supporting policies to develop a sound national technology transfer system. Since most of the biotechnologies reside in the private sector of the developed countries, multinational companies are beginning to explore overseas markets which already have sound technology transfer systems.

REFERENCES

- Barton, L.H., and B. Bedford. 1993. Intellectual Property Rights: the ABSP Intellectual Property/ Patent Workshop. *Biolink* 1, 4, Agricultural Biotechnology for Sustainable Productivity Project, Michigan State University, East Lansing, MI., USA.
- Council on Governmental Regulations (COGR). 1998. Managing externally funded programs at colleges and universities: A guideline to good management practices. *Principle IX: Intellectual Property*.
- Erbisch, F.H., and K.M. Maredia. 1994. Intellectual property rights in agricultural biotechnology. *Biotech. Agric Series No. 20* CAB International, U.K.
- Maredia, K.M. 1995. ABSP workshop targets intellectual property rights in developing countries. *Biolink* (2): 2-3, Agricultural Biotechnology for Sustainable Productivity Project, Michigan State University, East Lansing, MI., USA.
- Maredia, K.M., and J.H. Dodds. 1994. Agricultural biotechnology for sustainable productivity: A unique initiative in USAID research and development. p. 449-450. *Proceedings: 3rd International Symposium on "Biosafety Results of Field Tests of Genetically Modified Plants and Microorganisms"*. Nov. 13-16, 1994, Monterey, CA., USA.
- Maredia, K.M., F.H. Erbisch, and J.H. Dodds. 1996. Strengthening technology transfer framework in developing countries: A Michigan State University internship program." *J. Assoc. Univ. Technol. Managers* 8: 21-32.

Strategy for Brassica Improvement for Arid Environments

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ABSTRACT

The studies on the improvement of Brassicas, particularly Indian mustard (*Brassica juncea* L. Czern & Coss), for stress conditions started with the inception of this project. The early breeding efforts consisted of acquiring the maximum number of germplasm lines, testing them under stress conditions in the field, and evaluating for seed yield and its attributes. The screening of the germplasm on conserved soil moisture in a highly variable climate of Hisar, India, led to identification of some genotypes suited to these environments. Under these conditions, stress is invariably experienced at the reproductive stage. To enhance the stress tolerance ability of Indian mustard, interspecific crosses with Ethiopian mustard (*B. carinata* A. Braur), the most drought-tolerant among oleiferous *Brassica* species, was initiated. The breeding program culminated in the release of genetic material having early maturity, higher dry matter yield, high harvest index and high seed yield under stress conditions. The hybridization program for generating material for medium rainfall areas consisted of interspecific crosses involving *B. juncea* and *B. napus*. The material generated was tall and late with high dry matter and long and more primary and secondary branches. The experiment, aimed at breeding short duration and tall genotypes with improvement in seed weight, involved interspecific crosses between *B. napus* and *B. campestris* var. *Toria*

INTRODUCTION

In India, three species of *Brassicas* and their different forms have been in cultivation from the prehistoric times. In the early periods, three forms of *B. campestris*, viz., variety *Toria*; var. brown *sarson* and var. yellow *sarson*, were preferred by ancient farmers due to their high oil quality. *Eruca sativa*, a related member of this group, was grown under very late and stress conditions on poor soils. Later on, the cultivation of Indian mustard (*B. juncea* Czern & Coss) gained momentum due to its high yield potentials and tolerance to diseases and pests. Now, 70% of the area under *Brassica* is covered by this species in India. This group, commonly known as rapeseed and mustard, are grown in the winter season in India and are adapted to rainfed conditions and low input and poor management, resulting in low yields. These crops are grown as a single crop a year on conserved soil moisture in light-textured soils with limited water-holding capacity.

Domestication, breeding, and selection have greatly reduced genetic variability in these crops. Wild relatives of *Brassica* with rich source of genetic variability have been used for introgression of desirable traits through wide hybridization (Warwick and Black, 1993; Chopra *et al.*, 1996). Transfer of many useful traits from different donors have been reported in the alloplasmics of crop *Brassicas*, e.g., dwarfness and early flowering to *B. carinata* from *B. oleracea* (Parkash and Chopra, 1991).

As these *Brassicas* are grown under rainfed conditions on conserved soil moisture and with very little precipitation in the growing season, medium to high water deficit is experienced at the reproductive stage and a good percentage of harvest is lost under stress-prone ecosystems (Boyer, 1982), particularly in Indian conditions where farming is mostly at the mercy of the weather conditions. Improving the drought tolerance of crop species has long been a major objective of most breeding programs, as water deficits during some part of the growing period are common to most crops. Studies have been carried out to identify factors involved in drought tolerance and using them as selection criteria (Varshney, 1980; Singh *et al.*, 1988; Sangwan, 1996). Very little information is available on the existence of usable genetic variability for drought tolerance in *Brassicas*. However, Ethiopian mustard (*B. carinata*) is adapted to moisture stress due to in-built capacity of extracting more moisture at the reproductive phase (Anand *et al.*, 1985; Kumar *et al.*, 1987).

Keeping the above facts in mind, it was planned to upgrade the present cultivated *Brassicas* through interspecific hybridization to introgress the desirable attributes in a good agronomic base and impose selection pressure on characters associated with drought tolerance. The present study, therefore, was undertaken to achieve the broad objective of improving the local cultivars of *Brassica* species by introgressing the desirable genes from newly introduced *Brassica* species for stress conditions, particularly the arid environments.

MATERIALS AND METHODS

The present study was carried out as a part of regular research work being done under the All India Coordinated Research Project on Dryland Agriculture (AICRPDA) at the main center of CCS Haryana Agricultural University, Hisar (29° 10' N latitude and 75° 45' E longitude). Advanced generation materials of interspecific crosses (*B. juncea* × *B. carinata*; *B. juncea* × *B. napus* and *B. napus* × *B. campestris* var. *Toria*) were grown during the years 1996-97 to 1998-99 in furrows under a ridge-furrow system. The actual

crosses involving variety RH-30 of *B. juncea*; HC 2 of *B. carinata*, GSH-1 of *B. napus*, and TH-68 of *B. campestris* var. *toria* were affected during the year 1989-'90. The rigorous selections were made in F₂ and F₃ generations. Selected material was advanced to F₆ generation before evaluations in yield trials.

The material was sown in July, on conserved soil moisture following precipitation received from S.W. monsoons during July-September, in randomized block design with three replications having 2-rowed plots of 5-meters length at 30 cm apart. The plants were spaced at 10 cm apart within rows. The material was evaluated for seed yield and its attributes under rainfed conditions. The rainfall, temperature, and soil moisture values at different stages were recorded. The observations on characters associated with stress tolerance, viz., water loss % by plants, days to maturity, dry matter/plant at different growth stages, harvest index and other ancillary characters were recorded in the field on five randomly selected plants in each entry per replication.

The statistical analysis was done following standard procedures. Stability estimates of seed yield were calculated following Eberhart and Russell (1966).

RESULTS AND DISCUSSION

Genetic Variability

The interspecific crosses generated a large amount of genetic variability for various morphological and agronomical attributes in the alloplasmics of Brassicas in F₂ and F₃ generations, which enabled the selection of large number of variants/morpho-types. There was, in general, an overall increase in the mean values of the resultant populations of different interspecific crosses compared to the individual species. The results showed an indication of genetic inflow/ introgression of one species to another. A number of studies (Batra et al., 1989; Batra, 1992; Rao and Shivanna, 1997) on the introgression of useful genetic variability for desirable attributes by interspecific hybridization between different cultivator and wild species Brassicas have been reported. An unexpected spectrum of morphotypes exhibiting huge amount of genetic variability were observed, and many of them were fixed by genetic manipulation for general use.

Most notable observations in the resultant populations of the interspecific crosses in this study were: an increase in plant height, days-to-flowering and days-to-maturity, pods/plant and decrease in pod length in *B. juncea* × *B. carinata*; increase in plant height, primary and secondary branches, pod number/ plant and 1000 seed weight in *B. juncea* × *B. napus*; decrease in plant height, days-to-flowering and days-to-maturity; and an increase in number of primary and secondary branches and 1000-seed weight in *B. napus* × *B. campestris* var. *toria*.

Performance and Phenotypic Stability

In the present material, the interspecific cross of *B. juncea* × *B. carinata* through the desired combinations, retained the early maturity and 1000-seed weight intact and increase in the mean values of ancillary characters from the pollen parent. Selections DLARH 1 to DLARH 81 exhibited overall improvement in seed yield and its components. Among these, DLARH 41 and DLARH 81 recorded the highest yield in the genetic material in hand. DLARH 81, with high mean yield (2.61 t/ha), regression coefficient 'B' near unity (1.43) and low deviation from regression S_d^2 (1.98), was the ideal plant type for a rainfed environment.

Other three selections, viz, DLARH 1, DLARH 9 and DLARH 26 from the same cross, also showed better and stable performance. Selection DLARH 41 was a high yielder (24.59 q/ha), unstable ($S_d^2=7.88$), but showed a response to changing environments ($b=0.43$), thereby indicating its capacity to yield even higher in better climatic conditions.

The second interspecific cross of *B. juncea* × *B. napus* was aimed at bringing together the yield potential of RH 30 (*B. juncea*) and pod length and seeds/ pod of GSH 1 (*B. napus*) for rainfed environments with medium-to-high rainfall. It is interesting to observe that in two of the selections, viz., DLARH 185 and DLARH 249, an increase in pod length, seeds/ pod and 1000-seed weight indicated the introgression of genetic material from *B. napus* × *B. juncea*.

In the third interspecific cross between *B. napus* × *B. campestris* var. *toria*, the objective of getting segregant for rainfed areas with high precipitation having yielding ability of *B. napus* and 1000-seed weight, earliness and short plant-type of *B. campestris* was possible to some extent. The reduction in plant height and days-to-maturity was induced in most of the selections made in the population of this cross. However, there was an increase in 1000-seed weight.

Drought Tolerance

The interspecific cross involving *B. carinata* and *B. juncea* was specifically undertaken to impart drought tolerance in the progenies of the cross, particularly at the reproductive phase. *B. carinata* has the capacity to extract more moisture at this stage than other cultivated species. The material was tested for drought-related traits, viz., dry matter yield/ plant, harvest index, seed yield/ plant, seed yield, and water loss by plants after detachment at different intervals.

Early maturing selections had the advantage of converting more dry matter at early stages as observed in selections DLARH 26, DLARH 41 and DLARH 81. These genotypes also lost less water than others, thus showing more capacity to retain moisture after detachment. The selections from this cross also had a high harvest index (29 to 33) and high yield/ plant. Thus, adopting of *B. carinata* as a donor for imparting drought tolerance is in the right direction as reported by Subhudhi et al. (1994).

The crosses involving *B. juncea* × *B. napus* and *B. napus* × *B. campestris* via *toria* were intended to get recombinants which can perform better in different environments. The mean values were of lower order for drought-related traits in these two crosses.

CONCLUSIONS

Utilization of HC 2 of *B. carinata* as a potential source of drought tolerance in the improvement of *Brassicas* for rainfed environments has been demonstrated in this study. There was ample evidence of introgression of genetic material from one species to another in the form of generation of a large spectrum of genetic variability for different morphological traits in the population of interspecific crosses. The improvement in yield and its stability and drought-related parameter was achieved in some of the selections. The desirable combinations could be obtained by interspecific crossing in *Brassicas* and breeding plant types for different agroclimatic conditions was possible.

REFERENCES

- Anand, I.J., J.P. Singh, and R.S. Malik. 1985. *B. carinata* - A potential oilseed crop for rainfed agriculture. *Cruciferae Newsletter* 10: 76-79.
- Batra, V. 1992. Hybridization between cultivated *Brassicas* and their two wild relatives. *Ph.D. Thesis*, Univ. Delhi, India.
- Batra, V., K.R. Shivanna, and S. Parkash. 1989. Hybrids of wild species *F. gallicum*, and crop *Brassicas*. p. 443-446. *Proc. 6th Inter. Congr. SABRAO*, Japan.
- Boyer, J.S. 1982. Plant productivity and environment. *Science*. 218: 443-447.
- Chopra, V.L., P.B. Kirti, and N. Parkash. 1996. Accessing and exploiting gene of breeding value of distant relatives of crop *Brassicas*. *Genetica* 97: 305-312.
- Eberhart, S.A., and M.A. Russell. 1966. Stability parameters for comparing varieties. *Crop Sci.* 6: 36-40.
- Kumar, A., D.P. Singh, and P. Singh. 1987. Genotypic variation in the responses of *Brassica* species to water deficits. *J. Agric. Sci. (Camb.)* 109: 615-618.
- Parkash, S., and V.L. Chopra. 1991. Male sterility caused by cytoplasm of *B. oxyrrhea* in *B. campestris* and *B. juncea*. *Theor. Appl. Genet.* 79(2): 285-287.
- Rao, G.U., and K.R. Shivanna. 1996. Development of new alloplasmic CMS *B. napus* in the cytoplasmic background of *Diplontaxis*. *Cruciferae Newsletter* 18: 68-89.
- Richards, R.A. 1978. Genetic analysis of drought stress response in rape seed. *Euphytica* 27: 609-615.
- Richards, R.A., and N. Thurling. 1978. Variation between, and within species of rapeseed N response: I. Sensitivity at different stages of development, II. Growth and development under drought stress. *Aust. J. Agric. Res.* 29(3): 469-490.
- Sangwan, R.S. 1996. Yield stability of Indian mustard genotypes under dryland conditions. Presented in 3rd Nat. Agric. Sci. Congr. (P.A.U., Ludhiana), India.
- Subhuddhi, P.K., and R.N. Raut. 1994. Genetic analysis of yield, and its component traits in Indian mustard-Ethiopian mustard interspecific cross. *Indian J. Agric. Sci.* 64(3): 171-175.
- Varshney, S.K., B. Rai, and B. Singh. 1986. A comparative assessment of the harvest index, and other economic attributes in three cultivated species of *Brassica*. *J. Oilseed Res.* 3: 158-163.
- Warwick, N.I., and I. Black. 1993. Guide to the wild germplasm of Brassica and Allied species. *Agric. Canada Res. Branch Tech. Bull.* 161.

XIII. Role of NGOs and Indigenous Knowledge

Integrating Indigenous Knowledge and Modeling for Agropastoral Systems Development

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ABSTRACT

Planning for dryland agropastoral systems development requires the integration of a range of quantitative and qualitative biophysical and socio-economic information. A Geographic Information Systems (GIS) database and set of spreadsheet models form an effective platform by which to model the production system and their components at a variety of scales. The process involves the capture of indigenous knowledge through participatory research to formulate the decision rules for the planting of cereals in relation to rainstorm events and soils and the movement of small ruminants for grazing. The models are used to estimate the dimensions of the small ruminant "feed gap" in good, average, and poor rainfall years in an area on the northwest coast of Egypt and to examine the potential for rangeland improvement and the introduction of fodder shrubs on feed resources.

The study indicates that small ruminant production relies on purchased feeds, even in a year of good rainfall. More barley is consumed than produced in all years, with only two of three agroecological zones showing a barley surplus in a good year. Average rainfall years exert more pressure on the system, as indicated by the level of hand-feed use, than poor ones because in the latter case many animals are removed from the area for drought grazing in the Delta. The GIS database was used to determine the potential in the area for rangeland improvement and the introduction of fodder shrubs as a substitute for purchased concentrates. About half of the rangeland in the area has soils and water accumulation to allow improvement. The introduction of *Atriplex* spp. interplanted in barley fields could reduce concentrate use by almost half in good rainfall years, but would contribute one quarter or less in average and poor years.

INTRODUCTION

Agricultural activity in semi-arid lands in the West Asia - North Africa (WANA) area is dominated by range - dependent small ruminant production systems. Sedentarization and other forces have led to increasing small ruminant populations, expansion of rainfed barley into marginal lands, degradation of rangeland, and an increasing dependency on purchased feeds (FAO,

1995). A variety of technological solutions have been proposed to address this "feed gap" and reduce natural resource degradation (Haddad and Tutwiler, 1994) to be adopted by producers. Solutions must be technically appropriate for their production systems and recognize their biophysical and socio-economic resource constraints.

It is now widely recognized that participatory-based natural resource management and agropastoral development activities have significantly greater potential for sustainable results (Waters-Bayer, 1994). A critical problem in such projects is the challenge of integrating in a practical, cost-effective manner, the wide range of necessary formally and informally gathered, quantitative and qualitative biophysical and socio-economic information to ensure that needs are met, constraints identified, and practical solutions are generated.

The research addresses this problem by the use of a GIS database of biophysical and socio-economic information, coupled with simple spreadsheet models at the commodity and household scales, which describe the main elements of current production systems under simplified "good", "average" and "poor" rainfall conditions in a study area on the NW Coast of Egypt. This can be used both in diagnosis and to produce a preliminary evaluation of possible technological development options at the household level and, by aggregation, a variety of other scales in the area. In this paper, the methodology for database development is outlined and the databases used to examine the dimensions of the small ruminant feed gap and provide a preliminary evaluation of the potential for rangeland improvement and the impact of the introduction of fodder shrubs as a substitute for purchased feeds.

CONTEXT

The study area comprises two watersheds (Wadi Naghamish and Wadi Garawla) 270 km west of Alexandria. Mean annual rainfall is 144 mm with a coefficient of variation of 45% and high spatial variability. There are three agroecological zones: *Zone 1* (coast - 5 km inland) has the deepest soils and highest rainfall; production systems are predominately orchards (figs and olives), with cereals and some rainfed vegetables. *Zone 2* (5-15 km) has fewer orchards and more cereals and small ruminants. *Zone 3* (15-25 km) is dominated by livestock production, small ruminants,

and to a lesser extent camels, with cereal production. Total Bedouin population is approximately 1800 in 107 extended households. The formerly semi-nomadic population began becoming sedentary in the 1960s, and the process is now complete. With sedentarization, the small ruminant population has grown considerably in the past three decades, and the natural environment degraded.

The small ruminant production system in the area is based on winter rangeland grazing, movement of flocks to the cereal fields for stubble grazing after harvest, and several months on hand feed (barley and concentrates) prior to returning to the range again. In drought years, many animals are moved to irrigated areas at the fringe of the Nile Delta to survive on cultivated forage or residual vegetation.

Estimating Animal Numbers and Feed Consumption

To generate the small ruminant feed budget under each of the three rainfall scenarios, it is necessary to estimate the number of animals in the system in each rainfall-year type and the local and purchased feeds consumed. The number of flocks and their sheep/goat composition under the "good" rainfall scenario were determined from an initial survey of all households, supported by key informant interviews. Adjustment factors based on such interviews were used to estimate the numbers for the other rainfall scenarios. A summary of total animal numbers is provided in Table 1. Of the 80 flocks in the study area, 72% are mixed sheep and goats, 21% are goats only and 6% sheep only. The flocks ranged in size from less than ten animals to over 500.

hand-feed consumed daily per animal and the percentage of the animal's total daily diet derived from grazing rangeland or cereal stubble. For each flock type in each location, hand-feeds were converted to Scandinavian Feed Units (FU) to allow for comparison and aggregation.

Hand feed consumption (excluding straw) by small ruminants in each year type for each flock type generated from the feed calendars and animal numbers is shown in aggregate form in Table 2. In addition to barley grain, hands feed comprise manufactured concentrates and maize, which is used primarily for goats. Total hand-feed consumption was highest in Zone 1, reflecting the size of the animal population, but the maximum consumption occurs in an "average" rainfall year rather than "poor", since in that type of year production of cereals and annual rangeland vegetation is reduced. The lower total for the "poor" year is caused by flock components being moved to drought grazing on the irrigated lands adjacent to the Nile Delta.

Estimating On-Farm Cereal Production

The principal on-farm feed crop is barley and wheat based on run-off cultivation with the area planted each year and the proportion planted to barley and wheat varying each year in relation to rainfall conditions and soil type, as well as other factors such as availability of seeds and personal circumstances. Given the limited land base and variability in precipitation, Bedouins attempt to maximize the cereal area planted each year to support their small ruminant flocks.

Bedouin cereal-planting decisions are largely determined by the amount/ intensity of rainstorms, their timing of occurrence, and the type of soil in their cereal

Table 1. Number of small ruminants and movement.

<u>Zone</u>	<u>Good Year</u> -----No.-----	<u>Move Outside</u> ----%----	<u>Average Year</u> ----No.----	<u>Poor Year</u> ----No.----
1	2801	69	2370	2171
2	2103	68	1691	1539
3	1010	43	828	760
Total	5914	64	4890	4469

Many Bedouin move all or some parts of their flocks for grazing, depending on rainfall, flock size, and flock composition. Key informants in each zone identified the grazing resources used both range and cereal stubble within and outside the study area and the differential use of these resources by flock size and composition, as well as periods on hand-feed. The percentage of animals which move outside their zone for grazing remains approximately the same in the different rainfall years; however, the time spent outside is longer in "good" years.

To determine feed consumption, feed calendars (Goodchild et al., 1994) were constructed with key informants to determine the types and quantities of

land. To estimate the area planted under each rainfall year scenario, Bedouin indigenous knowledge was employed. Local terms for rainstorm events were ascertained. Two storm sizes were found to be critical: *Sale*, 8-14 mm, and *Salezein*, 15 mm+, their quantitative values being determined from rain gauge records. For soils, the Bedouin nomenclature was determined by participatory transects and participatory mapping of selected areas. A complete Bedouin soils coverage for the study area was produced from a SPOT 20 m. XS image using locations from participatory mapping as training sites. The Bedouin soil type for each cereal field was then determined by GIS overlay of cereal fields and the area of each type calculated.

To relate planting decisions to the rainstorms and soil type, decision-tree models (Gladwin, 1989) were constructed with key informants in each zone, relating storm timing and intensity to soil type. The resulting models were applied to the cereal field data to estimate the area planted in each zone under the three rainfall scenarios. Data on yield of barley by Bedouin soil type for these scenarios was collected from key informants in each zone and used to generate estimates of total production.

degrees are suitable for water harvesting (FAO, 1995). Shallow soils with depth less than 30 cm were excluded. Water accumulation was problematic because of a lack of directly measurable data. Flow accumulation (ESRI, 1996) as generated from a Digital Elevation Model (DEM) was substituted. However, this assumes that all rain becomes runoff with no loss by interception, infiltration, or evaporation. The flow accumulation values generated were categorized simply as low, medium, and high.

Table 2. Small ruminant hand feed consumption in various years

<u>Zone</u>	<u>Year</u>	<u>Barley Grain</u>	<u>Maize</u>	<u>Concentrates</u>	<u>Total</u>
-----Feed Units-----					
1	Good	223609	0	75261	298870
	Average	32839	126401	307703	466942
	Poor	0	0	339785	339785
2	Good	63363	0	75726	139362
	Average	154604	54645	176831	386080
	Poor	106159	0	146850	253008
3	Good	20303	0	45196	65498
	Average	41832	0	39589	72421
	Poor	24610	0	154289	178899
Total	Good	307547	0	196183	503730
	Average	229275	181046	515123	925444
	Poor	130769	0	640923	771691

The Feed Gap and its Dimensions

The overall dimensions of the "feed gap" in the study area are indicated by adding the deficit/surplus in barley production to the consumption of concentrates and maize; an overall barley deficit occurred in all three rainfall-type years. The surplus in Zones 2 and 3 in a "good" year being offset by the deficit in Zone 1. When concentrates and maize are included, the total deficit increases twofold in an average year. The difference between barley production and consumption reflects the importance of transfers in the system from other areas of the northwest coast, either in the form of purchased grain, or by Bedouin share-harvesting for a percentage of grain and straw in the main cereal producing areas west of Marsa Matrouh.

In order to estimate the potential impact of rangeland improvement and fodder shrubs addressing the current feed gap using the project GIS databases, two activities are explored under the three rainfall scenarios: rangeland improvement supported by some form of water harvesting and the interplanting of *Atriplex* spp in cereal fields.

Potential for Rangeland Improvement

The area with potential for rangeland improvement in the study area was estimated using GIS overlay procedures. Three criteria are used; slope, soil depth, and water accumulation. For slope, areas less than 5

Currently cropped land (orchards and cereal fields) were excluded and the values for slope, soil depth, and flow accumulation were combined to generate an overall value for potential improvement of rangeland on a scale of 1 to 5. Only Classes 3 through 5 are considered as having potential. Overlay with parcel boundaries permits estimation of the area of each parcel which can be improved, and by aggregation Zone 1 and study area totals.

The analysis indicates that 42% of the 5658 hectares of rangeland in the study area could be improved based on the criteria selected. However, 54% of the improvable area is communal *Alia* grazing, which, if improved, might face problems either of overuse or of possible individualization. Of the land presently belonging to individual households, 60% of rangeland in Zone 3 has potential compared with only 30% in Zones 1 and 2.

Interplanting of *Atriplex* in Barley Fields

The planting of *Atriplex* in widely separated rows in barley fields has the potential to provide feed for small ruminants during the autumn. For the purposes of this paper, the following assumptions are used. Given a feed value of 0.35 FU/kg/DM after three years, *Atriplex* could produce about 0.5 kg/DM/shrub/year (Le Houérou, 1992), the equivalent of 0.175 FU per shrub.

Planting at 20 m between rows (1947 shrubs/ha) would generate 170.45 FU/ha/year. These are very conservative yield estimates for the *purposes of demonstration only*; yields could be double those used here (Hakkim, M., 1998, *personal communication*). It is assumed that this shrub is most suited to Zones 1 and 2 and that the practice is adopted on all cereal land.

The comparisons are made only in terms of replacement of purchased concentrates. In a "good" year, *Atriplex* could replace almost half the concentrates used in Zones 1 and 2; however, in "average" and "poor" years, this is reduced to approximately 10% in Zone 1 and 25% in Zone 2. The key element here as in other areas where fodder shrubs have been introduced, will be management of the resource to prevent destructive over-use, particularly under low rainfall conditions.

DISCUSSION

Although based to a large extent on respondents' estimates of feed consumption by their flocks, the techniques used here provide a rapid means to estimate the magnitude and changes in the production and consumption of small ruminant feeds in a highly variable low rainfall system. The variability in feed budgets both within a small area, and especially between rainfall type years, indicates the importance of designing interventions to meet the varying circumstances of producers and their resource base. The differential pressures on feed resources as demonstrated in these budgets emphasizes the need to adequately inform producers of appropriate management techniques to avoid their inad-

vertent destruction. Finally, a balanced approach is necessary. It has been repeatedly demonstrated in small ruminant production systems in this type of environment that removal of one constraining element in the system, be it water or feed, has invariably places pressure on the others.

REFERENCES

- ESRI, 1996. Using the ArcView Spatial Analyst. ESRI. Redlands. CA. USA.
- FAO, 1994. Water harvesting for improved agricultural production. *FAO Water Reports* 3. FAO, Rome. ITALY.
- FAO, 1995. Sustainable range-dependent small ruminant production systems in the Near East region. FAO Near East Office. Cairo. EGYPT.
- Gladwin, C.H. 1989. Ethnographic decision-tree modeling. Newbury Park. Sage.
- Goodchild, A., T. Nordblom, F. Shomo, S. Hamadeh, and R. Wachholtz. 1994. Using feed calendars to interface feeds with needs in Syria and Lebanon. *Third International Symposium on Livestock Farming Systems*. Aberdeen, UK.
- Haddad, N., and R. Tutwiler. 1994. Crop-livestock improvement in the Mashreq region. ICARDA, Aleppo, Syria.
- Le Houérou, H.N. 1992. The role of saltbush (*Atriplex* spp.) in arid land rehabilitation in the Mediterranean Basin. *Agroforestry Systems*, 18: 107-148.
- Waters-Bayer, A. 1994. Planning with pastoralists: PRA and more. GTZ, Eschborn. Germany.

Traditional Architecture in the Egyptian Desert

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ABSTRACT

This paper presents the results of analysis of different Egyptian desert traditional architectures. Egypt, covering about one million square kilometers, has 96% of its area as desert, which is distributed over different parts, namely, Northeastern, Northwestern, Southern, Southeastern and Southwestern. Architectural designs, symbols and patterns, use of natural building material, plans and facades, window openings, colors and finishing material for human shelters located in each of these desert parts reflect the prevailing climate, social, cultural and environmental conditions.

In the northeastern desert, indigenous architecture of the Sassanian, Phoenician, and Byzantine eras was clearly reflected in the traditional buildings of this area as seen in El Arish city and Sinai in general. In the northwestern desert (Siwa Oasis), the indigenous architecture is a reflection of neighboring Libya due to the interaction between the two cultures.

INTRODUCTION

The desert shelter is a reflection of its environment. In Egypt, desert architecture differs from one location to another, giving characteristic patterns, symbols, designs, openings, building material, all based on the local environment and patterns of life.

The northern part of the Egyptian desert is represented by Sinai in the east and Siwa Oasis, as well as Wadi El Natroun in the west. The southern part of the Egyptian desert is represented by the Nubian area, Dakhla and Kharga Oasis.

This paper attempts to (1) introduce the reader to the architecture of the above-mentioned desert areas, which is characteristic of its heritage, and (2) monitor this heritage and promote it when upgrading and developing these community.

ARCHITECTURAL ANALYSIS

The Northern Area

The Northeastern Part (Sinai)

The area of Sinai is approximately 61000 km² i.e., about 6% of the total area of Egypt. The desert tent is considered to be a major housing component. Buildings are made of clay or stone. Other building materials in Sinai include sand, gypsum, anhydrite, kaolin and marble.

The horizontal plan of these buildings shows a hospitality room, which occupies the main part of the building, bedrooms, kitchen, bathroom, a courtyard, an animal shed, as well as an area for cooking and baking bread.

The buildings are usually one or two floors with a flat roof, which used to be made of wood or palm tree trunks, and currently is made of concrete. Most of the openings are narrow and directed towards the inner part of the building. The residents of Sinai tend to have at least 10 meters spacing between their buildings and to use a tent in front of the house.

The North Western part

This is represented here by the Siwa Oasis and Wadi El Natroun. The Siwa Oasis is located at about 320 km southwest of Marsa Matrouh. A material called "Karsheif" is used for building construction. It is a very solid material composed of a mass of calcium sulfate, sodium chloride, and silicon dioxide. On the other hand, the roofs are made of palm tree trunks or olive tree wood with mud. For the foundation and the columns of the buildings, calcareous-material and sandstones are used. This combination gave an architectural form and pattern which blends with the natural environment.

The most characteristic aspects of the Siwa building are: The hospitality room; Multipurpose rooms; Kitchen, bathroom, baking area and animal shed; Courtyard; Walls are usually more than ½ meter thick with a façade, which is curved and covered with a 10-cm layer of "Karsheif"; The entrance of the building faces north; Kleems (indigenous carpets), mats (made of palm trees) and pillows are all colorful and with beautiful designs. It should be noted here that beds are not used in Siwa; Buildings are closer together for protection against sun radiation and outside openings are nearly absent.

The "Shali" village is a good representation of a basic clustering in Siwa oasis, in which the residents made use of the topographic relief. After the 1982 floods, which destroyed indigenous buildings, reinforced concrete was used to construct new buildings. The residents are not happy with this development and would prefer to use treated "Karshief". In general, the buildings suffer from open cracks and chapping as a result of high groundwater and agricultural sewerage.

Wadi El Natroun covers an area of 60 × 10 km. The name Natroun denotes the predominant mineral of hydrated sodium salts found in the dried lakebeds of the Wadi and used by ancient Egyptians in embalment processes.

Wadi El Natroun is famous for its old monasteries such as Saint Makarios, Baramoos, Bishoy, and El Seryan monasteries. The most important elements of *Monastery Architecture* are the church, the monks' housing building, the tower of bells, the fortress, the gate, storerooms and the water well.

The buildings are made of alternating bricks and stones separated by wooden veins and based on Byzantine architecture, which is known for its domes and vaults, arches and courtyards. Bricks, wood and palm tree trunks were used in some roofs. Fences of about 10 meters high are built around most monasteries (especially Saint Makarios Monastery). Most buildings are coated with a mixture of lime, gypsum, sand and clay giving it the coloration of desert sand. Roofs are not flat which helps in dispersion of sunrays. Walls are thick-surfaces are not at right angles but are curved, giving the site a beautiful primitive pattern.

The Southern Area

This area is represented here by Nubia, as well as the Dakhla and Kharga Oases. The name Nubia comes from "Noob" or "Nobo" which means gold, due to its proximity to golden mines. There are three communities living in Nubia: Konooz, El Arab, and the Nubians. Nubia is located 40 km south of Aswan.

The most characteristic aspects of the Nubian buildings are: Several bedrooms; The hospitality room is a basic element of the building; The inner courtyard which is covered with clean sand; A kitchen and bathroom as well as a baking area; The chicken shed is located inside the building, while the animal shed is located outside the building; The home furniture as well as the building facades is characterized by very bright colors.

Buildings are constructed from adobe bricks and clay, with roofing made of palm tree trunks and wood. However, these old buildings suffer from cracks resulting from high groundwater level. New buildings are constructed from concrete, bricks and stone, and contain modern equipment such as T.V, telephone, washing machine, and refrigerator.

Dakhla and Kharga Oases

These two oases were inhabited by ancient Egyptians followed by the Copts during the mid-second century to the fourth century AD. Their most important monuments are the Hybiss Temple and the Bagawat Cemetery, consisting of 263 shrines. The cemetery is located on the final slope of El Teir Mountain covering an area 500 m long and a maximum width not exceeding 200 m. The distribution of the different shrines was based on the topography of the site, with their facades overlooking passages, streets, valleys and high hills.

There are three basic characteristics of the Bagawat:

- The 263 shrines are constructed aboveground with adobe bricks. The shrines differ in size, pattern, and architectural elements, with beautiful colored drawings still shown on the walls.

- The principal graves are formed by digging under the rocks; each grave consisting of a well, 3-5 meters in depth, with two multi-purpose side rooms.
- Archaeological hills are located within the Bagawat buildings in the northern, northeastern, and north-western parts. Most buildings are made of adobe bricks. However, stone was used at doorsills, entrances, staircases and some columns. Adobe bricks were made out of clay to which straw was added. The bricks were in the form of rectangles or quadrants (quarter sections of a circle).
- All entrances are located in the south facing the city. The facades contained arches, squinches, and columns made out of bricks and coated with lime with light colors similar to the desert sand colors. There are several types of facade.
 - A. The Egyptian type similar to Type 1 with the addition of an arch supported by two columns; similar to Type 1 with a number of arches, the entrance is located in the middle arch.
 - B. A simple entrance with no decorations.
 - C. The façade consists of a number of decorated arches with no reflection of the Egyptian type, and three arches instead of only one arch.
 - D. More than three arches, with squinches on the sides of the entrance: Lighting for these types comes from small openings of 25-45 cm width.

Needless to say, there is social mobility and changes in the life pattern of the above-mentioned desert communities resulting from application of new technologies, such as electricity and television, as well as exposure to other communities and introduction of educational centers. This social mobility must be accompanied by plans and designs leading to promising urban development appropriate with the pattern of each community and conserving their architectural heritage.

RECOMMENDATIONS

The following courses of action should be adapted:

1. Protection of this cultural heritage through the support of universities and specialized agencies.
2. Preparation of plans and designs through a field survey and identifying appropriate conditions and regulations for each area.
3. Promotion of the use of environmental materials such as clay, silt and "karsheif" after its appropriate treatment to withstand natural disasters such as earthquakes and floods, and to maintain body comfort.
4. Contribution of Faculties of Engineering and Fine Arts to the preparation of a demonstration manual for each area, including new approaches for maintenance and development of the traditional architecture.
5. Taking necessary steps towards considering some of these areas as "National Parks"; Siwa Oasis could be a starting point.

6. Encouragement of specialized tourism to these areas and ensuring their protection against destruction and excessive modernization.

In conclusion, every effort should be made to respect and conserve our cultural heritage and indigenous environment.

REFERENCES

- Academy of Scientific Research and Technology. 1991. Research Authority for Sinai Development.
- Fakhry, A. 1989. Towards awareness of a Contemporary Civilization. The 1000-Book Project. Book # 14, Egyptian Organization for Archaeology.
- Rateb, H.K. 1995. Sinai, Egypt's Gate for the 21st Century. Arab Egyptian Center for Publishing and Information, Cairo, Egypt.
- Institute of Environmental Studies and Research. 1998. Ain Shams University - A Report on the new Nubian area.
- Saleeb, M. 1994 Fine Arts College. Helwan University. Private communication.
- Ministry of State for Scientific Research: " Sinai Development Project"
- Salkiny, M.E. 1994. Architecture and Environment. Kabbis Publishing House.
- El Nahas, O. 1987. Desert Architecture, Anglo American Bookshop.

C. POSTER SESSION

Soil Conservation and Degradation

Dry Atmospheric Fallout: Secondary Irrigated Land Salinization

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INTRODUCTION

Irrational human economic activity has resulted in an increase of chemical pollutant emissions into the atmosphere. Solid suspended particles of different chemical composition also get into the atmosphere from the natural sources: seas, oceans and lakes, and from deserts, and irrigated areas. Intensity of the process depends on many factors: *temperature, humidity, velocity, and direction of wind* and others. In the main, suspended particles are being removed out of the atmosphere with wet (precipitation) and dry fallout, and eolian transfer. Distance of transfer can reach of many hundreds of kilometers.

Long-term research conducted in SANIGMI in the field of dry atmospheric fallout (DAF) monitoring has revealed a definite role in the processes of secondary salinization of arid and irrigated lands. Major natural sources, which emit soil, soil-salt, and sand, and sand-salt aerosols into the atmosphere, underlay the surface of deserts and semi-deserts, and soil cover of irrigated lands. According to expert estimations, emission of sand-salt aerosol from natural sources exceeds that from anthropogenic sources and reaches 150-200 million tons (M t) per year in the whole region.

- increased up to 40-45 g/L. This has resulted in formation of the dried zone, with an area of 3 M ha.
- *Solonchaks*: the area of which has increased from 98.56 to 4292 km².

According to expert estimations, sand-salt aerosol emissions into the atmosphere from the Sea amounts to 53 M t/yr., from the dried part - 57 M t, and from solonchaks - 12.6 M t. Average total salt and sand removal per year from the Sea, the dried part, and solonchaks can reach 122 M t (Table 1).

Natural sources of sand-salt aerosol emission on the territory of Bukhara province emit about 2 M t/yr. of water-soluble salts. As mentioned above, in the conditions of arid climate, suspended particles, including water-soluble and insoluble salts, fall out of the atmosphere on the underlying surface as dry precipitation. According to long-term data, the proportion of water-soluble salts changes depending on the location of sampling points, season, nearness of emission sources (Table 2).

The research on macro-component composition of the upper soil layer on the territory of Pre-Aral region, Bukhara and Navoi provinces have revealed their role as a source of water-soluble salt emission, on the one

Table 1. Comparative of anthropogenic and natural emission sources to the atmosphere of the Aral Sea region.

Removal Source	Sand-Salt Aerosols	City	Total Capacity of Suspended Solids
	-----x10³ t-----		-----x10³ t-----
Aral Sea	53.0	Nukus	13.5
Dried Zone	30 - 57	Urgench	2.8
Solonchaks	13 - 43	Khodzheyli Takhiatash	3.5
Total Mass of Discharge	119		19.8

Contribution of natural sources to the sand-salt aerosol emission 99.9%; anthropogenic sources, 0.1%.

Taking the Pre-Aral region and the Bukhara province as an example, the sources of emissions of dust-salt and sand-salt aerosols were defined. It was given expert estimation of their capacity, conducting a gradation of relative salt content in the aerosols. In the Pre-Aral region, the major sources of sea salts and sand-salt aerosol emissions are:

- *Sea*: the area covered by sea has been reduced by the factor of 2 and salt content in the water has been

hand and as a natural accumulator of salts from the atmosphere, on the other hand. Contribution of upper soil layer in the processes of soil-salt aerosol removal has not been studied well as in the periods of dust storms as between them. The lack of such information and availability of meteorological conditions promoting eolian removal have led to the necessity for research on the chemical composition of surface soil layer, as the major emission source.

Table 2. Flow of dry atmospheric fallout in sampling points situated in the South Pre-Aral region and Bukhara province.

Sampling Points	Density of Fallout Flow			Distance from Aral
	Total	Water-Insoluble	Water-Soluble	
Sea	-----kg/ha-----			----km----
Muynak	1365.8	346.0	1019.8	80
Takhiatash	2258.7	586.0	1672.6	185
Buzaubay	945.7	731.2	214.5	345
Nurata	1225.8	1212.5	13.3	560
Gazli	403.8	184.6	213.2	450
Gizhduvan	219.2	115.3	103.8	550
Bukhara	385.3	265.3	120.0	600
Alat	611.5	473.0	138.4	650

As a result of the research, the macro-components, typical for marine and soil salts, have been defined. These macro-components can be tracers of dust and salt transfer. Complex investigation of the dried zone of the South Pre-Aral region has shown that the majority of soils of this zone are slightly saline. But there are some local sites with high level of surface layer salinization. These sites can be a sources of salt emission in the local process. Their role becomes more important in the period of dust storms.

Experimental data have shown that such macro-components as Na^+ , Cl^- , SO_4^{2-} -pre-dominate in the composition of strongly saline soils. The old dried zone (meteorological station Muynak) is characterized by the relatively non-high salinization of surface soil layer. Sulphates, hydrocarbons, and calcium predominate in the chemical composition of the soils of this zone.

Sulphates, chlorides, and sodium predominate in the surface layer composition of the new dried zone. The same substances predominate in the surface layer of irrigated lands. Depending on distance away from the Aral Sea, macro-component composition of the surface soil layer changes a little. Sulphate content decreases and concentrations of hydrocarbons, calcium, and magnesium (typical soil components of arid zone) increase. High content of water-soluble portion (to 20%) is typical for the soils sampled a considerable distance from the Aral Sea - on the territories of Bukhara and Navoi provinces. This is proof of the high natural level of surface soil-layer salinization.

Macro-component content in the soil samples of the Bukhara province varies in the following sequences: $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$; $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$. Besides the research of chemical composition of surface soil layer, we have investigated seasonal dynamics of salt accumulation in the upper soil horizon. Comparison of seasonal data on macro-component composition of surface layer has shown that the contents of Na^+ , K^+ , Cl^- , SO_4^{2-} vary to a considerable extent. For the hot period, they are being accumulated, and for the autumn-winter period, they are washed out easily.

There are two reasons for accumulation of the considered components. The first reason is predominance of evaporation processes over precipitation in this period (wick effect). The second one is ions dry-precipitating out of the atmosphere. The leaching of ions (Na^+ , K^+ , Cl^- , SO_4^{2-}) from the surface soil layer correlates with their strong solubility. Less soluble anions and cations (SO_4^{2-} , Mg^{2+} , Ca^{2+}) move in soil more slowly.

The problem of salt identification in the upper soil layer, revealing the contribution of air transfer, can be solved partially when using geochemical coefficients, being calculated as for surface soil layer as for dry atmospheric precipitation in the sampling points. Geochemical coefficients show the quantitative ratio between ions typical for different environments.

The calculated geochemical coefficients enable us to separate soil samples into the follow groups:

- Soils of the old dried zone of the Aral Sea;
- Soils of the new dried zone;
- Solonchak soils, situated a distance up to 100 km from the Aral Sea;
- Soils of the Bukhara and Navoi provinces, situated up to 500 km from the Aral Sea;
- Irrigated lands, situated around Bukhara town.

The data show that the proportions $\text{Cl}^-/\text{SO}_4^{2-}$ and $\text{Cl}^-/\text{Mg}^{2+}$ for the soil patterns sampled in the region of Nurata town are close to marine salts. It should be mentioned that Nurata town is situated at a substantial distance from the Aral Sea, but it is in the general flow of atmospheric transfer. On the other hand,, such similarity indicates that it is insufficient to use only geochemical coefficients for estimation of distant salt removal. In the Pre-Aral region, the surface soil layer contains more sodium chloride than HCO_3^- , Mg^{2+} , and Ca^{2+} . Sodium chloride accumulation in the surface soil layer is a result of emission from the local sources and from sea, winds transfer, and consequent precipitation on the underlying surface. Also, sodium chloride can get to the surface with groundwater.

Comparison of geochemical coefficients for soils and dry atmospheric fallout, sampled in the same point, has shown that the level of Cl^- content in fallout is higher than Mg^{2+} and Ca^{2+} and, in some cases, sulphates.

Comparison of geochemical coefficients for different types of soils has shown that the level of Cl^- in comparison with the above-mentioned compounds is highest in Solonchaks. Probably it is resulted from Cl^- getting into the upper horizon with hydrochemical flow according to the mechanism of "wick effect".

To estimate contribution of dry atmospheric fallout to the processes of water-soluble mineral salts getting out of atmosphere into the soil, it is possible to use enrichment coefficients together with geochemical

coefficients. We have applied such techniques for the estimation of possible contribution of salts being transported from the Aral Sea into the processes of salt and dust transfer on the territory of Bukhara province.

As a result of the research conducted, it has been determined that the composition of upper, soil horizon is formed in the main by hydrochemical flow and, to a small degree, by atmospheric precipitation. But in the presence of strong local sources of salt emission the contribution of DAF in the upper salinized soil layer near these sources increase considerably. At the same time, the upper soil layer in the Pre-Aral region, deserts, and lands of irrigated farming is a source of sand-salt aerosol emission into the atmosphere.

Organic Residues as Substitute for Chemical Fertilizers

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ABSTRACT

Clean and sustainable agriculture nowadays depend on natural treatments instead of chemical ones. Therefore, using the farm residues and other residues could be preferable instead of chemical fertilizers. Three types of composted residues were evaluated as possible substitutes for chemical N fertilizers. They were produced from bagasse (B) beet tops (BT), rice straw (RS) and sewage sludge (SS). The residues were mixed at weight ratios of 3 (B): 1 (BT): 2 (SS) to make up Compost I; 5 (B): 4 (SS) for Compost II; and 4 (RS): 2 (BT): 1 (SS) for Compost III. The composts produced were partly substituted for mineral N fertilizer as a source of N for wheat plants grown in pots packed with two light-textured soils of low and high lime content. The treatments involved were a control that received the recommended rate of N requirement as a mineral source (120 kg/feddan), and increasing rates of compost N at the expense of the mineral source.

Wheat grain yield produced under the high CaCO₃ soil (Soil II) was significantly greater than lower CaCO₃ content (Soil I). The highest yield of wheat grain as well as the straw yield of both soils was achieved with the combined treatment consisting of 90 kg mineral N and 30 kg N from organic compost. The productivity of both wheat grain and straw was higher in Soil II of heavier texture and higher lime content compared with Soil I. In general, Compost I showed the highest significant positive effect over the other composts tested with respect to the total content of P and Cu of wheat grain, the second for Zn and Fe, while Compost III showed superiority for N, K and Mn total content of plants. Soil II, as well as Compost III, showed the highest values of total content all the tested nutrients in wheat straw.

INTRODUCTION

Because of the climatic arid conditions dominating Egypt, the soils are very poor in organic matter content, which seldom exceeds 2% and is often less than 1%, or even less than 0.1% in some newly reclaimed desert soils. The organic wastes available in rural and urban communities can be utilized by composting to produce organic fertilizers to meet the requirements of the already cultivated soil as well as the newly reclaimed land and to reduce the dependence on chemical fertilizers.

Awad (1991) found that increasing the rate of sludge addition up to 150 g sludge/kg soil progressively increased the concentration of N, P, and K in plants grown on the non-calcareous sandy soil. Sakr et al. (1992) found that addition of poudrette and town refuse to both alluvial and calcareous soils increased the uptake of N, P, and K by wheat and maize plants. Mikhaeel et al. (1997) showed that application of bio-gas manure, town refuse and sewage sludge to sandy soils increased the uptake of N and P by wheat plants. Zwarich and Mills (1979) found that copper levels in wheat kernels and straw only slightly increased but Cu levels in the forage crop were elevated by the sludge treatment. There was a considerable increase in the Zn content of all crops, but levels were not excessive.

El-Sisi (1996) found that applying farmyard manure increased Fe, Mn, and Zn uptake. Nitta and Matsuguchi (1989) found that application of farmyard manure increased yield of crops (sugarbeets, potatoes, winter wheat, and beans); the yield increase with crop residues application was smaller than with farmyard manure application. They also showed that the application of both farmyard manure and crop residues increased yield as much as farmyard manure alone. El-Ghozali (1998) reported that application of different organic manures significantly increased the dry matter yield of wheat plants, and that enriching organic manures with inorganic fertilizers caused a great yield increase.

MATERIALS AND METHODS

The different organic waste materials used for this study were *sewage sludge*, *bagasse* (sugarbeet remains after sugar sap extraction), *sugarbeet wastes* and *rice straw*, whose main physical and chemical characteristics are presented in Table 1. Soil samples from two different locations in Egypt were selected for this study. Soil I was obtained from Meet Kenana, Kalubia Governorate, while Soil II was taken from Nubaria Research Station, located near Cairo-Alexandria Desert Road.

Three different composts were prepared by adding sewage sludge (dried) to one or more of the three materials of bagasse, beet tops and rice straw. They are referred to as Compost Mixes: Compost Mix I comprising bagasse and beet tops; Compost Mix II comprising bagasse; and Compost Mix III comprising rice straw and beet tops. The weights of the raw materials used for preparing the compost were calculated according to nitrogen and carbon so as to give a C/N ratio of 30:1. The process used for making the compost is described as follows:

An appropriate compost site was prepared for constructing the compost heaps. An area of 1.25 m (w) × 1.5 m (l) was used for each compost heap. The plant residues of bagasse, beet tops, and rice straw were thoroughly mixed with sewage sludge for homogenization purposes. A layer of 15 cm of plant residues was made on the prepared floor. A part of the dried sewage sludge was scattered on the layer surface. Each layer was moistened by sprinkling water to about 60% of the water-holding capacity. Ten layers of such specifications were compiled in sequence to form a compost heap. After heaping, each heap was weekly turned, and then wetted to moisture content around 60%. The composting process was continued for 16 weeks.

Greenhouse Experiment

The suitability of the composts produced as organic fertilizers was evaluated through a greenhouse pot experiment conducted at the Agricultural Research Center. The effects of these composts on plant yield were evaluated using wheat (c.v. Sakha 69) as an indicator plant.

Air-dried soil samples that passed through a 2-mm sieve were introduced in earthenware pots of 30-cm height, where each pot received 8 kg soil. The recommended amount of P (30 mg P/kg as superphosphate) and K (24 mg P/kg as potassium sulfate) were mixed thoroughly with soil samples before packing into the pots as a basal fertilization dressing. The N rate, 120 mg P/kg (as ammonium nitrate), was applied at six equal split application (3 weeks). Compost mixes were applied before sowing in combination with the mineral N source. All treatments received a total substitute either partly or entirely by the highest overall rate of N=120 kg/fed¹(1 mg/kg=1 kg/fed). Thus, the applied mineral N rates were 120, 90, 60, 30 and 0 combined with 0, 30, 60, 90, and 120 kg N as compost mixtures, respectively which were regularly irrigated to about the

soil field capacity. Treatments are presented in Table 2.

One gram of wheat grain was sown in each pot. After complete germination plants were thinned to five plants per pot. After 150 days growing period, the plants were harvested and dried at 70 °C to obtain the dry weight. Dried samples of grains and straw were ground and used for determining N, P, and K, as well as, micronutrients (Fe, Zn, Mn, and Cu). Analysis of soils and plant material were as described by Page et al. (1982) and Chapman and Pratt (1961).

The experimental design was a randomized complete block (factorial). The three factors were: A: *Soils* (two), B: *Added N* (five treatments combinations), and C: *Composts* (three). There were three replicates for each treatment. Analysis of variance of the data obtained was performed as recommended by Snedecor and Cochran (1969).

RESULTS AND DISCUSSION

Grain Yield and Straw

The data obtained showed that grain yield of wheat plants was affected significantly by soil type. The highest grain yield was recorded with the soil containing high CaCO₃ (Soil II). This trend, which was obvious with all the studied combinations, could be attributed to the higher fertility level of the Soil 2. The type of compost also had a great effect on wheat grain yield where compost Mix II and III were superior and compost Mix I was inferior. The highest wheat grain yield was with the combined treatment of mineral N of 90 kg fed⁻¹ and compost N having 30 kg fed⁻¹. Increasing rates of mineral N at the expense of compost N significantly increased the grain yield of wheat. Application of N as only mineral was superior to having all N in organic form, although it gave lower yields compared with the other treatments of both forms.

Table 1. Main physical and chemical characteristics of the raw materials used.

Characteristics	Sewage Sludge	Beet Tops	Bagasse ¹	Rice Straw
Physical				
pH 1:5 (w/v soil/water)	6.15	6.99	4.21	6.84
EC 1:10 w/v soil/water (dS/m)	2.72	17.27	1.26	5.12
Bulk density (g/cm ³)	0.42	0.11	0.10	0.08
Moisture content%	4.40	6.00	4.85	9.00
Chemical				
Total Nitrogen (%)	3.14	2.33	0.38	0.49
Organic matter (%)	64.97	73.09	97.60	80.18
C/N (ratio)	12.1	182.1	149.1	95.1
Total P (%)	1.05	0.88	0.23	0.52
Total K (%)	0.433	1.18	0.52	0.771
Ash (%)	35.0	26.9	2.4	19.8
Total (mg/kg)				
Fe	10330	1800	420	722
Zn	3235	458	244	220
Mn	326	126	85	75
Cu	466	130	100	61

¹Remains of sugar cane after extraction of sugar sap.

Table 2. Experimental treatments and rates of organic and mineral fertilizers.

Treatment No.	Compost Mixture	N Fertilizer	
		Mineral	Organic
		-----mg/kg-----	
1	Control	120	0
2	Mix I	90	30
3	Bagasse +	60	60
4	Beet tops +	30	90
5	Sewage sludge	0	120
6	Mix II	90	30
7	Bagasse +	60	60
8	Sewage	30	90
9	sludge	0	120
10	Mix III	90	30
11	Rice straw +	60	60
12	Beet tops +	30	90
13	Sewage sludge	0	120

1 mg/kg = 1kg/fed on the bagasse of plow layer = 1 million kg.

The combined application of supplemental N as organic and mineral forms was superior to the sole application of either N form with respect to wheat grain yield. The results may suggest that about 75% of mineral N could be replaced successfully by the organic fertilizers represented by compost. Statistical analysis of the results obtained revealed that the highest wheat grain yield was obtained with the second treatment e.g., 90 kg mineral N combined with 30 kg organic N (as compost Mix III), while the lowest grain yield was obtained when the whole nitrogen requirements were supplied as organic forms (compost Mix I) to the soil of lower CaCO_3 .

Straw Yield

The calcareous soil (Soil II) produced higher dry matter yield of straw compared with that the Soil I of lower CaCO_3 content. The difference between Compost I and II on straw yield was not significant. However, Compost III was superior to both.

In case of wheat straw, the best treatment was 90 kg Min. N + 30 kg Org. N, which was followed by the 60 kg Min. N + 60 kg Org. N. Using the organic N alone produced the lowest straw yield, like in case of wheat grain.

Such results are in agreement with those obtained by Nitta and Matsuguchi (1989), Ashour (1992), Sakr et al., (1992), and Fahmy (1995), who found that mixing mineral organic N sources gave better yield than having mineral or organic N alone.

Statistical analysis of the obtained results indicate that the highest yield of wheat straw was achieved from Soil 2, of the higher lime content, treated with 90 kg mineral N combined with 30 kg org. N as Compost I, while the lowest yield (6.18 g/pot) was observed with Soil I (lower lime content) when treated entirely with the organic N source. These results are in agreement with those obtained by Abd El-Hamed (1996), Abd El-Salam et al. (1996), and El-Ghozoli (1998).

Nutrient Uptake

Nitrogen uptake by wheat grain. It increased significantly in calcareous soil compared with the Soil I. Compost III was superior to the other two composts regarding the N uptake by grains. With respect to the effect of N treatments, using treatment which contained 90 kg Min. N + 30 kg org. N increased N uptake significantly. This treatment was superior among the tested treatments followed by the treatment in which the mineral N was used alone. Applying all N as organic N, showed less N uptake by grains. Decreasing N uptake with this treatment could be attributed to the incomplete N mineralization of the organic composts applied.

Statistical analysis of the data obtained show that A $\times$ B $\times$ C effect of compost was affected significantly by both of soil and value of N treatment. The highest grain uptake (830 mg/pot) was noticed when Compost III was applied in combination with mineral N in the treatment No.2 to the calcareous soil. However, the lowest N uptake value (49 mg/pot) was observed when Compost. I was entirely applied to the soil of the lower lime content in complete absence of the mineral N source.

Applying all N as mineral N (treatment one) increased N uptake by straw significantly. However, the difference between the second and third combinations was not significant; applying all N as organic N only reduced the N uptake significantly. These results were in accordance, at least partly, with those of Mostafa (1994), Mahmoud (1996), Mikhaeel et al. (1997) and El-Ghozoli (1998). Significant interactions occurred through all the tested combinations. The most effective treatment with the respect to N uptake in wheat grains (830 mg/pot) was that of Soil II, having higher lime content, treated with the mineral N in complete absence of the applied organic N. On the other hand, the lowest value (61 mg/pot) occurred in Soil I (lower CaCO_3 content) when treated with Compost II, applying all the N in mineral form.

Soil II yielded wheat grain of higher uptake of P than Soil I (lower lime) content. The efficiency of applied composts showed the order: Compost III > Compost II > Compost I with significant variations. The treatment of 90 kg Min. N and 30 kg Org. N showed the maximum P uptake; it decreased sharply with increasing the rate of organic N on expense of the mineral N, to reach a minimum value with the entire application of the organic N. The most effective treatment was that of Soil II having Compost II, applied by 90 kg Min N + 30 kg org. N. The least effective treatment was that of Soil I, having Compost I applied by N entirely as organic form. Where the P uptake was about 1/20 of the general average.

Significant increments in P uptake by wheat straw occurred with Soil II of the higher lime superior than Soil I. Compost I was followed by Compost III, then by Compost II. Applying N entirely in a mineral form yielded the highest value of P uptake by wheat straw; uptake gradually decreased with increasing the organic portion of applied N. Thus, P uptake increased progressively as the N fertilizer portion in mineral form increased; having mineral N along with organic materials enhanced P uptake by plant. This was shown by the greater P uptake by plants receiving mineral N+ organic N over those not having mineral N.

Organic materials have beneficial effects on P uptake, particularly when enough readily available N is present. The final effect of inducing the availability status of P in soils, and hence P utilization by the flowering plants, is clearly shown by adequate supply of N as shown by Awad (1991); Ahmed (1993); Mostafa (1994); Mahmoud (1996); Mikhael et al (1997), and El- Ghazali (1998).

Soil II was superior to Soil I, in supplying wheat grain with K. All the composts showed comparable effects in this respect. As for the tested treatments, it is evident that the values of total K content of wheat grains tended to be significantly higher with organic N (30 kg fed⁻¹) combined with 90 kg mineral N. Increasing the rate of the organic resource (at the expense of the inorganic one) to 90 kg did not give any significant effect. Moreover, with the entire application of the organic source (i.e., in complete absence of the inorganic source) led to a sudden sharp reduction in K uptake of wheat grain. Accordingly, it may be suggested that a rate of 30 kg organic N combined with 90 kg mineral N could be optimum for increasing the K uptake.

The soil of higher lime content, having compost II and supplied with 30 kg org N+90 kg mineral N, was the most effective treatment (giving 462 mg K/pot). Significant interactions occurred. The lowest value occurred in Soil I with Compost II supplied with N as entirely organic. These results are in accordance with those of El-Sirafy et al. (1989), Sakr (1992) and Mahmoud (1996). Because K is not actively involved in plant organic compounds, it is so easy get out of plant residues subjected to mineralization processes in soils.

Total Fe uptake of wheat grains revealed significant differences due to soil. The highly lime soil showed wheat grain of relatively higher Fe uptake than the lower lime soil. The progressive rate of substituting the organic source instead of the inorganic one in turn increased the Fe uptake up to the rate of 30 kg min. N + 90 kg Org. N. However, entire application of the organic N form gave lower Fe uptake than that observed with the entire application of the mineral N. There was a drastic reduction in Fe uptake in case of Soil I treated entirely with the organic N, particularly when receiving Compost I. Treatments can be ordered as follows: Compost II > Compost I > Compost III.

Results reveal significant interactions for the factors tested. The highest uptake was of the treatment of Soil I treated with Compost II receiving 30 kg mineral N + 90 kg organic N. The lowest occurred with Soil I, treated with Compost I receiving the entire rate of N as the organic N.

Maximum Fe uptake by wheat straw occurred mainly with applying (30 kg org. N + 60 kg mineral N) and, in a few cases with applying 60 kg organic N + 60 mineral N. Results reveal significant interactions. The most effective treatment with respect to Fe uptake was that of Soil II, having Compost III supplied with (90 kg mineral N + 30 kg organic N). The positive effect due to organic manuring on Fe uptake by plant was reported Mostafa (1994), Fahmy (1995), Abd El-Hamid, (1996), Tadross (1997), and El-Ghozali (1998). Such a trend is a predicted and could be attributed to the Fe release of applied manure Fe as the mineralization process takes place. Released organic acids during degradation of wastes increase Fe availability.

Manganese uptake by wheat grain with Soil II significantly surpassed that of Soil I. Compost III was the most effective followed by Compost II and then Compost I; Compost application increased Mn uptake. Application of added N as entirely organic gave the lowest Mn uptake, followed by application of the entire N as mineral applying mixtures of mineral and organic N for superior to applying as only one form. Applying 90 kg min N+ 30 kg, organic N gave the highest uptake.

Organic manuring led to significant increase in Mn uptake in wheat straw, showing a maximum effect with the application of 60 Min N + 60 organic N. Soil II, having Compost I and receiving 30 kg organic N + 90 kg mineral N, gave the highest uptake. The increases occurred in Mn concentration as well as in yield and consequently Mn uptake. This could be attributed to the high content of Mn as well increases in yield in the organic manures (compost). The obtained results agree with those obtained by Shata et al. (1990), Awad (1991), Faiyad (1994), El-Sisi (1996), and El-Ghozali (1998).

Soil II of the relatively higher lime content showed Zn uptake in grain exceeding twice that of Soil I. The maximum effect due to the different types of compost mostly occurred with the treatment of 30 kg inorganic, and 90 kg organic N. Significant interactions of Zn

uptake of wheat grains were detected. It is evident that the least values of Zn uptake occurred in Soil I treated entirely with Compost I or entirely with mineral N fertilizer. On the other hand, the maximum value of Zn uptake occurred in Soil II, when treated with Compost II or Compost I at the rate of 30 kg mineral N source combined with 90 kg organic N source.

It is evident that Zn uptake in the straw was significantly increased by about 2.5 times with Soil II as compared with Soil I. Also, Compost II was followed by Compost I. The low organic N rate at (30 kg N) accompanied with 90 kg N in the mineral form gave the highest uptake. Results reveal significant interactions. The maximum positive effect on Zn uptake occurred in Soil II treated with Compost III at the rate of 30 kg organic source and 90 kg inorganic one. These findings agree well with that reported by Hayes (1979, Mostafa (1994), Abd El-Hamied (1996), and El-Ghozoli (1998).

Soil II gave greater grain Cu uptake amounting to 2.6 times those of Soil I. Introducing organic source instead of the mineral one produced higher uptake, particularly with 30 kg organic N + 90 kg mineral N. Significant interactions occurred. The maximum was with Soil II treated with Compost receiving 30 kg mineral N + 90 kg organic N. As for wheat straw, Cu uptake was higher from Soil II than Soil I. Compost III was more effective than Compost I which in turn was more effective than Compost II.

Application of N, entirely as mineral N, was slightly more effective than the entire application of organic N. However, applying both sources considerable increase Cu uptake. There were significant interactions. The maximum Cu uptake straw occurred in Soil II when treated with Compost III receiving 90 kg Mineral N + 30 Kg organic N fed-1), The least occurred in soil treated with Compost I receiving N entirely as organic. These results agree with those of Hayes (1979) and Mostafa (1994).

REFERENCES

- Abd El-Hamied, A.H. 1996. Evaluation of some disposable wastes as sources of micronutrients in sustainable agriculture. *Annals Agric. Sci.* Moshtohor, 34: 1983-2000.
- Abd El-Salam, A., M.S. Amer, and M. Mikhimar. 1996. Natural conditioners in relation to nutritional status of some soils. *Annals Agric. Sci.*, Moshtohor, 34: 1969-1982.
- Ahmed, S.M. 1993. Organic manures generated from different biogas systems in relation to biological properties and nutritional status of soils. *M.Sc. Thesis*, Fac. Agric., Moshtohor, Zagazig Univ., Egypt.
- Ashour, I.A.I. 1992. Influence of some soil amendments on calcareous soil properties as well as on the yield and chemical composition of wheat under irrigation with saline water. *M.Sc. Thesis*, Fac. Agric., Moshtohor, Zagazig Univ., Egypt.
- Awad, S.S.M. 1991. Influence of sewage sludge on some soil characteristics and plant growth. *Ph. D. Thesis*, Fac. Agric. Fayoum, Cairo, Univ. Egypt.
- Chapman, H.D., and P.P. Pratt. 1961. Methods of analysis for soils, plants and water. Univ. of California, Davis, CA.
- El-Ghozoli, M.A. 1998. Studies on some organic residues riched with some macro- and micro- nutrients. *Ph. D. Thesis*, Fac. Agric., Zagazig Univ., Egypt.
- El-Sisi, S.M.O. 1996. Use of (Tafla) bentonite for improving of Beni-Suef Governorate. *M.Sc. Thesis*, Fac. Agric. Ain Shams Univ., Egypt.
- Fahmy, F.M. 1995. Effects of some organic wastes on availability of some micronutrients in calcareous soils. *M.Sc. Thesis*, Fac. Agric., Moshtohor, Zagazig Univ., Egypt.
- Faiyad, M.N. 1994. The combined effect of some organic residues and N.P. fertilization of wheat grown in recently reclaimed sandy soil. *Zagazig J. Agric. Res.* 21: 999-1013.
- Hayes, M.M. 1979. Effects of some soil manures on soil properties. *M.Sc. Thesis*, Fac. Agric., Zagazig Univ., Egypt.
- Mahmoud, M.M. 1996. Natural conditioners effects of some physical and chemical properties of soils. *M.Sc. Thesis*, Fac. Agric., Moshtohor, Zagazig Univ., Egypt.
- Mikhaeel, F.T. ; A.M., Estefanous, and G.G. Antroun. 1997. Response of wheat to mycorrhizal inoculation and organic fertilization *Agric. Fac. Bull.*, Cairo Univ., 48: 175-186.
- Mostafa, M.H. 1994. Microbiological studies on the management of urban wastes. *Ph. D. Thesis*, Fac. Agric., Moshtohor, Zagazig Univ., Egypt
- Nitta, T., and T., Matsuguchi 1989. The effects of organic materials added to the soil on growth and yields of upland crops through improvement in the microflora of the rhizosphere. *Bull. Hokkaido Agric. Exp. Sta.* 152: 33-89
- Page, A.L., R.H. Miller, and D.R. Keeney. 1982. Methods of soil analysis, Part 2. Soil Soc. Amer. Inc., Madison, Wisc. USA.
- Sakr, A.A.S.A. Rizk, and A.S. El-Sebaay. 1992. Effect of organic manures on plant growth and NPK uptake by wheat and maize plants. *Egypt. J. Soil Sci.*, 32: 249-263.
- Shehata, S.M., and B.E. Ali. 1990. Composting municipal solid wastes. *Agric. Res. Rev.*, 68 (2): 359-365.
- Snedecor, G.W., and W.G. Cochran. 1969. Statistical methods 6th Ed. Iowa State Univ. Press, Ames, Iowa, USA., 120-245.
- Tadross, S.Y. 1997. Studies on the status of some micronutrients in soils of kalubia Governorate. *M.Sc. Thesis*, Fac. Agric., Moshtohor, Zagazig Univ., Egypt.
- Zwarich, A.M., and G.J. Mills. 1979. Effect of sewage application on the heavy metal content of wheat and forage crops. *Can. J. Soil Sci.*, 59: 231-239.

Land and Water Management in Yemen

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INTRODUCTION

The Republic of Yemen is arid to semi-arid, its water resources are scarce, and most of the land consists of barren mountains and deserts. The country is located at the south edge of the Arabian Peninsula between latitude 12 and 19 N of the Equator and between 42 longitude and 55 E. The country is bordered by Saudi Arabia in the north, Oman in the east, the Arabian Sea and the Gulf of Aden in the south, and the Red Sea in the west. The total land area of Yemen is 55 million (M) hectares (550,000 km²); the arable land is about 1.8 M ha (3.3% of the total area). The total population is estimated at about 15.8 M (1995), with 85% are working in the agriculture. The highest percent of water consumption is for agricultural purposes, estimated at 93% of total water consumptive in Yemen. If we look at the total cultivated area, we find that there are many water losses in irrigation beside land degradation and desertification. The objective of this paper is to identify water and land management in Yemen and characterize the methods in its development with the aim to improve water and land-use efficiency.

TOPOGRAPHY AND CLIMATE

Yemen is situated in the northern stretches of the tropical climate zone. Temperature, relative humidity and rainfall, varies greatly due to the extreme differences in elevation. Yemen can be divided into three climates:

- **Arid Tropical:** The climate covers the coastal plains region and lower mountain slopes in the west and south, the altitude ranging from 0 to 500 m a.s.l. This is characterized by high temperatures where the monthly mean is 20-30 and low precipitation ranging from 0 to 400 mm.
- **Arid Sub-Tropical:** This is a transitional climate between the tropical climate of the coastal plains region and the temperate climate of highland region, the altitude ranging from 800 to 1200 m a.s.l. Mean monthly temperature varies from 16°C to 28°C. Precipitation ranges from less than 100 to 600 mm; it covers the lower and upper mountain slopes and the eastern plateau region.
- **Temperate:** This climate covers the mountains, ranging in altitude from 1800 to 3700 m above sea level. Mean monthly temperature in this climate ranges from 10 to 18°C. Precipitation varies from 200 to more than 800 mm.

Based on climatological data and drought indices calculated using Dju Marton formula, it is clear that all cultivated areas in Yemen are under arid zones, except

the Ibb area. In terms of monthly drought index most cultivated areas may be considered desert to arid zones almost all the months of the year, except some areas such as Zabid (September), Dhala (July, Aug.), Hajjah (March, April, May, June), and Ibb (April, May, July, Aug., Sept.) which can be considered as temperate to humid zones.

From above information, we conclude that irrigation water supply is a necessity for satisfied growth, and yield of the different crops in Yemen.

LAND RESOURCES

The total land area of Yemen is estimated at 55 M ha. Rainfall and irrigation water impose a limit on the arable land, which reach 1.8 M ha; therefore, only 1.1 M ha of which 52% is rainfed, and 36% is irrigated by underground water, 2% by spring water, and 10% irrigated by spate water.

The genesis of the soils of Yemen is influenced primarily by six natural processes and two human-induced processes. These processes result in the accumulation of the soil itself. The natural processes, which result in, the accumulations of soil parent material, are *aeolian deposition*, *fluvial sedimentation*, *colluvial deposition*, and a combination of these three processes. The human-induced process affecting parent material formation is the accumulation of sediment through terracing and irrigation.

The country's soil are generally sand to silty and clay loamy in the highland region, and poor in nitrogen, phosphorus, organic matter and high percentages of calcium carbonate (30-70%). In many areas, shallow soil limits the amount of water available for rainfed crops.

WATER RESOURCES

Statistics data indicates that the total renewable water in Yemen does not exceed 2.1 billion m³, while the total amount of water consumed is 2.8 billion m³, indicating Yemen is suffering from 0.7 billion m³ deficiency in its available water resources.

Rain-water

Rainfall occurs in two main seasons, April - May and July - September. The dry period is 4-5 months from November - March. During this period and in the period of December - January rain seldom falls. The amount of rainfall depends of topography (elevation from sea level) and distance from the sea, where the influences begins on horizontal and vertical distances. The annual rainfall varies between 50-100 mm for the

minimum to 800 for maximum. These figures indicate that Yemen can be considered lowest for countries suffering from water deficiency.

Groundwater

The groundwater is by far the most important water resource in Yemen, where it covers about 98% of requirements for different consumption sectors. The rainfall, direct or indirect, reaches the saturated layer, is a main resource of groundwater recharge. Direct recharge of groundwater is generally very low in Yemen given its dry climate and low level of rainfall. The groundwater pumping from wells, where the estimated number of wells in Yemen is 45000, with more than of 85% of these used for irrigation.

Exploitation of groundwater reaches a deficit up to 260 M m³/year in Tihama aquifer, 75 M m³/year in Mukalla aquifer, and 400 M m³/year in the highlands. Salt concentration of groundwater varies from one area to other; in Marib (eastern plateau) it reaches 0.75-2.25 dS/m and in the coastal areas it reaches 5-6 dS/m.

Surface Water

Surface water in Yemen is seasonal floods used for surface irrigation and recharge of local groundwater. Mean annual flow or runoff from *wadis*, when it rains, ranges from 0.75 M m³/year for *Wadi Juaymah* to 169.9 M m³/year for *Wadi Bana*. Annual flows for these *wadis* is irregular, where the coefficient of variation of annual flow volumes ranges from 22% for *Wadi Surdud* to 149% for *Wadi Thibi*.

The total annual surface water for all *wadis* in Yemen is estimated at about 2000 M m³/year. Of this total, 741 M m³ flows towards the Red Sea basin, including *wadis* Mawr, Zabid, Siham, and Rima. Another 535 M m³ flows towards Gulf of Aden including *wadis* Bana, Tuban, Hassan, and Ahwar; 553 M m³ flows towards the Arabian Sea basin, including *wadis* Al-Jawf, Adhana, Bayhan and Mrakha flowing into Ramlat Al-Sabatayn, Masila in Hadramawt and Al-Jiza in Al-Mahara; while 171 M m³ flows into Rub-Al-khali basin, including *Wadi Najran*, and eastern and western *wadis*.

LAND AND WATER MANAGEMENT

Water and slope are considered as one of the most important which influence methods for land and water use and conservation in Yemen. The total households in Yemen is 1,001,925. The households are distributed in the different regions as follows: less than 2 ha, 20%; from 2 to 5 ha, 24%; and from 5 to 20 ha, 56%.

Land tenancy is mainly in irrigated areas. In these conditions, the tenant gets 33% of the yield after paying the Zakat (religious taxes according to Muslim law), while the landowner gets 66% of the crop if he provides water for irrigation. If water is provided by a third party, the owner of the well gets 33-40%. Under rainfed conditions and flood-irrigated areas, the share of the landowner is 50% of the yield. The tenant's share is 50% plus the fodder and residues.

Cereals occupy a high 61.8% from the total of cultivated area, followed by cash crops, fodders, fruit, vegetables and legumes at 14.2, 8, 6.6, 4.8, and 4.9%, respectively. The average cultivated area for the same period (1994-'98) was 1,186,199 ha, with an average crop production of 1,640,053 tons.

From the earliest times, the local plough, which is pulled by animals, has been used by the Yemeni farmer. Some farmers, especially in highland areas, are still using these ploughs. During recent years, the soils are mainly prepared mechanically in most areas. Some of the farmers use manure for fertilizing their soils, but the most of them do not take the necessary preparation of the manure, which promotes weeds. Recently, farmers started to use mineral fertilizers such as nitrogen and phosphate. In general, the mineral fertilizers are used for vegetables and fruits.

Water Harvesting

There are three methods for water harvesting (basin, terraces, and spate irrigation); which have been practised by Yemen farmers.

Basins

Water harvesting by basins is conducted in the most of the governorates located in western and southern mountain slope. This method is characterized by gathering the rainfall water from the rocky areas and storing it in small basins or directing it through the earth canals.

Mountains Terraces

This method for water harvesting goes back thousands of years and is aimed to expand the cultivated area and water harvesting from the mountains slope. The terraces are differentiated by site; those in the upper part of the mountains are with deep sloping and are characterized by narrow width and high moisture content in the soil. Terraces in the bottom slope of mountains are characterized by low moisture content in the soil due to the shallow soil layers, while those in the *wadis* and the Thama mountains are characterized by wide width and deep soil profiles of more than 2 meters, irrigation by spate water, and slope less than 25%.

Spate Irrigation

Water depends on rainfall which falls on mountains. Yemeni farmers have built dams such as Marib dam. Some of these dams are used as water reservoirs, which serve smaller diversions and distribution. The water is distributed from dams to main and secondary channels to the fields with the size of 1-5 ha, and the irrigation depth varies from 50-100 cm.

On-Farm Water Management

In spite of past research on on-farm water requirements for cultivated crops in Yemen, there is a lot of work that need to be done regarding the number of irrigations, and timing and duration of irrigation, because of depletion of the water table.

The amount of water used for surface irrigation is double the water requirements for the crops: 9154-13760 m³/ha for cereals; 10,080-12,500 m³/ha for vegetables; 12,420-30,340 m³/ha for fruits; and 18,020-22,320 m³/ha for cash crops.

The average irrigation value-added and under surface irrigation for different crops is about 15313 m³/ha, while the average water irrigation under spring (spraying) is 6879 m³/ha, and under local irrigation is 9535 m³/ha. These figures indicate a system with low water-use efficiency under surface irrigation reason as a result of water loss in canals transferring water from wells to the farms, dunning transportation and adding, evaporation during irrigation, and water supply not corresponding with infiltration rate causing water losses by evaporation and infiltration under the rootdepth.

For improving water-use efficiency, a pilot farm study was conducted in order to introduce an improved surface irrigation system (border) in Marib, Thamha, and northern highland areas. A modern irrigation system was introduced in Marib to irrigate citrus by drip and other vegetables by sprinkler. Lately, drip irrigation is used to irrigate protected crops in Sana'a. The soil to water conservation project distributed 17 sprinkler units, 33 drip units, and 16 bubbles units. Some of these units were designed without enough technical knowledge, which causes some maintenance problems.

CONCLUSIONS

The following issued need to be addressed: 1) Water - use efficiency because of limited water supply. 2) The limitation by the farmer for applying and implementing

correct crop water requirements. 3) Introducing of modern irrigation systems for improving irrigation efficiency. 4) Constructing drip irrigation with minimum maintenance problems. 5) Limited research in the field of modern irrigation. 6) Misuse of machinery which causes problems of soil degradation. 7) Insufficient land use management is another cause of degradation. 8) Terraces are one of the most important methods of rainwater harvesting. 9) Regulation or laws for land to water resources use.

RECOMMENDATIONS

- Introducing of modern irrigation systems to irrigate fruit and vegetable to minimized water quantity used, and still supply of crop water needs.
- Add excess water in order to leach the salts at the root zone.
- Use cropping systems according to the quality of soils to conserve soil fertility.
- Applying of manure to raise organic matter of soil.
- Deep plough not less than 3-4 years.
- Carry out studies to maintain, evaluate, and develop of terraces.
- Necessity of implementing of rules or regulation in order to organize water/land use to establish a fair distribution and use of these resources.

Crop Sequence Effects on Compaction under Rainfed Conditions

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ABSTRACT

A series of field experiments were conducted in 1996/1997 season on a sandy soil at El-Barth in North Sinai, which represents a rainfed area with an average annual rainfall of 100 mm. The objective of this study was to evaluate the effect of crop sequence on compaction under rainfed condition. The treatments included three rotations (barley/lentil, barley/pea, and barley/fallow) conducted in comparison with the prevailing rotation, barley or wheat (monoculture). After 2 years' crop rotation cycle, soil samples were collected at 0-30 cm depth and were analyzed for soil salinity (EC), alkalinity (ESP), pH, CaCO₃ %, and soil aggregate stability.

The results indicated that no clear-cut difference between zero time and after 2 years' crop rotation data with respect to pH and CaCO₃ % values. Introducing food and forage legumes (pea and lentil) in the barley rotation significantly decreased salinity and alkalinity hazards. The percentage of aggregates 10-0.25 mm diameter in surface layer (0-30 cm) was improved when legume crops were included in the rotation. The highest aggregate values of 10-0.25 mm diameter in the top 30-cm soil layer were found under the pea/barley sequence. The values of 10-0.25 mm diameters under different crop sequence were in the following decreasing order; pea/barley > barley/fallow > fallow/barley > wheat/wheat > barley/barley > barley/pea > lentil/barley > barley/lentil. The domination of this aggregate diameter range in the soil is an indication of improving soil physical properties.

INTRODUCTION

Two environmental hazards (drought and desertification) menace land productivity in arid and semi-arid regions. Drought is an inherent feature of arid and semi-arid climates, while desertification is the gradual degradation of the land productive systems. It results from the combination of excessive use and abuse of ecosystems and the inherent fragility of these systems (Kassas, 1987). Management of desertification is related primarily to improved land-use systems. Farming systems on drylands of Egypt are continuous barley monoculture or wheat rotations. Continuous cropping with barley depletes soil fertility, stimulates the buildup of pests and diseases, and subsequently the barley yield was declines (Haddad, 1997). Ryan et al. (1997)

reported that barley in rotation with legume yield was better than or equal to barley in rotation with fallow or cropped every year. Nour and Abd El-Naim (1998) found that introducing a forage crop (*Medicago* spp.) in a barley rotation improved soil chemical properties and subsequently barley yield was increased.

Also, soil structural degradation is widely perceived as a major problem in the cropping of dry land. Poor structural stability is the result of low and inactive clay content and a low content of decomposed organic matter. The consequence of poor and unstable soil structure is susceptibility to the formation of a surface crust or seal resulting in decreasing infiltration and increasing in runoff. Prevention and/or reversal of this deterioration is essential to the improved of the long-term productivity and sustainability of this important group of soils (Rao et al., 1997). Thus, the aim of this work was to evaluate the effect of a crop sequence on the of desertification under rainfed condition.

MATERIALS AND METHODS

Long-term rotation studies were established in the 1996 / 1997 season on sandy soil at El-Barth, North Sinai, which represents a rainfall area with an average annual rainfall of 100 mm. The treatments included three rotations (barley /lentil, barley /pea, and barley /fallow) in comparison with the prevailing rotation, barley, or wheat (monoculture). The design of the experiment was randomized complete block with three replications.

On June 1998, soil samples were collected to detect the change on soil characteristics after two years' crop rotation. Soil salinity (EC), alkalinity (ESP), pH, and CaCO₃ % were determined in soil samples. Soil aggregates stability was measured in disturbed soil samples by dry sieving (Richards, 1954). The soil used in this investigation is characterized by sandy texture (more than 90% sand), pH values of 7.9-8.3; CaCO₃ of 11.6-23.2%, organic matter of 0.2%, EC of 1.14 of dS/m at 25°C, ESP of 2.8%, clay and silt content of 5.7%. The initial percentage distribution of soil aggregates were: 10-2 mm, 12.4%; 2-1, 4.1%; 1-0.5, 2.9%; 0.5-0.25, 21.8%; 0.25-0.125, 37%; 0.125-0.063, 17.1; and < 0.063, 4.7%.

RESULTS AND DISCUSSION

Crop Sequence: Soil Chemical Properties

As might be expected, there was no clear-cut difference was observed between zero time data and after two years' crop rotations with respect to pH and CaCO₃ %

values. However, when forage crops peas were introduced with barley, the soil CaCO₃ % was decreased compared to plots with continuous cropping with barley. This may be due to superiority of legume crops (in the rotation) to improve the hydro-physical and chemical properties and sustainable agriculture of calcareous soil. These results are in a partial agreement with those of Meier et al. (1993) who found that inclusion of peas in crop rotation had a moderating effect on bulk density and penetration resistance.

As for soil salinity and alkalinity hazards, introducing food and forage legumes (peas and lentil) in barley rotation significantly decreased salinity and alkalinity hazards, compared to continuous cropping with barley or wheat. The same trend was observed in barley /fallow rotation with respect to ESP. However, leaving the land fallow for one year is not acceptable from the economic point of view. In this respect, Nour and Abd El-Naim, (1998) found that introducing a forage crop (*Medicago* spp.) in a barley rotation decreased the soil salinity and sequential barley yield increased.

Crop Sequence: Soil Aggregate Stability.

The results presented in Table 1 show that percentage of aggregates of the diameter (10-0.25 mm) was highly increased after two years' crop rotation, compared to zero-time data. The domination of this aggregate diameter in the soil is an indication of improving soil physical properties. Soil aggregate stability was widely affected by various factors such as crop sequences and soil salinity - alkalinity hazard.

and wheat, the percentage of aggregates less than 5 mm was significantly higher than for continuous one.

The results in the same Table also indicated that the aggregate values of 10-0.25 mm diameters under different crop sequences were in the following decreasing order; pea/barley > barley/fallow > fallow/barley > wheat/wheat > barley/barley > barley/pea > lentil/barley > barley/lentil. This agrees with the finding of Saad et al. (1997).

As for alkalinity hazard effect on soil aggregates stability, the results indicated a significant negative correlation coefficient ($r=-0.65^*$) between ESP and aggregate diameter (10-0.25 mm). However, this study will be continued for several years to detect the changes in these parameters and its effect on long-term productivity and sustainability of these soils.

CONCLUSION

From these results, it can be concluded that under the conditions of this investigation, introducing food and forage legumes (peas and lentil) in a barley rotation significantly decreased salinity and alkalinity hazards compared to continuous cropping with barley. The kind of crop had a great influence on soil aggregation. The highest aggregate values of 10-0.25 mm diameters were found under the condition of pea /barley rotation. The domination of the such aggregate size category in the soil is an indication of improving soil physical properties.

Table 1. Aggregate size distribution after two years' crop rotation at El Barth.

Crop Rotation	Aggregates Size Distribution by Dry Sieving, mm						
	10 - 2	2 - 1	1 - 0.25	0.5 - 0.25	0.25 - 0.125	0.125 - 0.063	< 0.063
	-----%						
Barley/Fallow	18.5	5.2	3.4	31.5	23.3	14.3	3.8
Barley/Barley	14.8	6.5	4.6	17.9	34.1	17.2	4.1
Fallow/Barley	16.6	4.5	3.5	24.7	33.9	14.3	2.5
Barley/Pea	14.4	4.6	3.2	19.6	36.5	17.8	3.9
Barley/Lentil	12.2	4.5	2.7	20.5	40.4	15.4	3.7
Pea/Barley	26.5	8.2	6.1	18.7	31.8	6.3	2.4
Lentil/Barley	12.4	4.1	3.0	21.5	41.9	14.0	3.3
Wheat/Wheat	15.3	4.5	2.8	22.1	35.5	15.8	3.2

Concerning crop sequence effect on soil aggregate stability, the results indicated that percentage of aggregates (10-0.25 mm) diameter in the top 30-cm soil layer was improved when the leguminous crops were included in rotation. The highest values of 10-0.25 mm diameter in surface layer were found under the condition of pea / barley rotation. The same results were obtained by Romboult and Vyn (1991), who found that soil after continuous corn cultivation had the lowest proportion of aggregates less than 5 mm diameter, whereas when red clover was interceded with barley

LITERATURE CITED

Haddad, N. E. Al-Karablieh, and E. Bailey. 1997. Development and transfer of improved technology for integrated crop-livestock production in low rainfall zones. *Achievements of the Mashreq Project*. ICARDA, Aleppo, Syria.

Kassas, M. 1987. Drought and desertification. "Second Intern. Conf., Desert Development, Cairo, Egypt.

Nour, M., and M. Abd El-Naim. 1998. Studies on the effect of introducing forage crop (*Medicago* spp.) in barley rotation on crop productivity at north western

- coast of Egypt. Conference of "Rainfed Agriculture in Egypt", Cairo, Egypt.
- Meier, J. N, J.W. Fyles, A.F. Makenzie, and I.P.O. Halloran. 1993. The effect of tillage system and crops sequences on soil bulk density and penetration resistance on a clay soil in Southern Saskatchewan, *Canadian J. Soil Sci.* 73(2): 232-233.
- Rao, K.P.C., S.T. Srinivasan, A.L. Cogle, G.D. Smith, and D.F. Yule. 1997. Dynamics of soil structure amelioration and degradation of a semi-arid tropical Alfisol under different management systems. Workshop on the "Challenge of Production System Sustainability". ICARDA, Aleppo, Syria.
- Richards, L.A. 1954. Diagnosing and improvement of saline and alkaline soils. Agric. Handbook No. 60. USDA, Washington DC.
- Ryan, J., M. Pala, S. Garabet, S. Masri, Z. Masri, and R. Makboul. 1997. Workshop on the "Challenge of Production System Sustainability". ICARDA, Aleppo, Syria.
- Raimbault, B.A., and T.J. Vyn. 1991. Crop rotation and tillage effects on corn growth and soil structural stability. *Agron. J.* 83: 979-985.
- Saad, A.F., H.M. Ramadan, and H. El Zaher. 1997. Effect of crop rotation on some soil physical and chemical properties in calcareous soil. *Alex. Sci. Exch.*, 18(1): 1-18.

Soil Mulching and Irrigation Methods: Soil Temperature

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ABSTRACT

A greenhouse experiment was conducted to study the effect of different mulch treatments: Control (C); at 50; 100 g/m² bituminous emulsion (B₁; B₂), white and black plastic sheets (WPS; BPS), and 0.5; 1.5 cm thick gravel layers, (G₁; G₂) on soil temperature under subsurface (SSI), surface (SI) and drip (DI) irrigation. Corn was planted in sandy soil and soil temperature was measured once a week during 63 days at 10 A.M. and 2.30 P.M. at the depth of 5 cm. The increase in the mean soil temperature during the growing period ranged from 1.0-2.0, 0.8-1.7, and 0.2-1.2 °C at 10 AM, and 5.2-6.2, 1.1-2.2, and 5.2-6.2, 1.1-2.2, and 0.4-1.6 °C at 2:30 PM, under SSI, SI, DI, respectively. The minimum and maximum increase in soil temperature were achieved with B₁; G₂ and B₁; WPS under both SSI, SI and DI, respectively.

INTRODUCTION

Many processes occurring in the soil such as fluid movement, biological activities, organic residue decomposition, nutrient availability, and subsequently plant growth are affected by soil temperature. Our ability to control soil temperature is limited.

Since small changes in soil temperature can have great effects upon plant growth, soil temperature management can achieve significant results. Willis et al. (1957) and Gerb (1966) indicated that mulching soil surface with plant residues decreases its temperature. According to Adams (1967), gravel mulch has a beneficial effect on some crops through increasing soil temperature 2 to 4 °C at the 15 cm depth compared with the bare soil.

Weigand et al. (1968) found that the monthly means of daily maximum and minimum soil temperature measured at the 10-cm depth were in the order: 1.5-cm thick mortar sand mulch (0.25-0.80 mm dia.) > bare soil > cotton bur mulch (44.8 ton/ha) > bermudagrass sod. The higher soil temperature under the sand mulch did not reduce its effectiveness in evaporation suppression. According to Kohnke (1968), mulching soil reduced its temperature fluctuation. Walker (1969) had shown that temperature measured in July for the 15 cm soil depth between rows under gravel affected corn seedlings adversely.

Fairbourn (1973) indicated that mulches affected soil temperature less in the crop rows; than in the areas between rows at 15 cm depth, soil temperatures between plant rows were 2 to 3 °C higher under gravel

and 1 to 6 °C lower than under cornstalks relative to the control until the middle of July. His data (1974) indicated different ranges of increased soil temperature under coal mulch in the field for 2.5 and 15-cm depths. The 2.5-cm depth temperatures for the coal mulch and bare soil were about the same at night, but it ranged up to 4.0 °C higher under the first case in the daytime. The 15-cm depth temperatures ranged from 1 to 2 °C higher under coal mulch than in the bare soil.

Nagmouh (1981) noticed that the changes in soil temperature due to mulching with black and white plastic and date fronds ranged between 0.5-2.5 °C; mulched soils showed considerably less variation in temperature than the bare ones. In a field experiment, Tayel and Wahba (1986) found that the relative effect of different mulches on soil temperature at 1 and 5-cm deep were in the following order: bitumen > urea formaldehyde > ureasol = polyacrylamide. They added that soil temperature increased with the rate of application. Wahba and Tayel (1987) showed that the diurnal temperature fluctuation in soil as affected by soil mulching during and irrigation cycle could be described by the following order: urea formaldehyde < control < bitumen emulsion.

Morote et al. (1990) monitored the effect of mulching (0, 3.3, and 6.6 t/ha) on the temperature of a sandy soil. Mean weekly temperature taken daily at 9 A.M. varied little, but there were marked variations among mulch treatments at 3 P.M. They added that mulching reduced soil temperature to 8 °C, whereas bare soil reached temperatures as high as 38 °C. El-Hady et al. (1991) stated that the temperature of soil mulched with bitumen at the rate of 75-300 g/m² increased, particularly during the colder months. The effect of colored plastic polyethylene mulches on soil temperature was studied by Alkayssi and Alkaraghoul (1991). The highest temperature was recorded under the red mulch followed by the transparent, green, blue, yellow, and black mulches. Thus, it decreased with decreasing energy balance in the order: red > transparent > green > blue > yellow > black. Mbagwu (1991) showed that the maximum daily soil temperature was the lowest on the straw plots (32.5 °C), about equal on the bare and white polythene treatments (38.6 and 39.8 °C) and the highest on the black polythene plots (45 °C).

Relative to unmulched and plastic sheet-covered soils, an organic mulch delayed the onset of heat transfer through the soil itself, reduced the rate of heating, limited the peak temperature reached, and reduced the initial cooling rate for a soil in a laboratory study

(Wooldridge and Harris, 1991). They added that although light-colored granular materials confer the highest level of thermal stability, differences between types of organic residues are small and that plastic sheeting offered no benefits in terms of soil heat control, and should be avoided. This work was carried out to study the effect of irrigation methods and mulches used on soil temperature.

MATERIALS AND METHODS

A representative soil was taken from the surface soil layer (0-25 cm) from Abo-Rawash area, Giza Governorate. A sandy soil (*Typic Torripsamment*) containing 0.7 organic matter and 0.34% CaCO_3 was used. Its water content was 9.1 and 2.14% (w/w) at F.C. and W.P., respectively. The soil pH (1:2.5) was 7.95, while the electrical conductivity (1:5) was 0.23 dSm^{-1} .

The experiment was conducted using 63 plastic pots (20-cm inside diameter and 22-cm deep) in the greenhouse experiment of Soils and Water Use Department, National Research Center, Dokki, Giza, Cairo, Egypt. Mixed, air-dried, and sieved soil (0.2 cm sieve) were packed in each pot (7 kg/pot). The pots were divided into three groups (21 pots/irrigation group) according the following methods: subsurface irrigation (SSI); surface irrigation (SI) and drip irrigation (DI).

Five seeds of corn (single hybrid) were planted per pot on 27/8/1992 at a depth of 2 cm. After planting, the main irrigation treatments were divided into seven subgroups (3 pots /subgroups) according to the following mulch treatment: *control* (C); *bituminous emulsion* 50 g/m^2 (B₁);¹ *bituminous emulsion* 100 g/m^2 (B₂); white plastic sheet (WPS); black plastic sheet (BPS); gravel layer 0.5 cm in thickness (G₁) and gravel layer 1.5 cm in thickness (G₂).

The pots were irrigated twice weekly to restore their moisture content to field capacity by weighing. After thinning the plants, fertilizers were applied at the rate of 116.6, 250.0 and 77.5 kg/acre as NH_4NO_3 , KH_2PO_4 , and K_2SO_4 , respectively, in two equal applications. The experiment lasted 9 weeks. During the experiment, soil temperature was measured once a week at the depth of 5 cm at 10 A.M., and 2.30 P.M. using thermometers according to Taylor and Jackson (1965).

RESULTS AND DISCUSSION

The soil temperature and its changes relative to the control at 5 cm deep measured at 10 A.M. and 2.30 P.M. versus irrigation methods and mulches used are summarized in Table 1. According to the mulches used, soil temperature increased from 1.0 to 2.0°C at 10 A.M. and from 5.2 to 6.2°C at 2.30 P.M. over the control

Table 1. Mean soil temperature at 5 cm depth with irrigation methods and mulches.

Irrigation Method /Mulch			Soil Temperature			
			10.0 A.M.		2.30 A.M.	
			°C	°C	°C	°C
Subsurface (SSI)						
Control	(C)		23.4	0.0	25.4	0.0
Bitumen, 50g/m ²	(B1)		24.4	1.0	30.6	5.2
Bitumen, 100g/m ²	(B2)		24.6	1.2	31.1	5.6
White plastic sheet	(WPS)		25.2	1.8	30.9	5.5
Black plastic sheet	(BPS)		25.3	1.9	30.8	5.4
Gravel layer, 0.5 cm thick	(G1)		25.1	1.7	31.0	5.6
Gravel layer, 1.5 cm thick	(G2)		25.4	2.0	31.6	6.2
Mean			24.8	1.4	30.2	4.8
Surface (SI)						
Control	(C)		23.4	0.0	29.6	0.0
Bitumen, 50g/m ²	(B1)		24.2	0.8	30.7	1.1
Bitumen, 100g/m ²	(B2)		24.5	1.1	31.1	1.5
White plastic sheet	(WPS)		25.1	1.7	31.6	2.0
Black plastic sheet	(BPS)		24.6	1.4	31.4	1.8
Gravel layer, 0.5 cm thick	(G1)		24.8	1.2	31.5	1.5
Gravel layer, 1.5 cm thick	(G2)		25.1	1.7	31.8	2.2
Mean			24.5	1.1	31.1	1.5
Drip						
Control	(C)		24.1	0.0	30.3	0.0
Bitumen, 50g/m ²	(B1)		24.3	0.2	30.7	0.4
Bitumen, 100g/m ²	(B2)		24.5	0.4	30.8	0.5
White plastic sheet	(WPS)		25.3	1.2	32.0	1.7
Black plastic sheet	(BPS)		25.1	1.0	31.1	0.8
Gravel layer, 0.5 cm thick	(G1)		24.6	0.5	30.9	1.6
Gravel layer, 1.5 cm thick	(G2)		24.9	0.8	31.4	1.1
Mean			24.7	0.6	31.0	0.9

under the SSI. In both cases, the minimum and maximum increase in soil temperature were achieved with B₁ and G₂, respectively.

Concerning soil temperature versus mulch, under the SI, the increase in temperature over the control ranged from 1.7°C and 1.1 to 2.2°C according to the mulch used at 10.0 A.M. and 2.30 P.M., respectively. Also, the maximum and minimum measured soil temperature were found with B₁ and G₂, regardless of the measuring time.

Under DI, the minimum and maximum changes measured in soil temperature were 0.2 and 0.4°C at 10 AM and 1.2 and 1.7°C at 2.30 PM. The minimum soil temperature was recorded with B1 while the maximum soil temperature was recorded with WPS.

It is interesting to note that both soil temperature and its increase were higher at 2:30 PM relative to 10 AM under the three irrigation systems, regardless of the mulches used. This was quite obvious under SSI. Also, the increase in soil temperature was higher under SSI in comparison with SI and DI. This may be due to the relatively higher soil moisture content of the surface layer under both SI and DI. This moisture content increased the soil heat capacity and facilitated heat transmission downward in soil. Therefore, soil temperature will be least affected under SI and DI, but the reverse is true under SSI. The data in hand stood in good agreement with those of El-Shaabassy and Gohar (1971), Callebaut and De Boodt (1981), Tayel and Wahba (1986), and Wahba and Tayel (1987).

CONCLUSIONS

It is well known that our ability of controlling soil temperature is limited. But since even relatively small changes in soil temperature can have a great effect upon germination and plant growth, soil temperature can achieve significant results. It can be concluded that a considerable net increase in both soil temperature and its content can be achieved by soil mulching in the zone of soil where seedlings emerge, and both chemical and biological reactions are active. Therefore, early crops production can be obtained during the cold seasons. However, when soil is covered by crops during the hot season, we have to be cautious not to adversely affect some seed germination by mulching.

REFERENCES

- Adams, J.E. 1967. Effect of mulches on soil temperature and grain sorghum development. *Agron. J.* 57: 471-74.
- Alkayssi, A.W. and A. A Alkaraghoul. 1991. Influence of different color plastic mulches used for soil solarization on the effectiveness of soil heating. *FAO Plant Production and Protection Paper*. No. 109, 297-309.
- Callebaut, F., and M. De Boodt. 1981. Effect of various soil conditioners used as mulches on soil temperature. Laboratory experiment. *Egypt. J. Soil Sci.* Special Issue, 13.
- El-Hady, O.A., M.M. Khattab, A.H. Hanna, and K.M. Ebtisam. 1991. Interaction of locally production bitumen emulsion with calcareous saline soil and the growth response of pomegranate (*Punica granatum*, L.) transplants. *Egypt. J. Soil Sci.* 31: 89-114.
- El-Shabassy, A.I., and A. Gohar. 1971. Effect of asphalt application on a sandy soil in Tahrir province and peanut yield. *Agric. Res. Rev.* 49, No. 2, 1.
- Fairbourn, M.L. 1973. Effect of gravel mulch on crop yields. *Agron. J.*, 65(6): 925-928.
- Fairbourn, M.L. 1974. Effect of coal mulch on crop yields. *Agron. J.*, 66: 785-789.
- Gerb, B.W. 1966. Effect of surface applied wheat straw on soil water losses by solar distillation. *Soil Sci. Soc. Amer. Proc.* 30: 786-788.
- Kohnke, H. 1968. Soil physics. Tata McGraw-Hill Publ. Co. Ltd., Bombay-New Delhi, p. 35.
- Mbagwu, J.S.C. 1991. Influence of different mulch materials on soil temperature, soil water content and yield of three cassava cultivars. *J. Sci. Food Agric.*, 54(4): 569-577.
- Morote, C.G.B., C. Vidor, and N.B. Mendes. 1990. Soil temperature as affected by mulching and irrigation. *Revista Brasileira de Ciencia do Solo*, 14(1): 81-84.
- C.F. Soils Fert. 1991, 54, 5.
- Nagmouh, S.R. 1981. Soil reclamation and improvement report. Regional Project for Land and Water Use in the Near East and North Africa, p. 70-113. FAO, Doha, Dec. 1981. TF/RE/508 (Mul)NECP. Terminal Report.
- Tayel, M.Y., and S.A. Wahba. 1986. Soil temperature as affected by various soil conditioners used as mulch. *Egypt. J. Soil Sci.* 28: 261-267.
- Taylor, S.A., and R.D. Jackson. 1965. Temperature. p. 331. *Methods of Soil Analysis*. No. 9. Part 1, (C.A. Black Ed.) Amer. Soc. Agron., Inc. Madison, Wisc., USA.
- Wahba, S.A., and M.Y. Tayel. 1987. Diurnal temperature fluctuated by mulching during an irrigation cycle. *Egypt. J. Soil Sci.*, 27: 321-328.
- Walker, J.M. 1969. One-degree increment in soil temperature affect maize seedling behavior. *Soil Sci. Soc. Am. Proc.* 33: 729-736.
- Weigand, G.L., M.D. Heilman, and W.A. Swanson. 1968. Sand and cotton bur mulches, bermudagrass sod, and bare soil effects on: 1. Evaporation suppression. *Soil Sci. Soc. Am. Proc.* 32: 276-280.
- Willis, W.O., W.E. Larson, and D. Kirkham. 1957. Corn growth as affected by soil temperature and mulch. *Agron. J.* 49: 323-327.
- Wooldridge, J. and R.E. Harris. 1991. Effect of organic mulches and plastic sheet on soil temperature. Deciduous Fruit Technology Research Institute, Stellenbosch, South Africa. *C.F. Soils Fert.* Vol. 55, No. 5 1992.

Annual Irrigation to Prevent Indirect Soil Degradation

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ABSTRACT

The physical, chemical and biological properties of soils and their fertility in agricultural lands could be changed by two basic ways: *Direct*, as a result of fertilizer application and plant, soil and water management; *Indirect*, as a result of change of natural hydrothermal conditions of soil formation processes. These conditions could be expressed in form of local hydrothermal index (*HTI*) as a ratio between annual values of solar net radiation and precipitation. The *direct* changes of soils occur during the relatively short term (some years) and can be predicted, for example, with mathematical models like CENTURY, SCUAF, EPIC, etc. The *indirect* changes of soils occur during much longer periods.

The approach to predict them is based on the theory of energy of soil formation and the geographic law of soil zonification. Regional average numerical data of some soil chemical, physical and biological characteristics representative for the areas with certain types of soil were used in the analysis. The data were selected for the areas with the same topographic conditions, similar subsoil texture and mineralogical composition, and zero or minimal land use. These data were compared with the index *HTI*. In general, the procedure of treatment of the set of geographic data is the following: climate - topography - subsoil composition - land use - soil properties.

The graphic relationships between available data of soil properties and the local index *HTI* were obtained for Mexico and earlier for the European and Asian parts of ex-USSR from tundra to desert zones. In order to develop such relationships for Mexican conditions, the set of geographic maps on climate, topography, subsoil composition, land use, soil types, and their properties with the scale 1:250,000 were used. The soil with the same geomorphology and only with zero or very small (less than 0.001) surface slope were considered in the analysis. The plane surfaces with very small slope were preferred in order to exclude the necessity to take into account surface runoff and soil erosion. In arid zones, the *HTI* index in irrigated lands is reducing because of huge increase of annual accumulative infiltration of water to soil profile (precipitation plus irrigation requirement minus surface runoff), although the annual value of net radiation is growing as well. So, according to relations obtained between properties of soils and *HTI* for conditions without agricultural land use it is possible to estimate how the soil properties will be changed because of change of *HTI* in irrigated lands.

This approach was used to verify the annual water requirements of irrigation in the Mexican arid zone in order to prevent *indirect* soil degradation during long periods. The analysis permitted us to conclude that in some irrigation districts the annual amount of water application should be reduced (up to 40%) to prevent slow soil degradation in the long term, according to change of *HTI*. It means that in those lands a gradual reduction is expected in the crop response to the present practice of irrigation and fertilization if the annual water requirement would not be decreased.

INTRODUCTION

Conservation or improvement of soils is a very important part of environment protection. As it well known that, in general, the physical and chemical properties of natural soils (not used in agriculture) depend on climate and topographical conditions, subsoil properties, flora and fauna, and duration of soil formation. According to investigations of Russian soil scientist Volobuyev (1974), the main soil types in the world are in a good correlation with such two climatic characteristics, annual values of net radiation *R* and precipitation *Pr*. It means that these climate characteristics have great importance for the soil formation processes. So, it is possible to look for the relationship between soil properties and *R* and *Pr*.

Agricultural practices of land use change soil properties. It is possible to consider two ways of soil changes: *Direct*, because of soil and plant treatments (fertilizers, farming, etc.), and *indirect*, because of change of microclimate conditions (as *R* and *Pr*) due to a change of albedo of agricultural fields in comparison with and irrigation or drainage application (which cause a change of annual accumulative infiltration). The direct and indirect changes can occur in the same or different direction. They can both improve or damage soil properties, or one improves and the other depletes those properties.

If the indirect changes provoke soil degradation, although the direct changes improve the soil that means in general that the efficiency of the agricultural practice is not good. The direct changes, which are realized mostly in a short term (some years) can be predicted by several models like CENTURY, EPIC, SCUAF, etc. (Young, 1994). The indirect changes occur during much longer terms (many years), they are less obvious, more difficult to predict, and require special methodology. The problem is more difficult when the climatic, topographic and soil conditions are as complex as there are in Mexico.

Corresponding methods has been developed in the USSR (Volobuyev, 1974; Aydarov, 1985, Aydarov et al., 1990). This method is based on the geographic law of soil zonification and on the theory of energy of soil formation (Volobuev, 1974). The theoretical principles of this approach were proposed during the years 1930-1970s, by several investigators in USSR, United States, and England. Its practical application appeared recently in Russia (Aydarov, 1985; Nikolski, 1987, Parfenova and Reshetkina, 1995).

According to Volobuev (1974), the total solar energy Q_{Σ} that is used for soil formation processes can be expressed in form of following balance equation:

$$Q_{\Sigma} = Q_{ft} + Q_{et} + Q_{hf} + Q_{hcr} + Q_{et} + Q_{pt} + Q_{ce}, \dots\dots\dots(1)$$

Where:

Q_{ft} and Q_{et} are parts of energy that are used during the processes of physical and chemical transformation of subsoil, respectively;

Q_{hf} is energy that is accumulated during the humus formation;

Q_{hcr} is energy that is used in microbiological and chemical reactions in transformation of organic and mineral substances (nitrogen transformation and cation exchange);

Q_{et} is energy that is used in the process of evapotranspiration;

Q_{pt} is energy that is used during the processes of transport of nutrient, toxic salts and soil particles along the soil profile;

Q_{ce} is energy that is used in the process of calorific exchange in the soil - atmosphere system apart the process of evapotranspiration.

The terms of Q_{ft} , Q_{hcr} and Q_{st} are mainly responsible for the soil fertility. The total energy Q_{Σ} can be estimated by the following formula:

$$Q_{\Sigma} = R e^{(0.47HTI)} \dots\dots\dots(2)$$

Where:

R is average annual value of net radiation, HTI is "hydrothermal" index:

$$HTI = \frac{R}{L Pr} \dots\dots\dots(3)$$

Where:

Pr is average annual value of precipitation, L is a latent heat.

MATERIALS AND METHODS

The investigation was made for the whole area of Mexico, for all those points in which geographic information on climate, topography, hydrogeology, vegetation, and soil use was available. For this purpose, the corresponding geographic maps published by National

Institute of Geographical and Statistical Information (INEGI) with the scale 1:250,000 was used. Some information (like topographical and land use) is presented in digital form. The data treatment was made in the following steps:

1. Collection and verification of annual average climatic information about global radiation and precipitation in different parts of Mexico. Taking into account a lack of data on net radiation R , the last one was estimated using the data on annual average global radiation Q_g and cloudiness.
2. Selection of areas with significant difference of annual precipitation Pr ; net radiation R and HTI index.
3. Analysis of topography of selected above areas and selection of sub-areas with:
 - Altitudes from 0 to 500 m above sea level (first stage of investigation),
 - Almost horizontal surfaces (with slope less than 0%).
4. Analysis of hydrogeological information for the selected sub-areas and selection of territories (inside the sub-areas) with similar subsoil mineralogy and deep water-table.
5. Analysis of maps of land use. Selection of sub-territories (inside selected above territories) with no land use in agriculture.
6. Analysis of soil maps for the above selected sub-territories. Search of the main soil types and collection of their physical and chemical characteristics for each selected sub-territory. Statistical treatment of those data and finding out of median values.
7. Construction of diagrams of relationship between median values of soil characteristics and HTI .
8. Collection of typical average annual irrigation requirements Ir for some selected geographical points of Mexico.
9. Estimation of possible change of HTI (which was initially equal to $HTI = R/L Pr$) in those selected geographical points because of change of annual accumulated infiltration into the soil (with irrigation this index is equal to $HTI = R/[L (Pr + Ir)]$).
10. Conclusion if the soil characteristics are getting worse or better as a result of change of HTI (using diagrams of the relationship between soil characteristics and HTI , obtained in Step 7). In case of negative result, it is possible to develop some suggestions about the necessary limitation of change of annual irrigation requirement Ir and the index HTI .

A calculation of annual net radiation R was realized by means of following equations (Chang, 1968):

$$R = a R_{cloudy} + (1 - a) R_{clean} \dots\dots\dots(4)$$

Where:

a is a fraction of cloudy days in a year, *R_{cloudy}* is annual net radiation for cloudy days, *R_{clean}* is annual net radiation for clean days. *R_{cloudy}* and *R_{clean}* are measured here in cal. cm⁻². year⁻¹.

R_{cloudy} = (0.75*Q_g* - 21.4) 365,(5)

R_{clean} = (0.87 *Q_g* - 82.0) 365,(6)

Where:

Q_g is an average daily global radiation (cal.cm⁻².year⁻¹).

The interpolation of *HTI* values between the geographical points of their estimation has been done (when it was necessary) with SURFER program using Kriging.

RESULTS AND DISCUSSION

The relationships between median soil properties, such as organic matter content (OM), pH, cation exchangeable capacity (CEC), Ca and Mg content for the top layer with thickness 20 cm show that the *HTI* values in areas with altitudes from 0 to 500 m above sea level in Mexico change from 0.8 in tropical humid zones to 9.8 in arid zones. These values change rather slowly in plain areas and very sharply in mountainous areas. The analysis shows that the regularity of relationship between soil properties and *HTI* index has been obtained in Mexico with proposed methodology in spite of complex topographical and climatic conditions as well with lack of measured data on solar radiation.

The best soil fertility corresponds to geographical areas with values of *HTI* index between 1.3 and 1.6 (Veracruz, Guanajuato, Michoacan, Colima, Chiapas, and Campeche states).

This relationship can be used to predict indirect changes of agricultural soils because of *HTI* index change. In case of irrigation of agricultural lands, this index changes from *R*/(*L Pr*) to *R*/(*L (Pr + Ir)*). If the soil properties corresponding to the new index *HTI* = *R*/(*L (Pr + Ir)*) are better than before the irrigation (when the index was *HTI* = *R*/(*L Pr*), it means that the indirect changes improve the soil and support the agricultural practice.

In the opposite case, it means that indirect changes degrade soil and gradually reduce the efficiency of the agricultural practice. The best case is when *HTI* changes approximately up to 1.2-1.4. If the agricultural area is located in an arid zone with *HTI* > 2 (in natural conditions before irrigation) and after application of irrigation and the local hydrothermal index is smaller than 1. 3 or more than 1. 6, it means that the indirect change of soil will cause improvement of soil properties, but not enough in comparison with those corresponding to *HTI* = 1.3-1.6.

According to such an approach, the average annual irrigation requirements were evaluated in different states of Mexico. The results of the evaluation are presented in the Table 1. Here there are values of real and recommended irrigation requirements *Ir*; average annual precipitation *Pr*; annual net radiation *R*, kind of influence of indirect change on soil (positive, negative and

Table 1. Preliminary evaluation of average annual irrigation requirements for typical crops in some areas of Mexico Republic.

Area (State)	Real Irr. ¹ Value	Annual Precipitation	Annual Net Radiation Kcal.	HTI Without Irrigation	HTI With Irrigation	Influence on Soil	Recommended Irr. ¹ values
	--mm.yr ⁻¹ --		cm ⁻² .yr ⁻¹				---mm.yr ⁻¹ ---
Río Blanco (Chiapas)	365	1700	111.5	1.70	0.90	negative	200
Delicias (Chihuahua)	939	287	108.2	6.50	1.50	positive	same
La Antigua (Veracruz)	1568	1301	110.1	1.50	0.70	negative	500
Pabellón (Aguascalientes)	610	527	112.3	3.70	1.70	NEP	750
Palestina (Coahuila)	425	595	97.6	2.80	1.60	positive	same
Alto Lerma (Guanajuato)	548	653	112.0	2.90	1.60	positive	same
La Begoña (Guanajuato)	808	679	109.4	2.80	1.30	positive	same
Sto.Domgo (Baha California)	635	648	106.2	2.80	1.40	positive	same
Tula (Hidalgo)	1027	613	115.0	3.20	1.20	NEP	700
Alfajayucan (Hidalgo)	939	463	111.4	4.10	1.40	positive	same
Guaymas (Sonora)	549	224	104.2	8.00	2.30	NEP	980
Zacatecas (Zacatecas)	710	449	109.6	4.20	1.60	positive	same
Mocorito (Sinaloa)	282	663	108.2	2.80	2.00	NEP	570
El Fuerte (Sinaloa)	659	511	108.2	3.60	1.60	positive	same
Mante (Tamaulipas)	546	1164	112.9	1.70	1.10	negative	130
Río Verde (San Luis Potosi)	478	572	109.3	3.30	1.80	NEP	670
Jilotepec (Mexico)	280	779	107.7	2.40	1.70	NEP	450
Morelia (Michoacan)	401	900	112.4	2.10	1.48	positive	same
Tuxpan (Michoacan)	473	861	110.6	2.20	1.40	positive	same

Note: NEP signifies "not enough positive". 1Irr = Irrigation.

not enough positive NEP), and values of *HTI* indexes without and with irrigation.

REFERENCES

- Aydarov, I.P. 1985. Management of water, salt and nutrients regime of irrigated soils. *Agropromizdat Publ.*, Moscow, USSR. 204 p. (in Russian).
- Chang, Jen-Hu. 1968. Climate and agriculture, an ecological survey. (Aldine Publ. Co.). Chicago, USA.
- Nikolski, Y.N. 1987. The theoretical and practical aspects of prediction of indirect soil properties change under irrigation and drainage in humid zone of the USSR. *Guidrotecnica y Melioratsia*, 7: 20-24 (in Russian).
- Parfenova, N., and I. Reshetkina. 1995. Ecological principles of hydrochemical regime management in irrigated lands. *Hydrometeoizdat Publ.*, Saint Petersburg, Russia (in Russian).
- Volobuyev, V.R. 1974. Introduction to the theory of energetic basis of soil formation processes. *Nauka Publ.*, Moscow, USSR (in Russian).
- Young, A. 1994. Modeling changes in soil properties. p. 423-447. *In: Soil Resilience and Sustainable Land Use*. CAB International, Bristol, UK.

Deep Percolation Water Loss in Fields during Irrigation

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ABSTRACT

The agricultural sector is the principle consumer of water among different water users. Irrigation (mainly in the arid zones) annually consumes about 80% of the total human consumption of fresh water. Unfortunately, the efficiency of water use in agriculture is very low. Only about 40% of the water extracted from nature (rivers, lakes and aquifers) is used to produce a crop yield. Another 60% is lost in the channels of irrigation systems because of infiltration through the channel beds (40%) and in agricultural fields because of deep percolation through the soil profile (about 20%). Agricultural residual waters frequently are contaminated with pesticides and fertilisers and have harmful impacts on the natural environment. As a result, agricultural water conservation is one of the current major areas for the prevention of depletion contamination of water resources in arid zones.

The purpose of this investigation is to understand how much and in what forms water losses take place in agricultural fields because of deep percolation through the soil profile during irrigation applications and what factors the loss depend on. Deep percolation in agricultural fields is one avenue of water losses. The other major loss occurs between applications and between crop seasons. In general, water loss occurs because of deep percolation occur in two forms: q_1 with and q_2 without change of soil moisture along the soil profile. The form q_2 is difficult to measure in the field. Therefore, this investigation was realised by means of simulation of the infiltration process, considering differences in soil texture, methods of water application (gravity or sprinkling with different intensities) for fields with deep or shallow water table, different depths of root zone, and different soil moisture regimes.

The results show that the "invisible" water loss (q_2) can be significant. It can be greater than 50% of the accumulated infiltration in sandy soils during sprinkling with low intensity (around 0.5 cm h⁻¹), and even as high as 30% in clay soils when the initial soil moisture is maintained at a high level (about 0.8 field capacity). This kind of loss is reduced when the initial moisture is much less. However, in the latter case, water loss up to 20% occur mainly as q_1 , especially in heavy soils with gravity irrigation or sprinkler irrigation with rather high intensity. Losses in the form of q_2 do not depend on the depth of the root zone. The losses in form q_1 slowly

increase with greater depth of the root zone. In order to reduce deep percolation during irrigation, the amount of each of the two forms of losses must be minimized.

INTRODUCTION

Approximately 80% of all the water resources used by humans worldwide, and in Mexico, are used for irrigation (Manual of Irrigation, 1990; Aguila, 1997). Agricultural activity is the sector that consumes more water than any other, nevertheless, *it is the one that uses it most inefficiently*. In a study by the World Bank in 1988 (Aguila, 1997), they considered that the average efficiency around the world in the use of water for agriculture is 30%. In Mexico it is estimated that the conduction efficiency of irrigation systems is on the order of 60% (Palacios, 1990) and that at the parcel level irrigation efficiency is similar (Perea, 1996, mentioned by Aguila, 1997), which gives a total irrigation efficiency of approximately 36%.

The purpose of this paper is to estimate irrigation water losses in agricultural plots due to deep percolation, mainly during sprinkler irrigation applications. This investigation was done using the mathematical model of unsaturated water flow through the soil profile based on classic differential equations by Richards. According to Darcy's law of unsaturated soil water flow, the vertical velocity of water movement V is proportional to hydraulic conductivity ($K\theta$) and capillary potential gradient ($d\psi/dz$)

$$V = K\theta - K\theta \frac{d\psi}{Dz} \dots\dots\dots (1)$$

Where: z is depth from the soil surface, $K\theta$ is hydraulic soil conductivity, ψ is capillary potential of soil water, $K\theta$ and ψ are functions of volumetric soil water content θ .

The term $-K\theta(d\psi/dz)$ corresponds to water movement caused by the capillary potential gradient or soil moisture gradient and is accompanied with change of water content (θ) along the soil profile during the process of infiltration. The term $K\theta$ in the Equation 1 corresponds to a gravitational movement which is not accompanied with change of water content (θ) along the soil profile during infiltration.

The total amount of water (q_0) that is percolating below the root zone ($z = z_r$) during irrigation applications can be expressed as:

$$q_0 = \int_0^t I dt = \int_0^t K_0 dt - \int_0^t K_0 \frac{d\psi}{dz} dt = q_1 + q_2, \dots (2)$$

Where: t is duration of irrigation application. From Eq. 2 follows the observation that percolation consists of two parts:

$$q_1 = \int_0^t K_0 dt \text{ and } q_2 = \int_0^t K_0 \frac{d\psi}{dz} dt, \dots (3)$$

It means that water loss due to deep percolation q_0 occurs by two ways: without (q_1) and with (q_2) change of soil water content (θ) below the root zone with depth (z) compared to the initial water content (θ_1). The percolation in form q_1 is very difficult to measure in the field and is not easy even under laboratory conditions.

So, it is interesting to investigate regularities of this kind of water loss change as a function of irrigation practice. It seems convenient to establish such regularities using numerical experiments based on the infiltration simulation model. Such approach can be used with confidence taking into account the strong and well-known agreement between calculated and measured rates of water movement during infiltration processes.

MATERIALS AND METHODS

Numerical calculations were carried out using a model developed in the Post-graduate College, Monticello, Mexico, (Barrios Diaz, personal communication, 1998) and based on Richard's equation:

$$C(\psi) \frac{\partial \psi}{\partial t} = \frac{\partial}{\partial z} \left[K_0(\psi) \left(\frac{\partial \psi}{\partial z} - 1 \right) \right], \dots (4)$$

Where: z is soil depth, t is time, $C(\psi) = \delta\theta/d\psi$ is a specific soil capacity and $K\theta(\psi)$ is hydraulic soil conductivity expressed as a function of capillary potential ψ . The relationship between ψ and θ were used as described by Van Genuchten (1980):

$$\theta(\psi) = \theta_r + \frac{(\theta_s - \theta_r)}{\left[1 + \left(\frac{\psi}{\psi_d} \right)^n \right]^m} \dots (5)$$

and the function $K\theta(\theta)$ as described by Averyanov (1949) and Brooks and Corey (1964):

$$K(\theta) = K_s \left[\frac{(\theta - \theta_r)}{(\theta_s - \theta_r)} \right]^\eta, \dots (6)$$

Where: θ is variable volumetric soil water content, θ_s is saturated soil water content, θ_r is residual soil water content, ψ is capillary soil water potential, and μ , n , η and ψ_d are soil characteristics which play a role as correction factors.

The soil profile was considered as uniformly with a given homogeneously distributed initial water content θ_1 ($\theta_1 > \theta_r$) in all calculations of water movement during irrigation applications. The initial water content has been changed in numerical experiments from 0.5 to 0.8 of field capacity θ_{cc} . The depth of the root zone were considered as 0.5, 1 and 2 m. The calculations were done for three kinds of soil with known physical characteristics: Grenoble sand (Parlange *et al.*, 1985), Yolo light clay (Romero, 1995), and silty clay soil (Zaidel and Russo, 1992). For the applications of gravity irrigation the following boundary conditions were considered:

$$t > 0 \quad z = 0 \quad \theta = \theta_1 \text{ or } \psi = \psi_1(\theta_1) \dots (7)$$

The constant intensity of application (and always less than saturated hydraulic conductivity in order to prevent surface runoff) was considered for the sprinkler irrigation:

$$t > 0 \quad z = 0 \quad -K(\psi) \left(\frac{\partial \psi}{\partial z} - 1 \right) = i \dots (8)$$

The intensities of application were 0.5, 1.0 and 1.5 cm.h⁻¹ for sandy and silty soils and 0.2-0.4 cm h⁻¹ for clay soils. The simulated sprinkler irrigation applications were terminated in each simulation when the accumulative infiltration reached a desirable level. The values of deep percolation, q_1 and q_2 , were calculated at the end of each simulated application. The q_1 value was calculated as the accumulated flux through the lower root zone boundary during irrigation application. The q_2 value was calculated as the increase in water storage in the soil profile (including the root zone and below).

In order to be sure that the model gave good results, it was calibrated and validated using the experimental data of Staple and Gupta (1966) on the infiltration in different textures of soil. Those experiments were performed in soil columns. The comparison of calculated and measured data was in a good agreement. This validation exercise strongly suggests that the investigation of deep percolation based on numerical experiments produces realistic results.

RESULTS AND DISCUSSION

Water Losses during Gravity Irrigation

The results show that deep percolation during application of irrigation by gravity occurs mainly in the form of q_1 (without change of soil water content below the root zone) when infiltration ends immediately after reaching the desired level I_r (which corresponds to planning the increase of water storage in the soil profile). In these conditions, q_1 water loss can reach 5-10% and the q_2 loss is less than 5% of I_r . The larger initial soil water content (θ_1) and higher watertable cause big-

ger q_1 losses. The role of deep percolation in the form of q_1 is surprisingly more significant in clay soils. The water loss in the form of q_2 can be observed (up to 10% of I_r) in sandy soils when the water table is deep enough (more than 3 m) and the initial soil water content is no more than 60% of field capacity. In practice, the accumulated real infiltration normally is greater than planned I_r because of non-uniform distribution throughout the field during furrow or border applications. Thus it may be that in practice the role of losses in the form of q_2 are larger than q_1 losses. It is well known that in practice the sum of both forms of deep percolation is about 10-30% of I_r .

Water Losses during Sprinkling Irrigation

During application of sprinkler irrigation, deep percolation is greater in sandy soils in comparison with clay soils. The total loss ($q_1 + q_2$) can reach as much as 70% of I_r in sandy soils when the initial soil water content is at least 80% of field capacity, the watertable is shallow (less than 1.5 m from the soil surface), and with low rain intensity (0.5 cm h⁻¹ or less). The fraction of I_r that is lost because of deep percolation is always greater with shallow root zones. An increase in initial water content (q_1) causes greater q_1 water losses and a decrease in initial water content leads to greater q_2 water losses (Fig. 1).

The total amount of percolation losses ($q_1 + q_2$) increases with the growth of θ_i in different soils, but more significantly in sandy soils. Water loss occurs mainly in the form of q_2 when the water-table is deep, initial water content (θ_i) is less than 60-65% of field capacity, and the soil texture is sandy or silty. The intensity of water application has a strong influence on deep percolation.

Such water loss can be reduced by increasing the application intensity up to 1 cm h⁻¹ or more. But, as is well known, this greatly increases the risk of high soil erosion losses. Low intensity application (0.6 cm h⁻¹ or

less) inevitably causes large total losses (more than 10% of I_r in silty soil and even more than 30% in sandy soil). The role of water losses in the form of q_1 is always greater when the watertable is closer to the soil surface.

REFERENCES

- Aguila, F. 1997. Alternativa tecnologica y organizacional para mejorar la eficiencia en el uso del agua en la agricultura. *Tesis de Maestría en Ciencias*. Colegio de Postgraduados, Montecillo, México (in Spanish).
- Averyanov, S.F. 1949. Hydraulic permeability of soils with the entrapped air in the pores. *Doklady AN SSSR*, Vol. 46, No. 2 (in Russian).
- Brooks, R.H., and A.T. Corey. 1964. Hydraulic properties of porous media. *Hydrol. Paper*, No. 3, Colorado State University, Fort Collins.
- Irrigation Manual. 1990. Ed. Agropromizdat, Moscow, USSR, p. 27-44 (in Russian).
- Palacios, V.E. 1990. La eficiencia en el uso del agua en los distritos de riego. Memoria: Análisis de la problemática del agua y perspectivas para la modernización de su uso en la agricultura de Guanajuato, Celaya, Gto., México (in Spanish).
- Rendon, L. 1994. Riego por melgas. III. Curso internacional de sistemas de riego. Universidad Autonoma Chapingo. Departamento de Irrigacion. Chapingo, México (in Spanish).
- Staple, W., and R. Gupta 1966. Infiltration into homogeneous and layered columns of aggregated loam, silt loam and clay soil. *Canadian J. Soil Sci.* Vol. 46: 293-305.
- Tabuada, M., Z. Rego, G. Vachaud, and L. Pereira. 1995. Two-dimensional infiltration under furrow irrigation: Modelling, its validation and application *Agric. Water Manage.* 27: 105-123.
- Van Genuchten, M. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Amer. J.* 44: 892-898.

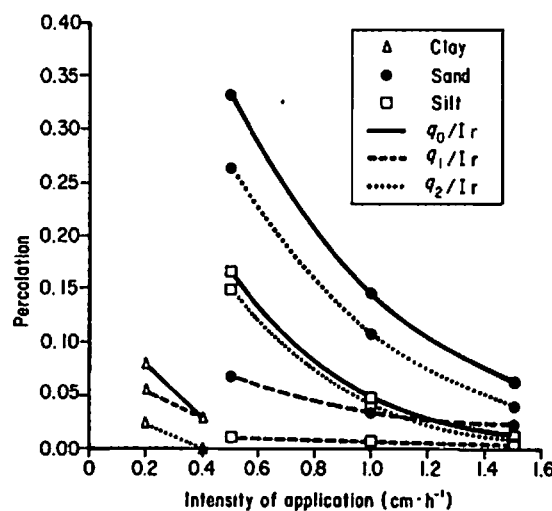


Fig. 1. Change in water loss because of deep percolation during sprinkler irrigation as a function of initial soil water content in sandy, silty and clay soils.

Balancing Water Supply and Demand for Agriculture in the Hexi Corridor, China

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ABSTRACT

The Hexi Corridor is an important base of agriculture development in northwest China. According to recent statistics, there are $65.94 \times 10^8 \text{ m}^3$ of water resources available in the Hexi Corridor. At present, net consumption in development and utilization is $43.33 \times 10^8 \text{ m}^3$. Water supply and demand have reached a balance at the recent level of production, but loss of evaporation and evapotranspiration is as much as $25.69 \times 10^8 \text{ m}^3$. So, net-use efficiency of water resources is 59%. Based on analyzing the balance between water and land and considering the ecological environment, there exists a serious water shortage in the Shiyanghe River system, where irrigation lands are overloaded. There is a comparative balance between supply and demand of water resource in the Heihe River system; and the Sulehe River system has some surplus water to extend irrigation land. Use of agriculture water accounts for 83.3% and ecological forest and grass account for 6.9%.

The Hexi Corridor has a great potential for water saving in agricultural production. Water-saving efficiency of irrigation is about 10% by using furrow and border-dike irrigation and small check irrigation. Common technologies such as saving water with plastic film covers and techniques of advanced sprinkler and drip irrigation can save more than 60% of total water resources. The water-saving potential of the Hexi Corridor has been estimated at 30-197%. Secondary water sources can be developed from saving water for agriculture in the Hexi Corridor. This potential can be carried out step-by-step under the following conditions: developing the water-saving agriculture, improving the ecological agriculture of oases in the river systems, and optimizing allocation of water resources.

AVAILABLE WATER RESOURCES

Situated in the Gansu province $27.1 \times 10^4 \text{ km}^2$ in area or amount to 59.7% of Gansu's total area, the Hexi Corridor is a main economic development region and an important marketable base, whose annual grain yield gains about 2.31 billion kg and therefore supplies the Gansu province with over 60% marketable grain.

Located in the arid zone in NW China, the Hexi Corridor has scarce rainfall dry climate, and strong evaporation. Therefore, its agriculture is completely dependent on irrigation and most of water supply originated from the southern Qilian Mountain where precip-

itation, glacier, and snow melted water formed the river runoff.

The inland river basins in the Hexi Corridor include the Shiyanghe River system, the Heihe River system, and the Sulehe River system from east to west. There are 60 inland rivers in the Corridor and runoff volume of each river is 0.01 to $16.12 \times 10^8 \text{ m}^3$. Runoff volume of 24 rivers in the hydrological observation accounts for 91.2% of the total surface water resources.

Surface Water Resources

The total water resources in the Hexi Corridor consist of surface and groundwater. The surface water, which mainly originates from the southern Qilian Mountains, can be divided into the station-controlled river flow the non-station-controlled stream flow and the front-mountains runoff their surface runoffs, respectively, amount to 91.2%, 5.8%, and 3.0% of the surface water resources in the Hexi Corridor. Among the three river systems in the Hexi Corridor, the Shiyanghe River system makes up $15.87 \times 10^8 \text{ m}^3$, the Heihe River system $36.83 \times 10^8 \text{ m}^3$, and the Sulehe River system $17.22 \times 10^8 \text{ m}^3$, and the total adds up to $69.92 \times 10^8 \text{ m}^3$. According to statistical data the water volume flowing out from the Qilian mountain area is $68.5 \times 10^8 \text{ m}^3$, of which the Shiyanghe River system is $15.55 \times 10^8 \text{ m}^3$ the Heihe River system $36.22 \times 10^8 \text{ m}^3$ and the Sulehe River system $16.73 \times 10^8 \text{ m}^3$.

Groundwater Resources

In the Hexi Corridor, the natural groundwater resources mainly come from the leakage of the river courses, the channels, and fields. In addition, a part of phreatic water of valleys and the rainfall infiltration in the plain area also form the groundwater that is not included in the surface water resources. According to statistics of the Hydrogeological Department of the Gansu Province, the total groundwater volume in the Hexi Corridor is about $4.94 \times 10^8 \text{ m}^3$, of which the Shiyanghe River system occupies $1.32 \times 10^8 \text{ m}^3$, the Heihe River system $2.49 \times 10^8 \text{ m}^3$, and the Sulehe River system $1.13 \times 10^8 \text{ m}^3$.

Available Water Resources in the Hexi Corridor

In the Hexi Corridor, available water resources, which exclude the consumption in the Qilian Mountain area, are surface waters flowing out from the mountain area adding to the non-repeated groundwater, of which, the

Shiyanghe River system makes up $16.87 \times 10^8 \text{ m}^3$ the Heihe River system $31.21 \times 10^8 \text{ m}^3$ and the Sulehe River system $17.86 \times 10^8 \text{ m}^3$. Excluding water flowing into the lower reaches of the Heihe River, the total resources available in the Corridor is $65.94 \times 10^8 \text{ m}^3$. The surface water and groundwater occupy 92.5% and 7.5%, respectively.

According to the present situation, in the Hexi Corridor water volume per capita is about 1713 m^3 and per ha is 11235 m^3 . For three river systems, the Shiyanghe River is 787 m^3 per capita and $5580 \text{ m}^3 \text{ ha}^{-1}$, Heihe River is 1807 m^3 per capita and $11010 \text{ m}^3 \text{ ha}^{-1}$, and the Sulehe River is 1272 m^3 per capita and $26445 \text{ m}^3 \text{ ha}^{-1}$. Analyses of the balance between supply and demand of water resources and balance between water and land in the Hexi Corridor

Water Resources: Supply and Demand Balance

The main users of water in the Hexi Corridor are agriculture, industry, municipal supply drinking for human beings and livestock in rural regions, and forest and grassland. Among these, water supply to agriculture accounts for 88.3%, to industry for 6.8%, to municipal supply and to drinking water in the rural region for 2.9%, and to ecological forest and grassland for 6.9%. For calculating and analyzing the balance between supply and demand of water resources, the paper takes the available water in the Corridor as supply items and the net utilization as consumption ones.

The results showed that the net consumption of water resources is $17.46 \times 10^8 \text{ m}^3$ in the Shiyanghe River system, but as loss as ineffective evaporation is as much as $2.66 \times 10^8 \text{ m}^3$, the water shortage is $3.25 \times 10^8 \text{ m}^3$. Thus, the conflict between supply and demand is evident the ratio between supply and demand is about 0.81:1, especially in the lower reaches in the Minqing Basin, where water resources is seriously short and the groundwater is over-exploited. The net utilization of the Heihe River system is $19.64 \times 10^8 \text{ m}^3$, the ineffective loss and surplus water amount to $13.6 \times 10^8 \text{ m}^3$, and the surplus which mainly supplies the Ejina oases of the lower reaches is $5.5 \times 10^8 \text{ m}^3$; so there is a balance between supply and demand in the Heihe River system, with the ratio being 1:1. The net water utilization in the Sulehe River system is $6.23 \times 10^8 \text{ m}^3$ and the ineffective loss is $9.48 \times 10^8 \text{ m}^3$. Thus, there is surplus water of $2.15 \times 10^8 \text{ m}^3$; the ratio of supply and demand is 1.3:1.

At present, the net water consumption in the whole corridor is $44.33 \times 10^8 \text{ m}^3$, supply and demand of water reach a balance on the recent level of production, with a ratio of 0.98:1. Based on above analysis, the ineffective loss amounts to 35% of total water resources in the Hexi Corridor and the net utilization efficiency of water resources is 59%.

Balance between Water and Land

According to a detailed survey of land use status in Gansu in 1992 the Hexi Corridor has $65.38 \times 10^4 \text{ ha}$ of

cultivated land of which the Shiyanghe River system amounts to $30.27 \times 10^4 \text{ ha}$ the Heihe $28.36 \times 10^4 \text{ ha}$ and the Sulehe $6.75 \times 10^4 \text{ ha}$. In addition, the Hexi Corridor also has rainfed farmland of $15.35 \times 10^4 \text{ ha}$, and wasteland potentially suitable for agriculture amounts to $31.15 \times 10^4 \text{ ha}$. Thus, the land development has great potential in the Hexi Corridor.

Based on the present level of agricultural production and adopting the theory of water balance, the equations of land and water balance in every river system are set up in the Corridor; when the water volume $W > 0$, it means that irrigation land have overloaded, when $W = 0$ water and land balanced and when $W < 0$, there is surplus water to increase irrigation land. At present, irrigated lands are overloaded by $6.5 \times 10^8 \text{ m}^3$ in the Shiyanghe River system, there is basically a balance in the Heihe River system, and there is some surplus water in the Sulehe River system, which could extend $3.33 \times 10^8 \text{ m}^3$ of irrigation area.

WATER-SAVING POTENTIAL FOR AGRICULTURE

Water-saving agriculture is one of effective ways of increasing the efficiency of water resources utilization and alleviating the shortage of water resources. Its main measures can be adopted, such as decreasing the loss through leakage in channels by concrete channels, reducing the irrigating water quota by new techniques, and controlling the ineffective loss of evapotranspiration, so as to enhance the efficiency of water resources utilization.

According to the analysis on actual crop irrigated quota in the Hexi farmlands from 1990 to 1993, the average net irrigation quota in Shiyanghe River system is $5850 \text{ m}^3 \text{ ha}^{-1}$, the Heihe River system is $6975 \text{ m}^3 \text{ ha}^{-1}$, and the Sulehe River system is $7950 \text{ m}^3 \text{ ha}^{-1}$. Water-saving efficiency of irrigation is about 10% by normal techniques, and saving water with plastic film cover to wheat and maize can gain more than 60% of total water resources so these techniques of water-saving have potential in crop irrigation and are suitable for developing country's conditions.

According to irrigation experiments of wheat and maize, net consumptive water use in the wheat fields is 33% for soil evapotranspiration and 67% for leaf transpiration; and in the maize field 39% for soil and 61% for leaf. Based on experiments in the fields of Wuwei Zhangye and Jiuquan we calculated that net consumptive water for leaf transpiration during the wheat growth period is 2820 to 3555 m^3 per ha. According to net irrigation quota at present, the loss of evapotranspiration in the field amounts to 52-55% of the irrigation water in the cropped field, the efficiency of water use is only about 45-48%. At present, the net coefficient of water use from channel to field is 0.48 and the effective use rate of water resources from channel to crop absorption is 0.23.

According to traditional water-saving technologies in the Hexi Corridor from 1990 to 1993. If substituting

furrow irrigation, border-dike irrigation or small check irrigation for flood irrigation, the water-saving efficiency can get to 10%, and if farming with plastic covers, the water-saving efficiency can gain as high as 60%. On the basis of water balance calculation, raising the water-saving efficiency and increasing the carrying potential of water are analyzed and the relations of water and land balance were set up in order to utilize water more efficiently. From these relations we can see that the potential of water-saving in the Hexi Corridor is great and this can be the main direction of water rational utilization in future.

After taking the water-saving irrigation measures, the potential of water resources is indicated by the percentage (X) of the ratio of incremental irrigation area to original irrigation area. The relationship between water-saving efficiency (Y) and the potential of water resources (X) is non-linear. The correlative coefficient between X and Y is 0.98 ($\alpha=0.01$). From such non-linear models we can determine the potential (X) of the carrying capacity of water resources according to achieving the water-saving degrees (Y), or can determine the needful water-saving degrees based on the developing the scale of irrigation area for safeguarding the balance between supply and demand of water resources and coordinating development of water and land resources.

CONCLUSIONS

Based on the above analysis we concluded that water resources in the Hexi Corridor, which are not exploited fully, had great potential by adopting advanced water-

saving technologies. This potential can be carried out step-by-step under the following conditions: developing field irrigation technologies and ensuring stable water-saving measures, improving the ecological agriculture of oases in the river systems, and optimizing allocation of water resources. At present, the stress and shortage of water resources in the Hexi Corridor is mainly caused by the low use-efficiency and waste of water. According to the water-saving approaches such as plastic cover in wheat, the water-saving efficiency can gain 60%. Then water-saving potential in the Shiyanghe River systems has been estimated as 30%, in the Heihe River system 100%, and in the Sulehe River system 197%. So, it is very important to popularize the advanced water-saving technologies such as drip irrigation, seepage irrigation, and plastic covers so as to enhance the efficiency of water resources utilization. We can exploit the second water source from saving water of agriculture in the Hexi Corridor.

REFERENCES

- Cheng Longheng, and Qu Yaogan. 1992. Water and land resources and their rational development and utilization in the Hexi region. Science Press, Beijing.
- Gao Qianzhao, and Li Fuxing. 1991. Case study on rational development and utilization of water sources in the Heihe River Basin. *Gansu Sci. Tech. Press*.
- Li Shouqian, and Lan Nianjun. 1992. The study on water requirement of crop and water-saving irrigation in arid regions. *Gansu Sci. Tech. Press*.

Low Quality Water Irrigation: Chemical Properties of Egyptian Soils

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ABSTRACT

Two soils in El-Gabal El-Asfar and Fayoum governorates differing in texture, i.e., sandy (I) and clay (II) were subjected to irrigation with sewage water and saline drainage water continuously for 10 years. Variations due to such treatments were quantitatively evaluated with corresponding sandy and clayey plots in the same area, but under Nile irrigation water (as a control). Results revealed that although the pH was increased annually by about 0.1 unit in the soil irrigated with saline drainage water, it tended to be reduced in the soil treated with sewage water. Both soils showed appreciable increases in soil electrical conductivity, cation exchange capacity (0.3, and 0.6 meq kg⁻¹), as well as in their content of smectite expense of micas and kaolinite clay minerals (0.5, and 0.81) with annual increments of averaging 0.20, and 0.61 unit dSm⁻¹, and for soil irrigated with sewage water and saline drainage water, respectively.

INTRODUCTION

Irrigation water quality is so important in the arid and semi-arid areas, particularly from the point of view of soil alkalization. The secondary salts released *in-situ* through the chemical weathering of soil, or of added to the soil by irrigation water of lower quality, accumulates in the soil profile. Irrigation of low quality water contains 3000 g salt per cubic meter compared to 5-40 g per cubic meter for rainwater.

Salem et al. (1989) showed that irrigating the soil with drainage water increased its electrical conductivity 2-3 times compared to its initial state. The sewage water irrigation also often increase the soil salinity, especially at the soil surface. (Waly et al., 1981), Khalil, (1990), and El-Gazzar (1996). Irrigation with saline drainage water resulted in an increase in the exchangeable sodium fraction, but on the other hand, decreased calcium and magnesium. Also, sewage water irrigation increased both exchangeable Na⁺, Ca²⁺, and Mg²⁺ at soil surface (Awad, 1969). Abd El-Ghany and Al Sharif (1997) and El-Gazzar (1996) found that treated the soil with low water quality resulted in transformations of same clay minerals.

The main goal of this study was to evaluate the role of irrigation with low water quality on soil chemical and mineralogical properties.

MATERIALS AND METHODS

Two main areas were investigated, the first area was of light texture and irrigated with Nile water as a control

and represented by Profile No.1 in El-Gabal El-Asfar. Another location in the same area was irrigated with sewage water for 10 years and represented by Profile No. 2. The second area was clay in texture and irrigated with either Nile water as a control, (Profile No. 3) or with agricultural saline drainage water for 10 years, Profile 4, in El Fayoum region.

Particle-size distribution was carried according to the (Piper, 1950) pipette method. Soil pH was measured in soil paste using Beckman's pH meter (Jackson, 1973). Electrical conductivity and soluble ions were measured in the soil paste extract (Jackson, 1973). Exchangeable cations and cation exchange capacity were carried out as described by Page et al. (1982). The x-ray diffraction of clay was obtained using Philips diffractometer, Ni-filter, and Cu-K α radiation.

RESULTS AND DISCUSSION

Soil Chemical Properties

The pH values of soils irrigated with Nile water were slightly alkaline (pH 7.6) whereas in the soil treated by sewage water the soil reactions or pH values tended to be neutral or slightly acidic (pH 6.5-7.0). This could be mainly due to the decomposition of organic materials contained in this sewage water as a result of microbial activity and release of carbon dioxide, and organic and inorganic acids (El-Tabey, 1993; El-Gazzar, 1996). On the other hand, the irrigation by agricultural saline drainage water irrigation increased soil reaction in the surface layer from slightly alkaline (pH 7.6), to strongly alkaline (pH 8.6). This is associated with using saline drainage water containing appreciable amounts of soluble bicarbonate ions, with a consequent increase in soil exchangeable Na⁺ and formation of a sodic (alkali) soil. The annual reduction in soil pH values amounted to about 0.11 units using the sewage water, whereas saline drainage water irrigation increased soil pH by about 0.10 units annually.

Data also show that soil irrigation with either sewage or saline drainage water increased the total soluble salts (electrical conductivity, ECe) of soils from 1.3 to 3.3 and from 3.0 to 9.1 dSm⁻¹ for the surface layer of two soils, respectively. One of the common features in the arid and semi-arid regions due to in addition to the fine soil texture and poor drainage is accumulation of salts on the upper surface, especially in soils irrigated with saline drainage water. The soil treated with sewage water for 10 years could be considered as very slightly saline (3.1 dSm⁻¹), whereas that treated with saline drainage water is moderately saline

according to Soil Survey Staff, (1993). Therefore, the annual rates of increase in ECE values are 0.2 and 0.61 dSm⁻¹. The relatively higher increasing of the soluble salts in the soil irrigated with saline drainage water than the irrigated with sewage water could be related to the fine soil texture and poor draining in the former soil.

As shown in Table 1 the soluble cations in the soil irrigated with sewage water are in order of: Ca²⁺ > Na⁺ > Mg²⁺ > K⁺, whereas it followed the order: Na⁺ > Mg²⁺ > Ca²⁺ > K⁺ in the soil irrigated, with saline drainage water. The relatively high contents of Ca²⁺ and Na⁺ in the former soil seem to be related to their high level in sewage water, whereas the relatively high amounts of Na⁺ and Mg²⁺ in the latter one could be attributed to their relatively higher values in the saline drainage water used for irrigation. Also, the data showed that soluble anions in both soils irrigated with sewage water or saline drainage water are dominated by SO₄⁼ followed by Cl⁻ and HCO₃⁻, which may be attributed to the relatively higher contents of SO₄⁼ in both types of water used for irrigation.

The distribution pattern of exchangeable cations through the soil profiles is markedly different as a result of irrigation with either sewage water or saline drainage water as compared to that irrigated with Nile water, particularly at the soil surface. The exchangeable Na⁺ increased from 0.71 to 1.7 and from 5.1 to 14.5 meq/100 g at soil surface treated with sewage water and saline drainage water, respectively. This increase in exchangeable Na⁺ is related to the dominance of Na⁺ salts in the used irrigation water. The annual increasing rates were 0.1 and 0.9 meq/100 g for soil irrigated with sewage water and saline drainage one, respectively. Both exchangeable Ca²⁺, Mg²⁺ and K⁺ behaved almost similar to the soil treated by sewage water with annual increase in rates of about 0.2, 0.1, and 0.01 - meq/100 g. for exchangeable Ca²⁺, Mg²⁺, and K⁺ respectively.

Also, data indicate that exchangeable cations decreased with increasing the soil depth, which seems to be directly associated with the distribution of salts and organic matter at the soil profile. On the other hand, both exchangeable Ca²⁺ and Mg²⁺ tended to be decreased in the soil irrigated with saline drainage water as compared to that of Nile water, due to the replacement of these two cations by Na⁺ on the exchange sites of soil clay. The values of annual reduction rates for both exchangeable Ca²⁺ and Mg²⁺ were about 0.3 meq/100 g.

Cation exchange capacity showed a remarkable increase in the soil irrigated with either sewage or saline drainage water as compared to those irrigated with Nile water, (Table 2), whereas the annual increase enrichment of smectites and micas on the expense of kaolinite was about 0.3 and 0.6 meq/100 g. for the soil treated with sewage or saline drainage water, respectively. This is due to the addition of organic and inorganic materials to the former soil and the increasing of smectite minerals in the latter one.

Soil Mineralogy

The composition of soil minerals is usually inherited from parent material and developed through the weathering processes (*in situ*). Both constituent of parent material and the intensity of weathering affect the amounts of primary minerals (allogenic minerals) and the secondary ones (authigenic). Clay is the most important soil fraction, which has the most significant effect on soil fertility or the agricultural production. This is due to the activity of the clay, as well as it controls the soil physical and chemical properties.

The x-ray diffraction analysis for soils under study which irrigated by sewage water or saline drainage water indicated that smectite (montmorillonite) minerals are dominant, followed by mica minerals and kaolinite). The semi-quantitative estimation data showed

Table 1. Chemical analysis of soil profiles as affected by varying quality water irrigation.

No.	Depth (cm)	pH	ECe dSm ⁻¹	HCO ₃ ⁻	Cl	SO ₄ ⁼	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
<i>Sandy Soil, Nile Water</i>										
1	0 - 25	7.6	1.3	2.6	6.3	4.1	6.3	2.5	4.1	0.5
	25 - 70	7.7	1.5	2.8	7.1	5.2	7.1	3.5	4.5	0.7
	70 - 150	7.6	1.1	3.0	4.5	3.3	5.1	2.3	3.5	0.3
<i>Sandy Soil, Sewage Water</i>										
2	0.25	6.5	3.3	1.5	12.3	18.5	15.3	7.2	10.1	1.5
	25 - 70	6.7	2.7	1.7	11.1	14.7	13.2	4.0	8.5	1.3
	70 - 150	7.0	1.9	2.0	6.5	10.3	9.5	3.1	5.3	1.1
<i>Clay Soil, Nile Water</i>										
3	0 - 25	7.6	3.0	2.5	17.3	9.5	10.3	6.1	12.0	1.5
	25 - 70	7.8	3.5	3.0	21.5	11.7	12.1	6.3	15.0	1.7
	70 - 150	8.0	4.1	3.5	22.3	15.1	13.5	8.0	20.3	2.3
<i>Clay Soil, Saline Drainage Water</i>										
4	0 - 25	8.6	9.1	3.5	40.3	47.1	21.2	30.3	40.7	2.5
	25 - 70	8.7	10.5	4.0	44.1	51.3	20.1	35.7	45.3	3.1
	70 - 150	8.9	9.7	4.5	43.2	49.1	20.5	33.2	43.1	2.3

No CO₃⁼ detected. ~

Table 2. Exchangeable cations, and cation exchange capacity of four profiles irrigated with different quality water.

No.	Depth -cm-	Ca ± 2	Mg ± 2	Na ⁺	K ⁺	CEC
-----mcq/100g soil-----						
Nile Water						
1	0 - 25	6.10	2.50	0.71	0.40	10.30
	25 - 70	5.00	1.90	0.60	0.21	7.91
	70 - 150	3.50	1.50	0.51	0.15	6.00
Sewage Water						
2	0 - 25	7.60	3.30	1.70	0.53	13.70
	25 - 70	6.50	3.70	1.30	0.35	12.45
	70 - 150	4.70	2.10	1.00	0.20	11.70
Nile Water						
3	0 - 25	28.30	15.10	5.10	1.00	49.50
	25 - 70	26.50	18.30	7.30	0.70	53.80
	70 - 150	25.10	19.10	6.50	1.90	53.60
Saline Drainage Water						
4	0 - 25	25.50	12.20	14.50	2.70	55.90
	25 - 70	231.00	15.30	13.70	2.50	55.80
	70 - 150	21.70	15.60	17.50	2.10	56.90

that smectite minerals ranged from 59.3 to 63.0 and 61.7 to 64.5 for the soils irrigated with Nile water and sewage one, respectively. The values of micas ranged from 13.5 to 15.8 and 8.5 to 12.5 for the untreated soils and treated ones, respectively, whereas kaolinite ranged from 12.0 to 13.8 and 7.1 to 11.2 of or the two soil types, respectively. The smectite minerals and mixed-layer ones were increased at surface layers of the soils irrigated or treated with sewage water on account of kaolinite and micas. This may be due to the chemical weathering and transformations of clay minerals and by addition associated with this sewage water.

Also, the semi-quantitative estimation of clay minerals for the soils irrigated with saline agricultural drainage water revealed that smectite constitute 52.5 to 59.3% and 60.3 to 73.1% for the untreated and treated soil, respectively, whereas the micas ranged from 10.1 to 14.3% and 6.5 to 9.5% for two soils, respectively. The kaolinite represented values of 9.1 to 14.8 and 5.0 to 7.1% for the soil irrigated with Nile water and ones with saline agricultural drainage water. The relative increase of smectites with depth of the soil treated with saline drainage water is due to the poorly drained, alkaline and gley conditions which are favorable for the transformation of micas, kaolinite to smectite minerals (Shendi, 1990). Also, the occurrence of vermiculite and mixed layer (interstratified) minerals (mica /vermiculite) in these soils irrigated with saline agricultural drainage water are due to the high concentration of magnesium.

The smectite peaks in the soils irrigated with sewage are border unsymmetrical and have less intensity compared with the soils irrigated with Nile water, which reflect the poorly crystalline smectite minerals. This is due to the effect of adding sewage water and increasing the chemical weathering. On the other hand, both smectite and kaolinite peaks of the soils irrigated

with saline drainage water are sharp and of low intensity, indicating their crystalline shape due to the formation of new crystals during pedogenic process and transformations of minerals (El-Gazzar, 1996). The transformations rates of micas and kaolinite minerals to smectite in the surface of soil irrigated with sewage about 0.7%, whereas it were 0.5 and 0.8%, respectively, in soil surface irrigated with saline drainage water.

REFERENCES

- Abdel E-Ghany, I., and A.A. Al Sharif. 1997. Effect of whey on chemical and mineralogical properties of bentonite. *Bull. Fac. Agric., Univ. Cairo*, 48: 749-758.
- Awad, F. 1969. The effect of different salt concentrations in irrigation water on the physical and chemical properties of different textured soils. *M.Sc. Thesis*, Fac. Agric., Ain Shams Univ., Egypt.
- El-Gazzar, A. 1996. Use of low quality of water in irrigation and its effect on soil properties. *Ph.D. Thesis*, Fac. Agric., Moshtohor, Zagazig Univ., Egypt.
- Al-Tabey, H. 1993. The effect of some trace elements on soil productivity. *M.Sc. Thesis*, Fac. Agric., El-Azhar Univ., Egypt.
- Jackson, M.L. 1973. *Soil chemical analysis*. Prentice Hall Inc. Englewood Cliffs, N.J., USA.
- Khalil, M. 1990. Accumulation of some nutrients and heavy metals in Abou Rawash area, Giza. *M.Sc. Thesis*, Fac. Agric., Moshtohor, Zagazig, Egypt.
- Page, A.L. 1982. *Methods of soil analysis*. Amer. Soc. Agron., No. 9, Part 2. Madison, WI, USA.
- Piper, C. 1950. *Soil and plant analysis*. Inter. Sci. Pub. New York.
- Salem, M., S. Abdel Aziz, and F. Mustafa. 1989. The use of drainage water for irrigating cotton. *Bull. Fac. Agric. Sci. Moshtohor*, 27(3): 1917-1927.

Shendi, M.M. 1990. Some mineralogical aspects of soil sediments with reference to both lithology and environmental conditions of formation in Fayoum area. *Ph.D. Thesis*, Fac. Agric. Fayoum. Cairo Univ., Egypt.

Soil Survey Staff. 1993. Soil survey manual. *USDA Handbook* No. 18. Gov. Printing, Washington.

Waly, T.E. Abdel-Naim, M. Omran, and B. El-Nashar. 1987. Effect of sewage water on chemical properties and heavy metals content of El Gabal El Asfar sandy soils. *Biological Wastes*, 22(4): 273-284.

Irrigation Water Sources in Egypt: Water Efficiency in Reclaiming Saline Soils

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ABSTRACT

The increase use of more water for land reclamation and irrigation has become so pressing that the use of low quality drainage and sewage waters has to be explored. Water suitability depends on what can be done with it under specific conditions of use. Numerous schemes have been proposed for classifying water with respect to suitability for irrigation. From those, the classification proposed by the U.S. Salinity Laboratory (1954) is the most widely used. The main objectives of the present work were to evaluate the quality of some sources of water used for irrigation in Egypt, i.e., *Nile, drainage, well, and sewage waters*, and the efficiency of these waters in leaching of salt-affected soils.

Water samples were collected from different irrigation canals to represent fresh (Nile) water in Cairo, Giza Kalubia, Sharkia, and Buhira governorates. Also, drainage, well, and sewage waters were collected from different locations in Egypt. Five soil samples, differing in their texture, representing saline, saline-sodic and magnesium-affected soils, were also collected, packed in PVC columns, and leached in the laboratory using a representative water sample from the different water sources under study.

With respect of the effectiveness of the above-mentioned water sources in leaching saline soils, the results obtained showed that there was not much difference between the different sources of irrigation water in the efficiency for salt leaching from soil. However, the efficiency of different water sources in leaching salt can be arranged as follows: Drainage water > Fresh (Nile) water > sewage water > well water. The efficiency of leaching, i.e., the time needed for leaching the soil to attain an EC value almost comparable to that of used water and the final EC of the soil paste extract after leaching are dependent mainly on soil texture, than initial soil salt content, and the EC of the water used. Also, the results show that the EC of the final leachate, in all cases, is almost equal to the EC of the used water except of the high saline-sodic soil, where the final EC remained higher than that of the water used.

It can be concluded that low water quality, especially when it has low salt content, can be used successfully in leaching saline soil and irrigation crops with little risk of adverse effects from the salinity and sodicity viewpoints, provided that some precautions are taken into consideration. With respect of magnesium-affected soil, the process will fail, as the water could not pass through the soil column.

INTRODUCTION

The Egyptian economy depends to a great extent on agriculture, a condition it seems will continue for many years to come. The rapidly growing population and the improvement of the standard of living increase the demands on agriculture. Thus, the main aim of Egyptian policy is to increase land production through better land use; improve agricultural techniques, and bring new land areas under cultivation. Looking at a future of increasing water demands, it is quite obvious that a very careful use of available water sources and development of new water resources such as drainage, well and sewage water must be taken into consideration.

At present, some drainage water of reasonable quality, estimated at 13.5 billion m³ /year, flows unused to the Mediterranean Sea and the coastal lakes which are in direct connection with the sea. Part of this water could and should be re-used for irrigation so that the country can overcome the shortage in agricultural production.

Presently, about 4.6 billion m³ of drainage water is re-used annually for irrigation, and it is planned to make use of about 7 billion m³ up by the year 2000. It is well known that the drainage waters are generally saline and may contain some polluting substances which impede its utilization (El-Wakeel and El-Mowelhi, 1991). Accordingly, adequate measures and precautions have to be taken into consideration to ensure the conservation of soils. El-Wakeel and El-Mowelhi (1994) concluded that, under proper water management, moderately saline drainage waters could be used successfully in irrigation; the reclamation process could be enhanced under adverse conditions using moderately saline drainage water for leaching which prevents or reduces soil dispersion and reduction in soil infiltration and permeability rates.

The utilization of wastewaters for irrigation adds appreciable amounts of heavy metals to soils. Sewage water may contain such elements at a level which could be lead to toxicity of plants, and hence cause harmful effects to animals and humans. Sadik et al. (1987) reported that sewage could also be used successfully for leaching salts from the salt-affected soils and improving some of its chemical properties

Quality of irrigation water is of particular importance, especially in arid and semi-arid regions such as Egypt. Salts formed in situ by chemical weathering of soil minerals or from applied irrigation water such as groundwater (brackish and saline well water). In addition, treated sewage water may be used for irrigation; however, care should be taken with regard to polluting

materials. These pollutants affect the quality of irrigation water and consequently the properties of soils on which these waters are used.

Water suitability depends on what can be done with it under specific conditions of use. The quality of irrigation water depends upon the total quantity of salts, the rate of water infiltration through the soil profile, and presence of some specific ions (Ayers and Westcott, 1976). Numerous schemes have been proposed for classifying water with respect to their suitability for irrigation. From these, the classification proposed by the U.S. Salinity Laboratory (1954) is the most widely used.

The quality and suitability of irrigation water is judged not only by the total concentration of salts, but also by the individual ions present. Therefore, Rijtema (1981) reported that water quality criteria for agricultural purpose should provide information on suitability of water for irrigation use. The characteristics of irrigation water that appear to be most important in determining its quality are: total concentration of soluble salts; total chloride concentration; relative proportion of sodium to other cations; concentrations of specific ions that may be toxic to plants and humans. The objectives of the present work were to evaluate quality of some sources of water used for irrigation in Egypt, i.e., Nile water, drainage water, well water and sewage water, and efficiency of these waters in leaching of salt-affected soils.

MATERIALS AND METHODS

Water and Soil Sampling

Fifty water samples were collected, from different locations in Egypt to represent various sources used for irrigation purpose, i.e., Nile (fresh irrigation water), drainage, well, and sewage waters. Water samples were analyzed for EC, soluble cations and anions and pH according to the standard methods described by Jackson (1973). Thereafter, SAR, SSP-Mg ratio, RSC, CIP were calculated for evaluating the water quality according to U.S. Salinity Laboratory (1954) and FAO/UNESCO (1973).

Five surface soil samples (0-30 cm), differing in texture, were collected from Giza, Qaliubia, and Kafer El Sheikh governorates to represent saline, saline-sodic, and magnesium-affected soils. Some physical and chemical properties of the studied soils are shown (Table 1).

Leaching Experiment

The soils were air-dried, ground, and sieved through a 2-mm pore size sieve. The soils were packed in PVC columns (30-cm long, 6.7-cm inner diameter) as follows: The bottom of each column was covered with filter paper (Watman No 1) followed by a layer of acid-washed sand, followed by another filter paper; then 800 g soil material were packed in each column to a height of 14.93 cm, the final bulk density in the columns was 1.52 g cm⁻³. A filter paper was placed on the top of the

Table 1. Some chemical and physical properties of the soils.

Soil Properties	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
pH	6.8	7.03	5.6	7.32	7.19
EC, dS.cm ⁻¹	7.99	74.5	12.7	30.0	70.5
O.M., %	2.1	2.2	1.2	1.5	2.1
CaCO ₃ , %	1.7	1.8	0.4	4.0	3.0
CEC, me/ 100 g	52.3	47.6	21.9	52.3	61.0
ESP	13.6	53.8	14.3	44.6	39.7
EMg, %	21.0	8.4	9.1	40.1	45.9
Soluble cations, me/L					
Ca ²⁺	29.6	34.0	63.2	42	32.0
Mg ²⁺	20.4	25.0	14.2	46	97.0
Na ⁺	27.1	593.0	26.16	195.7	543
K ⁺	4.3	57.1	24.3	22.1	35.3
Soluble anions, meq/L					
HCO ₃ ⁻	3.8	5.2	24.1	5.0	8.0
CO ₃ ²⁻	0.0	0.0	0.0	0.0	0.0
Cl ⁻	32.4	309.6	19.6	199.0	602.0
SO ₄ ²⁻	45.2	431.3	84.16	108.1	97.3
Particle-size distribution					
Coarse sand, %	11.65	13.25	46.6	4.95	1.55
Fine sand, %	18.0	19.14	21.6	4.75	5.06
Silt, %	36.25	45.0	8.75	38.75	32.75
Clay, %	30.0	20.0	16.25	46.25	57.25
Texture class	Clay loam	Loam	Sandy loam	Clay	Clay

ESP: Exchangeable sodium percentage; EMg: Exchangeable magnesium.

soil in each column to facilitate infiltration and prevent the disturbance of the soil surface during water addition. Each treatment was replicated two times, and all results presented are the means of two replications.

The packed soil columns were leached in the laboratory under a constant head (10 cm) of a representative water sample from the different water sources under study, i.e., Nile (irrigation), drainage, well and sewage waters. Table 2 shows the chemical analysis of these waters. Leachate fractions were collected each hour until reaching a constant value of EC. The leached soil samples were air-dried, ground, sieved and the final EC of the soil paste extract was measured.

Most of water samples recorded EC values were very close to the minimum limit of the third class.

Salinity of the *sewage water* samples ranged from 1.2 to 1.30 dS/m. The rating is thus C₃. It is noted that the EC values of the studied samples were near the minimum limit of the third class.

Sodicity Assessment: Sodium Absorption Ratio

The SAR values of *Nile water* were low in all the cases, ranging from 0.78 to 2.73; thus it belongs to the first class S₁. Therefore, no sodium hazards would be expected.

Table 2. Chemical analysis of water sources used in leaching.

Chemical Analysis	Nile	Drainage	Well	Sewage
EC dS m ⁻¹	0.32	0.77	1.86	0.90
PH	7.84	8.27	7.61	7.44
Soluble cations, mc/L				
Ca ²⁺	1.88	4.17	3.40	3.00
Mg ²⁺	1.00	1.43	5.50	2.20
Na ⁺	1.20	2.76	9.20	4.26
K ⁺	0.29	0.38	0.33	0.89
Soluble anions, mc/L				
HCO ₃ ⁻	0.61	5.8	5.00	2.5
CO ₃ ²⁻	-	-	-	0.80
Cl ⁻	0.5	1.8	5.60	3.40
SO ₄ ²⁻	3.25	0.87	7.83	3.65
SAR	1.00	1.64	4.36	2.64
Water class (USDA)	C2S1	C3S1	C3S1	C3S1

The soil samples were analyzed for soluble cations and anions and pH in the soil saturated paste extract according to the standard methods described by Jackson (1973).

RESULTS AND Discussion

Water Quality Criteria

The total salt content is the single most important criteria for evaluating irrigation water quality. Water samples collected from different canals of the *Nile River* showed the second class of salinity (C₂) according to the USDA (1954) classification system, except samples collected from El-Mariutia canal which showed the third class of salinity (C₃). The EC of the collected water samples ranged from 0.25 to 1.0 dS/m. It is worth noting that most of the recorded EC values were very close to the minimum limit of the second class, except those of Benha canal (0.5 dS/m) and El-Mahmodiya canal (0.56 dS/m).

The water EC of *drainage water* ranged from 0.41 to 9.33 dS/m. Thus, the water quality of the drains under study belongs to class C₃ except for water samples 18, 22, 24, and 27, where it belongs to C₂, C₄, C₄, and C₆, respectively. Fortunately, the EC values were very close to the minimum limit of the second, third, fourth and sixth class, respectively.

The EC of *well water* samples under study ranged from 0.7 to 13.25-dS/ m. The rating is thus C₂ to C₆.

The SAR of *drainage water* showed the first class S₁ of sodicity except the water sample collected from Drains 24, and 27, which showed the second class, S₂, and the third class S₃, respectively. These results indicate that the most of the samples have no sodium hazards, since its SAR values ranged from 1.37 to 6. These values occurred near the minimum limit of the first class; therefore, no sodium hazards would be expected. Concerning Samples 24 and 27, and owing to their high salinity (C₄ and C₆, respectively), no sodium hazards would be expected.

The SAR of the collected *well water* samples was low; its rating is S₁ it ranging from 0.32, 5.28, except that for Wells 41 and 42, where their SAR values were 13 and 19. Thus, their rating is S₂ and S₃, respectively. It is worth to noting that most of the samples are of no sodium hazard. The high salinity of Wells 41 and 42 could decrease the negative effect of sodium.

Sewage results showed that no sodium hazards would expected from using that water where the SAR of the collected samples were low. The obtained SAR values ranged from 2.14 to 4.49. Thus its rating is S₁. Also, it could be noted that the SAR values were in the lower limit of the S₁.

Sodicity Assessment: Soluble Sodium Percentage

For assessment of sodicity in terms of SSP (i.e., percentage of soluble Na relative to total cations), ratings mentioned in the FAO/UNESCO (1973) are used (SSP of 80 and over indicates hazards for non-saline waters of $EC < 1$ dS/m; those of 60 and over for saline waters of > 1 dS/m). The SSP of the water samples of Nile water were low; it ranged from 21 to 37 except for that of Banha canal where its SSP is high (50). In the light of the low EC of such waters, there would be no hazard due to soluble sodium in water.

In *drainage waters*, the SSP ranged from 28 to 54, except for Drains 21, 24, 27, and 29 which had SSP values of 64, 69, 71 and 61, respectively. In the light of the EC, water samples which had SSP of mostly above 60 indicate harmful effects.

Concerning *well water* samples, the SSP ranged from 7 to 60, except for Wells 41 and 42, since their SSP values were 66 and 64, respectively. From results, it could be noted that most of well water samples under study had SSP values which belongs to the maximum limit of the range. In the light of water salinity, water samples having SSP values above 60 indicate harmful effects.

In *sewage water*, the SSP values were low, ranging from 33 to 55, which render it not harmful.

Assessment of Magnesium Ratio

For assessment of Mg hazards, the parameter of Mg ratio (i.e., percentage of Mg in relation to $Ca + Mg$) was used; according to FAO/UNESCO (1973) a ratio of > 50 indicate Mg hazards on soil conditions. In *Nile*, water the Mg ratio ranges from 17 to 69. Thus, locations of Mg ratio exceeding 50 have harmful effects. In *drainage water*, the Mg ratio was high; it ranged between 34 to 65, thus being between non-harmful and harmful. In *well water*, Mg ratio ranged from 11 to 65, indicating harmful effects concerning soluble in cases of Mg ratio exceeding 50. In *sewage water*, Mg ratio is high; it ranged between 40 and 59; thus being between not harmful and harmful.

Assessment of Residual Sodium Carbonate

Regarding hazards of excess sodium bicarbonates, the parameter of residual sodium bicarbonate (RSC) was used. It consists of three classes as follows: Class 1 "safe" ($RSC < 1.25$), Class 2, "marginal" ($RSC = 1.25$ to 2.50), and Class 3, "unsuitable" ($RSC > 2.50$), according to FAO/UNESCO (1973). The RSC indicates whether irrigation water has the ability to precipitate soil soluble calcium and to a lesser degree, magnesium in soils. This brings about a change in the SSP in the irrigation water, and therefore an increase of the sodium hazard.

The values of RSC found in water sources of the current study were absent or less than 1.0, except in few cases where RSC was 1.1 and 1.9 for Samples 3

and 10 of the Nile water. Thus, the Nile water samples belong to Class 1, except sample No. 10 which belonged to Class 2 ($RSC = 1.90$). This indicates that Nile water samples have no RSC hazards except sample No. 10, which is marginal. Also, drainage water belongs to Class 1 except sample No. 21 which belongs to class 2 ($RSC = 1.60$). This indicates that drainage water had no RSC hazards except sample No. 21. Well water had no RSC hazards, except sample No. 35 which belongs to Class 3 ($RSC = 4$). On the other hand, all samples of wastewater have no RSC hazards.

Assessment of Chloride Hazard

Since the chloride ion has no effect on the physical properties of a soil and is not absorbed on the soil colloidal complex, it has generally not been included in modern classification systems. It appears, however, as a factor in some regional water classification due to its toxic effect on plants (Grillot et al., 1956).

For assessment of chloride hazards, the parameter of CIP (i.e., percentage of Cl in relation to total anions) was used. According to FAO/UNESCO (1973), there are five water groups (from excellent to unusable) with the limits 4, 7, 12, 20, and more than 20. In *Nile water* samples, CIP values ranged from 11 to 43. The rating is thus from the third group, "medium" (Sample No.8), fourth group, "poor" (Samples 1 to 7, and 9), and fifth group "unusable" (Samples 10 to 17). This indicates that water could be induce Cl hazards in plants. Concerning *drainage water*, results show that CIP ranged from 18 to 83. Thus, its rating is the fourth group, "poor" (Sample 19), and the fifth group, "unusable" (Samples 18, and 20 to 31). The CIP values of *well water* ranged from 15 to 58. Thus, it belongs to the fourth group, "poor" (Sample 37), and the fifth group "unusable" (Samples 32 to 36, and 38 to 43). In *sewage water*, the CIP ranged from 37 to 52. Its rating is thus the fifth group "unusable".

Leaching with Water Sources Soil Salinity

Electrical conductivity of leachates that were collected every hour from the soils leached with four water sources (Nile, drainage, sewage and well) reveal that of leachate collected from Soil 1 (clay loam) decreased sharply in all cases. Thereafter, leachates EC, decreased gradually with time till a constant minimum value almost equal to the salinity of the applied water. It means that the various water sources removed the soluble salts from the soil column by passing through.

In case of using Nile water for leaching, the EC of the leachates decreased from 66.5 dS/m in the first leachate to about 5.5 dS/m in the second leachate. The reduction in EC was almost similar with different water sources used. The EC decreased in the second leachate from 55.5 to 7.5 dS/m, from 47.5 to 7.5 dS/m and from 47.5 to 5.0 dS/m using drainage, well, and sewage waters, respectively.

The time and the quantity of water needed for complete the leaching process differed depending on the

water source used. The number of leachates reflect the time needed for leaching. The total quantity of water which passed through the soil columns after 21, 20, 21, and 16 hours was 1374, 1694, 1703 and 2908 mL for Nile, drainage, well and sewage waters, respectively. The EC of the final leachate was 0.4, 0.8, 1.9, and 0.9 dS/m in case of using Nile, drainage, well, and sewage waters, respectively. The EC values of the applied water were 0.32, 0.77, 1.86, and 0.90 dS/m for Nile, drainage, well and sewage waters, respectively. This indicates that after completion of leaching, Nile water, results in a final EC in the last leachate little higher than that of the applied water, but in case of drainage, well, and sewage waters, the EC of the last leachate was almost equal to that of the applied water.

Concerning the efficiency of these water sources in salt elimination from this soil, the results showed that in this soil the EC values of soil paste extract after leaching (final EC) and the percentages change were 1.0, 0.99, 2.5 and 1.1 dS/m; and 87.50, 87.61, 68.71 and 86.23% for Nile, drainage, well, and sewage waters, respectively. From these results it can be stated that the *drainage water was superior in soil leaching* compared with the other sources. This may be due to its high salinity and low SAR which enhances soil flocculation and leaching of salts from the soil column. In Soil 1 the efficiency of salt leaching from the soil followed this order: *Drainage water > Nile water > Sewage water > Well water*.

Soil 2 (saline-sodic loam) behaved almost the same as Soil 1; the similarity may be due to their comparable texture, the former is clay loam and the later is a loam.

In Soil 3, the EC values of soil paste extract after leaching (final soil EC) and the percentage change (% of EC reduction) was 3.25, 4.35, 4.10, and 3.85 dS/m for soil EC; and 96, 94, 95 and 95% for percentage reduction of soil salinity following treatments of Nile, drainage, well, and sewage waters, respectively. This means that these water sources reduced the high soil salinity (74.5 dS/m) to levels tolerable by most plants. The Nile water were superior in leaching to the other sources. This may be due to its low salinity. In this soil, the efficiency of salt leaching from the soil followed this order: Nile water > sewage water > well water > drainage water.

However, Soil 3 showed a different trend since the salinity of leachates reached a minimum value after a short time of leaching. In case of using Nile water, the EC decreased gradually from the first hour of leaching until reaching a constant value almost two times of that of Nile water. It decreased from 6.1 to 0.6 dS/m, from the first leachate to the 12th leachate. Drainage water is effective and showed an effect different from that of Nile water where the EC decreased sharply from the first to the second leachate, thereafter decreasing gradually, reaching a constant value below that of the applied drainage water after 9 hours' leaching, i.e., after the 9th leachate; EC decreased from 7.1 to 0.6 dS/m.

Well water showed a trend similar to that of the drainage water; the EC was reduced sharply from the first to the second leachate (from 12.5 to 4.5 dS/m), after that it decreased gradually, reaching a constant value (1.9 dS/m) after 16 hour leaching; the EC of the last leachate was almost equal to that well water. Well water succeeded in decreasing soil salinity in the beginning and recorded the highest salinity after leaching. This may be attributed to the high salinity of that water compared with the other water sources.

Sewage water was almost like drainage water, where salinity decreased sharply from Leachate 1 to Leachate 2 and therefore decreased gradually to Leachate 8; after that it decreased sharply again to record the minimum EC values. The EC decreased from 7.5 to 0.3 dS/m after 12 hours' leaching. Sewage water was the only source of water which reduced leachate salinity to a value lower than that of the applied water.

The quantity of water which passed through the soil column after 12, 9, 16, and 12 hours was 906, 1740, 435 and 699 mL for Nile, drainage, well, and sewage waters, respectively. It obvious that in case of using drainage water the quantity of water used for complete leaching was the highest. In case of using well and sewage water, the quantity of water was the lowest. The EC of the final leachate was 0.6, 0.6, 1.9 and 0.3 dS/m using Nile, drainage, well and sewage waters, respectively. The EC of the applied water were 0.32, 0.77, 1.86, and 0.90 dS/m for Nile, drainage, well and sewage waters, respectively. This result indicates that when these sources of waters were used for soil leaching, the EC of the last outflow leachate remained higher than that of the applied water, except for treatments of drainage and sewage water.

The final EC values were 1.10, 0.55, 1.36, and 1.65 dS/m; and the reduction in salinity values was 91, 95, 87, and 89% for Nile, drainage, well and sewage waters, respectively. In this soil, the efficiency of salt leaching from soil followed this order: *Drainage water > Nile > sewage water > well water*.

CONCLUSIONS

Fresh (Nile), drainage, well, and sewage waters fluctuated in their salinity, sodicity parameters, as well as their Mg ratio RSC and CIP. According to the criteria of U.S Salinity Laboratory (1954), the fresh (Nile), drainage, well and sewage waters can be classified as $C_2S_1-C_3S_1$, $C_2S_1-C_6S_3$, $C_2S_1-C_6S_3$, and C_3S_1 , respectively; it is worth noting that most of samples occur near the minimum limit of the class which belong to it. In case of drainage and well waters, samples belongs to S3 no have sodium hazards due to its high salinity. Also when most of samples no have RSC, Mg, Cl harmful effects, its rating is from non-harmful to harmful.

With respect of the effectiveness of the above-mentioned water sources in leaching saline soils, that there is no much difference, between the different sources of

waters used for leaching, in the efficiency for salt leaching from soil. However, the efficiency of different water sources in leaching salt can be arranged as follows: *Drainage water* > *fresh (Nile) water* > *sewage water* > *well water*. The efficiency of leaching, the time needed for leaching the soil till EC value almost comparable to that of irrigation water, and the final EC in soil paste extract after leaching are dependent mainly on soil texture, than initial soil salt content and the EC of the used water. Also, the results show that the EC of the final leachate, in all case, is almost equal to the EC of the used water except of the high saline high sodic soil, where, the final EC last leachate was higher than that of the used water.

It could be concluded that low water quality, especially when has low salt content can be used successfully in leaching saline soil and irrigation crops with little risk of adverse effects from the salinity and sodicity viewpoints, provided that some precautions are taken into consideration.

REFERENCES

- Ayers, R.S., and D.W. Westcot. 1976. Water quality for agriculture. *Irrig. Drain. Paper* 29. FAO. Rome.
- FAO, 1973. Irrigation, drainage and salinity FAO/UNESCO. London. 510p.
- Jackson, M.L. 1973. *Soil chemical analysis*. Constable & Co. Ltd. London.
- El-Wakeel, A.F., and N.M. El Mohwelhi. 1991. Reuse of drainage water on farm, with reference to soil properties, crop production, and heavy metals in plant tissues and dairy products. *Agric. Res. Rev.*
- El-Wakeel, A.F., and N.M. El Mohwelhi. 1994. Reuse of drainage of water on farm. 2. Managing moderately saline irrigation water. *Egypt. J. Agric. Res.* 72, (1): 45-58.
- Grillot G., Hayward, H.E., and D.H. Everett. 1956. Utilization of saline water. UNESCO. Paris.
- Rijtema, P.E., 1981. Reuse of drainage water. Model analysis. ICW-note 1274, Wageningen.
- Sadik, M.K., H.H. Abbas, S.M. Abdel Aziz, and S.M. Allam. 1987. Sewage water as a possible source for irrigation sandy soils. *Proc. 1st Conf. Agric., Develop. Res.* 11: 206-220.
- USSL, 1954. Diagnosis and improvement of saline and alkali soils. U.S Dept. Agric. *Handbook No. 60*.

Water Management and Conservation

Wastewater Reuse for Water Management in Tunisia's Arid Areas

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ABSTRACT

Water is one of the most important natural resources for socio-economic development in arid and semi-arid areas. More than 75% of Tunisia is under arid and semi-arid conditions. These areas are facing two major obstacles to its continued development: a growing scarcity of water resources and degradation of soil productivity. Water resources of arid areas of Tunisia are characterized by low water quality, over-exploitation of fossil resources, and a high risk of coastal groundwater salinization due to seawater intrusion. The average annual precipitation ranges between 50 and 220 mm/year, with 80% of the total area receiving less than 120 mm/year. Precipitation exceeding 180 mm/year occurs principally in mountain areas, where only a small portion percolates to become groundwater. The need for providing good water quality for irrigation is urgent to meet the increasing demand of food. Simultaneously, the same water is needed to satisfy the other economic activities (domestic, industrial, tourism). Under such conditions, low water quality from wastewater treatment plants should be used to alleviate high water quality demand. However, protecting public health environment and soil degradation are the main concerns associated with wastewater reuse. The challenge is to reuse treated wastewater for crop production in a highly skilled manner to minimize the risks.

POTENTIAL FOR WASTEWATER REUSE IN TUNISIA

During the last few years, the sewerage network in the largest cities located in arid areas of Tunisia has been expanding rapidly. Municipal wastewater disposal has become a pressing environmental problem, mainly in coastal cities. At present, the National Sewerage and Sanitation Agency (ONAS) operates five wastewater treatment plant and, by the end of 2006, the number will reach 12. Treatment processes are mainly activated sludge. The last treatment plant put into operation is Gabes plant, with a capacity of 17,000 m³/day of wastewater, serving an estimated population of 110,000 with treated effluent being discharged to sea with a biochemical oxygen demand less than 30 mg/l.

In the arid areas of Tunisia, local experience on reuse of treated wastewater is still limited to irrigation of golf courses or hotel gardens. However, the present

policy in Tunisia restricts the utilization of treated effluent to forestry, fodder crops, industrial crops, and fruit trees. It should be noted that Tunisian legislation prohibits the use of treated wastewater on irrigated crops to be eaten uncooked. For fodder crops, irrigation must stop 2 weeks before cutting and fruit-picking, and no fruit should be picked from the ground. Irrigation systems using wastewater must operate under low pressure and avoid dispersal of the spray irrigation by wind into the populated areas. Table 1 illustrates the maximum concentrations for several contaminants in treated wastewater to be used in irrigation.

Overall Objective

Both *opportunities* and *problems* exist in using treated wastewater in irrigation. Problems related to wastewater reuse are generally local, due to not only quality of effluent or the standards adapted, but also due to climate, soil types, choice of crops, agricultural and land use practices, farmers, and public attitudes.

As treated wastewater volume is increasing in arid areas of Tunisia and the local experiences in wastewater reuse are limited, the Institute of Arid Lands (IRA) and the International Center of Environmental Technology (CTET), with financial support of the Initiative for Collaboration to Control Natural Resource Degradation (Desertification) of Arid Lands in the Middle East, initiated a study to demonstrate the technical and social feasibility of wastewater reuse for agricultural purposes.

Effort is made to develop a pilot project suitable for large-scale application that can be easily applied to other parts of arid area of Tunisia or of the Mediterranean basin. In addition, special attention will be paid to the social awareness with private sector and non-governmental organizations (NGO). The study includes the following objectives:

- Utilize treated wastewater in irrigation under controlled conditions which ensure minimum health risks to human and environment.
- Identify economic crop varieties that present the optimum mix of income and public safety.
- Determine design criteria for semi-tertiary treatment (sand bed) based upon local conditions and experience.
- Study public acceptance attitudes of wastewater reuse for agricultural purposes in arid areas of Tunisia.

Expected Outputs

- Demonstrating the advanced water management to reuse treated wastewater in secondary level for additional appropriate agricultural production without related health and environmental problems;
- Demonstrating the best semi-tertiary level treatment method to be adapted in arid areas using the local available experience at feasible costs;
- Revising legislation, which may need to allow a broader choice of crops where treatment quality is higher, by taking into account the regulation, technology, environment and economics.

method on microbiological quality of crops. Data were collected during the growing season by taking samples of wastewater, plant, soils, and groundwater. Some chemical, physical, and biological analyses were made. However, the effect of irrigation method on microbiological quality of crops was not evaluated due to a shortage of laboratory equipment. Research was extended to study public acceptance attitudes of wastewater reuse for agricultural purposes.

The use of treated wastewater to demonstrate producing of forest fruit and ornamental trees and shrubs in nursery was continued. More than 3000 trees were produced and distributed with the collaboration of

Table 1. Treated wastewater standards for reuse in irrigation.

Parameter	Maximum Concentration ----- mg/L -----	Parameter	Maximum Concentration ----- mg/L -----
Electric conductivity (dS/m)	7.0	pH	6.5 - 8.5
Chemical oxygen demand	90	Copper	0.5
Biochemical oxygen demand	30	Iron	5
Suspended matters	30	Manganese	0.5
Chloride	2000	Mercury	0.001
Fluoride	3	Nickel	0.2
Halogenated hydrocarbons	0.001	Lead	1
Arsenic	0.1	Zinc	5
Boron	3	Intestinal nematodes	< 1/1
Cadmium	0.01		

Research/Development Activities

To achieve the overall objective presented above, an experimental farm (2 ha) adjacent to the treatment plant of Gabes is utilized to carry out the experimental activities. Effort is made to determine crop varieties best adapted to irrigation with treated effluent, changes in physical and chemical properties of soil, fertilizer value of water and suitability of irrigation methods.

In 1997, annual fodder crops (barley, oat, sorghum) perennial fodder crops (alfalfa, atriplex) and industrial crops (henne, tobacco) were planted and irrigated with treated wastewater using surface irrigation method. Data were collected during the growing season by taking samples of wastewater, plant leaves, soils, and groundwater. Some chemical, physical, and microbiological analyses were made. Crop yields were also evaluated. In the same time, wastewater was reused to produce forest, fruit and ornamental trees, and shrubs in a nursery. More than 2200 trees were produced and distributed with the collaboration of ATUMED (NGO) to schools and different local agencies. Even though the number of distributed project trees is very limited compared with the number of trees produced annually in the region and used to control desertification, the objective was to demonstrate to the target population an alternative to treated wastewater reuse in irrigation without using fresh water.

In 1998, research was conducted in the same location with some modifications. Two irrigation methods - surface and subsurface drainage/irrigation - for alfalfa were used in order to assess the effect of irrigation

ATUMED to schools and different local agencies. In this year, the Ministry of Agriculture has completed the construction of DISSA scheme project. Effluent from Gabes plant will be transported by pipeline over 9 km to a new agricultural area, where it is proposed to develop gradually a total of 400 ha under various crops by the year 2005.

In 1999, research activities focus on irrigation methods and on semi-tertiary treatment under arid-area conditions. Three irrigation methods - surface and subsurface drainage/irrigation and subsurface - for alfalfa were to minimize microbiological contamination and water efficiency. Data were collected during the growing season by taking samples of wastewater, plant, soils, and groundwater. Some chemical, physical and biological analyses were made. Unfortunately, in the second year, the effect of irrigation method on microbiological quality of crop was not evaluated. Research on a sand filtration system has started at column scale. A group of 24 young farmers was selected for the DISSA agricultural area and have followed a training program on wastewater reuse techniques. The project team was involved in this training program. In addition, it was planned that when the Tataouine city treatment plant will be in operation, the treated flow of 3,000 m³/day will be available for irrigation. An area of 100 ha adjacent to the treatment plant is proposed.

CONCLUSIONS

Since research activities have been started recently, only a few preliminary observations can be made. The chemical quality of treated wastewater from Gabes city plant does not pose problems on the uses of the water for irrigation. However, the microbiological quality of effluent allows a restrictive reuse. Collected data show the positive effects of wastewater reuse for fodder and industrial crops production. However, there is a need for multidisciplinary long-term research that investigates the optimum conditions for irrigation with treated

wastewater in terms of the environment, public health, and agricultural productivity. Also, additional financial support is needed to achieve the other objectives mentioned earlier.

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Range Management

Karakul Sheep Breeding Problems in Arid Zones of Uzbekistan

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ABSTRACT

Karakul sheep farming of the Republic of Uzbekistan is based on desert and semi-desert pastures and provides the population with foodstuffs and light industry with raw material. Problems of karakul sheep farming always require developing technology of production of this branch desert animal husbandry. This report is generalized from long-term research results and industrial testing connected with improving traditional technology of sheep feeding and keeping, which is based on distribution pasture territory, taking into account fodder store in the pastures and rangelands, and consideration of nourishing animals by the seasons of year.

This technology provides increasing life weight of sheep (13-15%), wool yield (7-8%), improving fertility, and quality of karakul pelts. Technological requirements for reaching purebred younger generations up to 1.5-year olds guaranteed good growth in the sucking period and wool yield in ewe lambing and spring periods. Technology improving of roughage nutritive value (22-24%), from base nutrition are shown. Technology of wool producing is on the basis of using one-time shearing and repeatedly bathing which provides increased wool yield of 10-13% and quality (yolk, tannins, length), and lower material expenditures. This developed production process recycles waste in karakul sheep farming based on quality glue necessary for furniture and other industries.

INTRODUCTION

Karakul sheep breeding is of great importance for supplying the population with foodstuffs (meat, fat, milk) and industry with raw materials (karakul, pelts, hair, sheepskin). In the Republic of Uzbekistan, karakul sheep breeding occupies a great area of about 19 million (M) hectares (ha) of arid deserts and semi-desert zones. Arid ranges are characterized by sharp fluctuation of fodder crops and their nutritive value. So, during favorable meteorological years, yield of fodder crops reached 250% relatively to normal years; in a productive year, it is 160%, non-productive one, - 50%, and a very bad year, -25%. On semi-shrub ephemeral pastures, in any 10-year period half of them are not productive.

The dry fodder store for sheep on shrub-grass pastures are 0.07-0.12 t/h, and on arid pastures 0.4-0.45 t/h. On average, yield of desert and semi-desert pastures are very low, i.e., 0.1-0.3 t/h of dried mass. In 1

kg of absolute dried fodder mass taken from spring pastures are 0.8-0.9 fodder units, summer pastures 0.6-0.65 FU, on autumn 0.45-0.50 FU, winter 0.3-0.35 FU. Therefore, karakul sheep productivity (living weigh, daily growth, hair, reproducing ability, lamb conditions, pelt quality) is like a crooked line, going up in the years of good conditions and down in bad conditions.

Increasing total number of karakul sheep depends on improvement of technology of keeping of sheep, based on effective use of natural pastures, optimum system of pasture management and feeding with supplying nutritive fodder for physiological requirements throughout the year.

During a long-term study, research focused on fodder store of pastures according to seasons of the year, nutritive value of pasture fodder, necessary additional feeding of sheep, technology of lambing, young lamb growth, live-weight growing, hair productivity, regime of grazing, dimension of flocks, and sheep breeding in the living space. To optimize conditions of grazing and young growing needs research both fodder standard and feeding technology. General scheme of improving technology of karakul sheep productivity includes emphasis on: sheep feeding and keeping, young lambs, hair, raw fodder, and rational using of wastes.

Studying of fodder store showed that in winter pastures of foot mountains are 0.65-0.185 t/h dry mass (80% wormwood and 20% dry ephemeroids and solianki), in spring fodder yield are 0.22-0.57 t/h (85-95% ephemeroids, 10-15% wormwoods), and in summer 0.25-0.51 t/h.

Shortages of fodder are observed in December - January, needing additional feeding with concentrates (250-300 g) and raw fodder (450-500 g) (0.4-0.5 FU) per sheep. From 1-15 February to 10-15 March, sheep need additional feeding with 0.3-0.4 kg concentrates and 0-0.55 kg of raw fodder (0.55-0.60 FU). In spring period, sheep cover their needs with grazing of 2.8-3 kg green mass (2.2-2.4 fu) per a day.

To improve sheep lambing technology, we kept sheep and lambs in the lambing time in a covered living space (koshara) separating the 1-3 day-old lambs and 3-7 day-old ones. It is also shown that optimal regime for young lambs in summer period is: watering 9-10 a.m., resting 10 a.m. - 17 p.m., watering 17-18 p.m., night grazing from 18 p.m., night-time resting 1-3 a.m., grazing 3-5 a.m., resting 5-6 a.m., and grazing 6-9 a.m.

Traditional technology of karakul sheep-wool production does not consider quality. So, we are offering a technology which allows us increasing production and

quality wool by repeatedly bathing of karakul sheep in a summer period one timely shearing; and extra feeding of sheep in a winter period.

In the Karakul Sheep Breeding Institute a technology was elaborated predicting glue production from hair, pelt, sheepskin, horn, and hoof wastes. This method was based on treating of raw material with alkaline solutions. Calculations show that Uzbekistan can produce 600 tons of glue per year.

Thus, organizing of farms and enterprises with a combination of karakul pelt, sheepskin, hair production and production of glue, and using of improved technology of shearing, the regime of grazing would allow increased profitability of this branch in the transitional period towards a market economy of Uzbekistan.

The long-term (persistent, perennial) research connected to perfection of the "know-how" of production of karakul sheep allows us to make the following conclusions and to give the offers to manufactures:

In arid regions with karakul sheep, the animals in a winter period receive less with pasture (fodder, forage, feed) i.e., 55-60% less nutrition. With the purpose of maintaining efficiency, the sheep receive additional (supplementary) feed by fodder (forage) mixes (share of concentrates 20-35%), rough foods (fodders, forages, feeds) 65-80%). The nutritive value of 1 kg such mix is 0.45-0.60 FU (fodders, forages, feeds), and 55-70 digestible protein.

For lamb use, mixed fodder from 30% of concentrates and 70% of rough foods (fodders, forages, feeds) has a nutritive value per 1 kg of a mix - 0.65 and 72% of digestible protein.

- Some technologies were developed with requirements to keep lambs in conditions of Artemisia-annual ranges, ensuring their good growth and weight gain.

- This allows raising nutritious value of pasture (fodders, forages, feeds), i.e., feed units 22-46%, exchange energy 17-22%, and protein on 22-30%.
- The technology of fattening on mechanized platforms allows an increase in live weight, of rejecting sheep at the end of fattening with 35 up to 50 kgs, lamb with 18 up to 32 kgs. The "know-how" of a wool management in bathing of sheep in summer period of shearing of sheep and high-grade feed to animals in a winter period.
- The technology of using waste products of raw material karakul sheep breeding, high qualities, consisting in preparation, of glue from waste products of astrakhan fur, wool, and also hoofs and horns of animals is developed rational wasteless.
- Identification of desert-pasturable karakul sheep breeding, increase of manufacture of food and industrial resources, decrease (reduction) of the cost price of production and increase of profitability of manufacture are necessary condition in farms.
- It is rational to use local fodder (forage) resources to raise (increase) a feeding level of animals in a winter period to compensate for deficiency of food (fodder, forage, feed) and additional (supplementary) feed.
- Developed technology of fattening of sheep on mechanized inside-farm platforms should be introduced.
- Waste products of raw materials of karakul sheep for organization of manufacture for other production, for example glue, can serve for improvement of social conditions of karakul sheep specialists.

Chemical Composition and Nutritive Value of *Ceratoides eversmaniana* (Stschegi et Losinsk.) Botsch et Ikonn

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ABSTRACT

One of the prospective fodder plants used for creating longstanding cultivated pastures in the conditions of desert regions of the Uzbekistan Republic is *Ceratoides eversmaniana*, a semi-shrub of the *Chenopodiaceae* family. This fodder crop possesses high ability of adaptation to bleak natural desert and semi-desert conditions, is long-lasting and has a wide area of habitat. It is distinguishing by variety within species, and but Teresken is insufficiently studied as regards to biochemical and nutritive values.

In this article, we present results related to research of chemical composition and nutritive value and palatability of Tersken. It was found that Tersken in the period of pasture ripening contains raw proteins of 7.8%; raw fat, 2.10%; raw cellulose, 33.0%; nitrogen-free extract compounds (NFEC) 48.4% and raw ash, 9.5% in dry fodder. In the phase of branching, the content of carotene is 4.06 mg%; in the bud stage and flowering, 3.26 mg%; and in the period of fruiting, it is 1.06 mg%, ascorbic acid, 53.42, 34.58, and 25.72 mg% according to phases of vegetation. In balance experiments carried out on karakul sheep, it was shown that digestibility of dry fodder is 50% and organic matter 51.5%. On organic substance, the efficiency of digestion is raw protein - 49.0% fat - 65.4%, cellulose 37.4% and NFEC 60.0%. Calculations have shown that in 1 kg absolutely dry fodder are 0.43 fodder units and 35 g digestible proteins; energetic fodder unit (EFU) is 0.52, and exchange index of energy is 3.05 MJ/kg.

INTRODUCTION

One of the promising fodder plants used for creating longstanding cultivated pastures in the conditions of desert regions of the Uzbekistan Republic is *Ceratoides eversmaniana*, a semi-shrub of the *Chenopodiaceae* family. This fodder crop is long-lasting and have wide area of adaptation. It is distinguishing by variety within species, and studying it may give samples for selection process. Research on introduction of *Ceratoides eversmaniana* into culture was conducted from the fifties (Makmudov 1972) but biochemical properties of varieties within species studied were not satisfactory (Griqoriev et al., 1984; Kesselman et al., 1986).

Earlier, it was revealed that in new branches and leaves of *Ceratoides eversmaniana* in the period of flowering contain proteins at 16%, raw fat 2.7%, raw cellulose 34% (Tommer, 1964) Keselman et al. (1986) studied chemical composition of 9 samples of

Ceratoides eversmaniana of different origin and growing periods: branching, flowering, and fruiting.

Analysis showed that depending on period of growing, proteins vary from 8.3 up to 12.5%, raw fat from 0.2 to 6.8%, raw cellulose 31.9-41.3%, NES (Non nitrogen Extractive Substances) 33.6-47.9% from dry fodder.

Shimanov et al. (1989) reported that protein contents vary from 10.6 to 17.3, raw fat 1.7 to 7.8%, and raw cellulose 32.9-4.5%. In the period of budding, nutritive substances increase the proteins up to 18.5%, raw fat to 9.2%, raw cellulose to 53%, but NES is reduced from 30.0 to 16.5%. At the period of flowering, proteins are reduced from 16.2 to 10.3%, raw fat 7.1 to 1.5%, raw cellulose are 26.8-59.7%, and NES 12.3 to 54.6%.

MATERIALS AND METHODS

The method, which takes into account only quantity of nutritive substances, is not complete. More reliable data gives method of accessing exchanging energy of the fodder (EE) as = 17.71dp + 37.89df + 13.44dc + 14.78 NES (dp: digestible protein, df: digestible fat, and dc: digestible cellulose).

Grigoriev et al. (1984), V.G. Shimanov (1989) published data of EE of *C. eversmaniana* in the phase of re-growing, e.g., 7.8-8.5 MJ and 0.46-0.59 FU (Fodder Unit), digestible protein 0.06-0.12 kg in 100 kg of dried matter, in the budding phase EE are 6.4-8.2 MJ, 0.50-0.54 FU and 0.10-0.13 kg digestible proteins and at the flowering phase EE are 5.1-11.2 MJ, 0.20-0.82 FU, 0.06-0.11 kg proteins in 100 kg fodder.

Tommer (1964) reported *C. eversmaniana* in the stage of fruiting contains 29.5 FU in 100 kg of fodder 4.5 kg digestible proteins and in the phase after fruiting 24.2 FU, 3.7 kg digestible protein in 100 kg. Shamsutdinov (1987; 1988) reported *Ceratoides eversmaniana* contain 45-70 FU in 100 kg of dry fodder and 24.2 FU in 100 kg of green fodder.

RESULTS

The chemical and nutritive value of *C. eversmanniana* (Table 1), along with vitamin content (Table 2) are presented as well as comparative characteristics with other fodder shrubs (Table 3).

Thus, the results show that *Ceratoides eversmaniana* among other crops like *Kochia prostrata*, *Halothamnus subaphyllus*, *Salsola orientalis*, and *Salsola richteri* (Makhmudov, 1972; Shamsutdinov, 1975) can be used for improving various types of desert pastures and foddering animals. The nutritive value of *Ceratoides eversmaniana* considerably increases when it is cut very small before using.

Table 1. Chemical composition and digestible ratio of *Ceratoides eversmanniana*.

<u>Fodder Conditions</u>	<u>Humidity</u>	<u>Protein</u>	<u>Fat</u>	<u>Cellulose</u>	<u>NES</u>	<u>Ashes</u>
		<u>Chemical composition</u>				
Dried	9.41	6.34	1.81	29.90	43.94	8.60
Absolutely dried	-	7.10	2.10	33.00	48.40	9.50
		<u>Digestibility ratio</u>				
	-	49.0	65.4	37.4	60.0	21.6

With these, we also studied vitamin contents in *Ceratoides eversmaniana* by growth phases.

Table 2. Contents of vitamin accordingly the growth phases of *Ceratoides eversmanniana*.

<u>Vitamins</u>	<u>Brunching</u>	<u>Budding - flowering</u>	<u>Fruiting</u>
		-----mg-----	
Carotene	4.06 ± 0.19	3.26 ± 0.14	1.06 ± 0.06
Vitamin C	53.42 ± 2.9	34.58 ± 2.9	25.72 ± 1.4

Table 3. Comparative chemical composition and nutritive value of some prospective fodder plants of arid and natural rangelands

<u>Type of Fodder</u>	<u>Chemical Composition</u> <u>Absolutely Dried Fodder</u>			<u>NES</u>	<u>Ashes</u>	<u>In 1 kg Contains</u>	
	<u>Protein</u>	<u>Fat</u>	<u>Cellulose</u>			<u>FU</u>	<u>Digestible Protein</u>
	-----%-----						---g---
<i>Ceratoides eversmaniana</i>	7.1	2.1	33.0	48.4	9.5	0.42	35
<i>Salsola orientalis</i>	6.9	1.8	34.5	46.7	10.0	0.38	29
<i>Salsola gemmascens</i>	8.9	10.3	31.5	25.9	23.4	0.30	50
<i>Kochia scoparia</i>	9.7	2.0	22.0	52.3	14.0	0.35	40
<i>Alhagi psevdohagi</i>	5.8	1.3	50.7	33.3	8.7	0.32	27
<i>Artemisia diffusa</i>	6.0	4.6	43.0	40.4	6.0	0.27	25

SUMMARY

One the base of this research we can make the following conclusions and practical recommendations:

- Chemical composition of *Ceratoides eversmaniana* is characterized with sufficiently high value of vitamins and other nutritive components. By the growing periods, the carotene content is 1.06-4.06 mg %, vitamin C is 25.72-53.42 mg %. Raw protein, raw cellulose, and NES are more than in other studied plants.
- Nutritive value of *C. eversmaniana* hay is more than other well-known fodder plants and it can be used for introducing new fodder plants.
- *C. eversmaniana* hay can be used as a supplement to low nutritive in fodder mixtures, thus, considerably increasing its nutritive value.
- Aim to increase natural pasture yield, *C. eversmaniana* should be widely introduced in culture; it lets to give new opportunity for improving of Karakul sheep feeding.

REFERENCES

- Grigoriev, N.G. 1991. Definition of exchange energy of fodder and regions. *J. Zootechics*. N8.
- Grigoriev, N.G., H.P. Volkov, E.S. Vorobiov, and A.M. Melchenko. 1984. Methodical recommendations for definition of energetic value of animal fodder.
- Hasanov, O.H. 1983. Wild plants use for creating pastures: biological characteristics. In "Adaptation of fodder plants to arid zones conditions of Uzbekistan". Tashkent. FAN.
- Keselman, N.A., A.R. Abhairova, and R.I. Istamova. 1986. Reports of Scientific Research Institute of Karakul Sheep Breeding. Samarkand.
- Makhmudov, M.M. 1972. Keyereuk is a valuable fodder plant for Karakul sheep. Uz. ISTI. Tashkent.
- Shamsutdinov, Z. Sh. 1975. Creating longstanding pastures in arid zones of Central Asia. Tashkent. p. 176.
- Shamsutdinov, Z. Sh. et al. 1988. Practical recommendations for creating and improving natural fodder pastures in arid zones of the country. Gosagroprom. USSR.
- Shamsutdinov, Z. Sh., L.A. Nazaruk, and V.A. Paramonov. 1987. About method of introduction arid fodder plants by species ecotypes. Selection and Seed Breeding of Arid Fodder Plants. Tashkent Gosagroprom Uz. SSR.
- Shimanov, V.G., I.G. Sagitov, and T.H. Mukimov. 1989. Biochemical selecting of introducing samples of *Ceratoides eversmaniana*. Genetics and Selection of Arid Fodder Plants. p. 98-105. Tashkent.
- Tommer, M.F. 1964. Fodder of USSA. Proteins and nutritive value.

Alternatives to Improve Low-Input Pastoral Systems of the Arid Andes

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ABSTRACT

Livestock production in some parts of the arid Andean highlands is the only possible agricultural activity since the combination of frost and aridity largely hinder crop growth. In this adverse environment, people developed highly adapted livestock production systems, usually composed of mixed camelid-sheep herds. However, these systems face a high sensitivity to major climatic events such as a prolonged drought or heavy snow falls, and are characterized by very low productivity.

Rangelands constitute the exclusive source of feed for livestock. They are dominated by so-called pajonales composed of coarse bunchgrasses from genera *Festuca* and *Stipa*. Among them, *paja brava* (*Festuca orthophylla*) is the most widespread species in the arid steppe. It is intensively grazed all year long by range herbivores, despite a low forage value. In this paper, we explore the possibility of treating *paja brava*-hay with dung ashes for increasing its digestibility in llamas and sheep.

Results from digestion trials showed that *paja brava* hay treated with a 20% dung ashes solution and 3% urea resulted in a significant improvement in dry matter digestibility, both in llamas and sheep (52.2 and 49.7% against 44.7 and 39.4% for non-treated dry standing *paja brava*, in llamas and sheep, respectively). These results were comparable to the ones obtained from the treatment of *paja brava* with 3% NaOH + 3% urea. Nutrient digestion coefficients showed the effectiveness of the alkali treatments for improving quality of this forage for both llamas and sheep. The significance of these findings is discussed in relation to feeding management strategies for low-input subsistence farming systems.

INTRODUCTION

Pastoral systems are traditionally characterised by a high degree of adaptation to the natural environment they utilize and by diversified strategies of risk avoidance, usually based on mobility and trade. However, drastic changes in land access and in socio-economical relationships between human groups observed during the four last decades have largely contributed to weaken them. Livestock management alternatives in dry areas are very scarce and confronted to high economical and ecological constraints. In this paper, we will illustrate these assertions in the case of original mixed

camelid-sheep pastoral systems of the arid Andes and explore the possibility of treating an Andean range forage with dung ashes, sodium hydroxide, and urea for increasing its digestibility in llamas and sheep. This research is oriented towards proposing a technical alternative for feed management in low-input, subsistence pastoral systems.

Ecological and Socio-Economical Environment

Livestock production in the arid Andean highlands, such as the west and south Bolivian highlands, is sometimes the only possible agricultural activity due to the combination of frost and aridity, which largely hinder crop growth (mean annual rainfall 300 mm, and 300 days of frost per year). In this adverse environment, people have developed for millennia livestock production systems that are highly adapted to local production constraints. Functioning of these pastoral systems appears to be oriented more towards optimising herbivore-rangeland relationships than introducing new forage sources or animal breeds.

The richness of traditional pastoral practices and management demonstrates a high ingenuity for improving natural resources. However, these pastoral systems, as in almost all parts of the world, face an important crisis, and their reproduction requires technical and socio-economic innovations. From a technical perspective, two main limitations have been found: a high sensitivity to major climatic events such as a prolonged drought or heavy snowfalls, and very low productivity (Genin and Picht, 1995).

Family herds of the arid Bolivian highlands are usually mixed, composed of llamas and sheep, which feed exclusively on rangelands (Tichit and Genin, 1997). These rangelands are dominated by coarse bunchgrasses from genera *Festuca* and *stipa*. For most of the year, they have a strawy aspect because of a very short growing period (3 to 4 months per year), and one of them (*Festuca orthophylla*) is called by natives "Paja brava" (brave straw). This species constitutes the main forage source during most of the year (Genin et al., 1994). The chemical composition of *paja brava* shows that this species is very poor quality forage even in a vegetative stage (high fiber content, 1-7% crude protein).

Forage alternatives are very scarce because of frost, which hinder the possibility of introducing classical forage crops, and of parcelling of land, which reduce possibilities for herd movements. Possibilities of purchasing forages from other regions are very low due to a very low cash mobilisation capacity, a high degree of

geographical isolation, and socio-cultural traditions. Native resources therefore represent a quite exclusive basis for further investigations in this area. Three orientations can be advanced: 1) More extensive surveys on plant resources of the region and possibilities for use in range management. 2) Development of "bofedales", marsh areas which offer high forage production but which represent less than 0.5% of the pastoral territory (Alvarez, 1995). 3) Management of the extensive areas of "pajonales" for hay crop and posterior chemical treatment of forage which will be detailed herein.

Chemical Treatment of *Paja Brava*

The genesis of this experiment was to investigate ways of constituting forage reserves for periods of scarcity. We oriented our research toward the treatment of the highly available range forage *paja brava*. The chemical spectrum of this forage (high fiber roughage) suggested the necessity of alkaline treatments which have been extensively investigated for improving feeding value of agricultural by-products, particularly straw (Jackson, 1978). The most common alkali used is NaOH, Ca(OH)_2 , and urea-ammonia. Due to the low temperature involved in the environment where we worked, the use of urea is restricted to a supplement for nitrogen (N) and not as a chemical for treatment of forages. The other chemicals are not easily available in the region, and, moreover, the one which could be used - sodium hydroxide - is a prerequisite for illicit cocaine manufacturing, and so is highly regulated in Bolivia.

One economical alkaline source is wood ashes. Nolte et al. (1987) found that treatment of wheat straw with a 30% solution of wood ashes for 6 hours significantly increased dry matter digestibility (DMD) for goats. Ramirez et al. (1992) confirmed these results and showed that DMD of diets containing 20% wood ash-treated corn stover increased up to 20% in sheep, compared to a control group. Unfortunately, wood is very scarce in the arid Andes, only available from shrubs of very low growth, and is already intensively harvested for fuel. Due to their high pH values, we hypothesised that dung ashes (DA) could have similar effects to wood ashes. Dung is easily available in the Andean pastoral area because of the particular behaviour of camelids which defecate on very specific areas in the shape of heaps, and because it is not utilised for agriculture, nor for fuel.

MATERIALS AND METHODS

Dung was collected from the heaps found in the proximity of the resting areas of camelids. It was provided by both alpacas and llamas, in an undetermined proportion. It was burnt for two days right there on the range. The ashes were dark to light grey and could have included several impurities such as soil. *Paja brava* used for chemical treatments was hand-harvested in the late growing period (February to March) when green, then it was air-dried, chopped to lengths of approxi-

mately 10 cm, and stocked in a dry area for further treatment. This base material will be herein called *paja brava hay* (PBH). Due to its very low N content (4.8 g N/kg D.M.), PBH was supplemented after alkali treatment with urea in order to allow a crude protein concentration superior to 7%.

Four digestion trials were conducted using three 4-year-old male llamas averaging about 90 kg in body weight, and three 2-year-old castrated criollo sheep of about 21 kg, per trial. Animals were housed in metabolism cages for 17 days and were fed *ad libitum* *paja brava* in different forms: 1) Fresh material collected daily during vegetative growth (GPB), imitating the selection of free-ranging animals (Genin et al., 1994) 2) Dry standing material (DSPB) collected during the dry period (September). 3) *Paja brava hay* treated with 3% NaOH and 3% urea (NaOH + urea PBH). 4) *Paja brava hay* treated with a 20% dung ashes solution (w/v) and 3% urea (DA + urea PBH). The experiment consisted of a 10-day adjustment period followed by 7-day faecal collection period. Feed was offered twice daily (7 and 14). Faeces and orts were weighed daily, and a 10% aliquot was composited across days for each animal for further analysis.

Sodium hydroxide and urea treatment followed the procedures used by Jackson (1978). It consisted in spraying a 40% NaOH solution (w/v) to give a final concentration of 3% NaOH to 10-cm *paja brava hay* dry matter, and ensiling for 3 days in polyethylene bags. After 2 days of outdoor drying, the hay was treated with 40% urea solution following the same procedures in order to obtain a final concentration of 3% urea to hay dry matter, and ensiled for 21 days in polyethylene bags. After 2 days of outdoor drying, the treated material was ready to use.

Dung ash treatment followed the procedure proposed by Nolte et al. (1987). *Paja brava hay* was soaked in a solution containing 20% (w/v) dung ashes, according to results found by Ramirez et al. (1992) for wood ashes. Approximately 200 litres of DA solution were used to soak sequentially five batches (about 35 kg each) of PBH for 6 hours. After soaking, the PBH was dried outdoors for 3 days, and 3% urea was added, following procedures described in the above paragraph.

Feed, feed refusal and faeces were analysed for dry matter (DM), organic matter (OM), ash and crude protein (CP) by standard procedures (AOAC, 1980). Neutral-detergent fibre (NDF), acid-detergent fibre (ADF) and acid-detergent lignin (ADL) were analysed according Van Soest's methods. Concentration of minerals in dung ashes was determined by atomic absorption spectrophotometry.

Data from the digestion trials were evaluated by a two-way analysis of variance procedure. Treatment means were separated using a Neuman-Keuls test when treatment effects were significant ($P < 0.01$).

RESULTS

Chemical Composition of Dung Ash

Solutions with 20% concentrations (w/v) of DA in distilled water had pH value of 10.4. Mineral analyses of DA showed the following composition (in g/kg): P, 1.4; K, 4.8; Ca, 6.0; Mg, 1.5 and Na, 2.5. We did not find literature data on chemical composition of dung ash. Compared to composition of wood ashes used in the experiments of Nolte et al. (1987) and Ramirez et al. (1992), DA presented very low values for Ca and Mg and a slightly higher value for P. The reported values are within the ranges found for livestock dung in tropical regions (De Rouw et al., 1998).

Chemical Composition of Paja Brava: Treatment Effect

Chemical analyses showed that both alkali treatments negatively affected the organic matter content of paja brava, which ranged from 93 to 95% for untreated paja brava to 91.3% for DA + urea PBH and 90.7% for NaOH + urea PBH (Table 1). This was presumably due to the significant addition of minerals to the ash fraction, which should also result in a decrease in the fibre components of the treated straw. The crude protein of untreated paja brava hay (PBH) did not meet N requirements for either sheep or camelids (San Martin and Bryant, 1989), while treated material presented CP concentrations of 6.5% for NaOH + urea PBH and 10.6% for DA + urea PBH. These latter values barely meet maintenance requirements or allowed a slight animal production in the case of DA + urea treatment. The nitrogen content of NaOH + urea PBH was significantly lower than that of DA + urea PBH in spite of the same urea supply. This could reflect a strong abrasive effect of the residual concentrations of NaOH on urea after the first step of treatment.

tion for NaOH-treated paja brava hay was reduced by about 12%, and is within the ranges found in the literature (Moss et al., 1990). NaOH treatment also dissolved a portion of acid-detergent lignin (ADL), as reported by Jackson (1978). DA + urea treatment had an overall lower abrasive effect on fibre fractions of paja brava hay than NaOH + urea. Nolte et al. (1987) found a similar pattern of results comparing the effects of wood ash and NaOH treatment on wheat straw.

Digestion Trials

For all treatments, digestion coefficients were higher ($P < 0.01$) in llamas than in sheep, except for crude protein (Table 2). For example, differences in DMD between these two animal species were 13.1, 5.3, 4.9, and 2.5 digestibility units for GPB, DSPB, NaOH + urea PBH, and DA + urea PBH, respectively. These results agreed with the ones obtained by San Martin and Bryant (1989) and Genin and Tichit (1997), who mentioned that the less degradable the forage, the greater was the difference between the two animal species. Alkali treatments significantly improved digestibility of DM, OM, NDF, ADF, with a superiority for NaOH + urea treatment, both in llamas and sheep. In llamas, DMD of NaOH + urea PBH and DA + urea PBH were 60.7 and 52.2%, respectively, compared to 44.7% for untreated dry standing paja brava, and, in sheep, 55.8 and 49.7%, respectively, compared to 39.4% for untreated DSPB.

These results confirm the general findings of Sundstol and Owen (1984) that NaOH is more effective than other chemical treatments in improving the potential digestibility of straw. Ramirez et al. (1992) also found improved digestibility of alkali-treated corn stover, but a significantly higher DMD when treated with 20% wood ash solution than when treated with

Table 1. Chemical composition (% DM) of untreated growing paja brava (GPB), dry standing paja brava (DSPB), and NaOH + urea, dung ash + urea treated paja brava hay (NaOH + urea PBH and DA + urea PBH).

Treatment	Organic Matter	Crude Protein	Neutral-Detergent		Acid Detergent	
			Fibre		Lignin	Fibre
GPB	94.9	6.6	85.0	52.5	8.8	
DSPB	93.8	1.4	81.2	57.7	11.7	
PBH	93.4	3.5	85.1	55.2	11.9	
NaOH + urea PBH	90.7	6.5	74.8	56.1	9.5	
DA + urea PBH	91.3	10.6	82.7	55.8	11.7	

Concerning fiber fractions of the roughages, analyses indicated that paja brava constitutes a typical material for alkali treatment, due to a high concentration of hemicelluloses (the difference between NDF and ADF), which is known to be significantly solubilized by alkali exposure. Compared to untreated hay, NDF concentra-

4% NaOH, both in sheep and goats. Gihad et al. (1981) pointed out that degradability of roughages was variety-specific, which may suggest qualitative differences in cell wall constituents and/or in their chemical and physical associations.

Table 2. Intake (g/KgW^{0.75}/d) and apparent digestion coefficients (% DM) of untreated growing paja brava (GPB), dry standing paja brava (DSPB), and NaOH + urea and dung ash + urea treated paja brava hay (NaOH + urea PBH and DA + urea PBH) in llamas and sheep.

Digestion Coefficient	Lamas				Sheep			
	GPB	DSPB	NaOH+urea PBH	DA+urea PBH	GPB	DSPB	NaOH+urea PBH	DA+urea PBH
DM	54.2b	44.7c	60.7a	52.2b	41.1b	39.4b	55.8a	49.7a
OM	56.9b	47.7c	63.5a	54.7b	42.3b	42.5b	57.0a	53.4a
CP	59.7a	-60.6c	40.9b	65.8a	52.0b	-57.2c	48.4b	63.7a
NDF	62.2a	55.5b	67.2a	61.8a	52.6ab	49.4b	56.5a	58.2a
ADF	58.3a	49.7b	64.1a	61.1a	49.2b	45.8b	58.5a	58.9a
ADL	20.2b	22.5b	7.8c	35.2a	-6.6c	11.2b	11.5b	27.4a
Intake	34.2b	24.4c	27.0c	43.7a	40.2b	30.9c	56.3a	34.9bc

Means in the same row, by animal species, without common letter differ ($P < 0.01$).

Following the roughage classification proposed by these authors, paja brava hay is an intermediate lignin roughage (10 to 15% lignin content), while roughages utilised by Ramirez et al. (1992) and Nolte et al. (1987) were low lignin roughages (less than 10%). However, both alkaline exposures resulted in a significant improvement of the different fiber fraction digestibilities (NDF, ADF and ADL) compared to DSPB. Apparent ADL digestibilities found in this study have to be analyzed with caution, since discrepancies in measures can occur due to the solubility of lignin throughout the digestive channel with formation of phenolic matter, some loss of immature lignin or failure to recover finely divided lignin in feces (Van Soest, 1994).

Intake of untreated paja brava was low compared to levels of intake previously reported by San Martin and Bryant (1989) for more conventional forages such as alfalfa or barley hay (Table 2). The effect of alkali treatments gave contrasting results for the two animal species considered. Llamas presented a reduced level of intake of NaOH + urea PBH of 27 g/kg^{0.75}/d, while DA + urea PBH was much more consumed (43.7 g/kg^{0.75}/d). This latter level of intake was similar to the one found by Cordesse et al. (1992) for llamas consuming NH₃-treated wheat straw. Concerning sheep, intake of NaOH + urea PBH was 56.3 g/kg^{0.75}/d, comparable to data found by Cordesse et al. (1992) for sheep consuming NH₃-treated wheat straw, and superior to the data found by Moss et al. (1994) for different NaOH treated straw (39 to 45 g/kg^{0.75}/d). Sheep intake of DA + urea PBH (34.9 g/kg^{0.75}/d) was very low, similar to the intake found using untreated DSPB, and slightly higher than data reported by Moss et al. (1994) for sheep consuming different untreated straws (24 to 30 g/kg^{0.75}/d).

These data are difficult to interpret given our current state of knowledge, but the smell and taste of the products, and source of the dung ashes could have influenced these differential patterns of intake by animal species. It should be noted that this study was per-

formed using sub-maintenance or medium quality diets, as observed during the dry season in the arid Andean highlands, and should therefore be repeated at more standardized planes of nutrition, especially those concerning N supply. However, live weight changes of animals during the experiments showed that llamas daily gained an average of 115 g when fed with DA + urea PBH, similar to a diet constituted of fresh growing paja brava (+140 g/d) (Genin et al., 1994). Treatment with NaOH + urea resulted in a lower weight gain of 83 g/d in llamas as a consequence of the low daily intake. Sheep showed weight gains only when fed with NaOH + urea PBH. These data were confirmed by an unpublished experiment of supplementing free-ranging lambs with NaOH + urea PBH for two months during the dry season (Choque, 1995).

CONCLUSIONS

Results of this experiment showed that livestock, and particularly llamas, can feed from treated paja brava hay at least for maintenance. Dung ash and urea treatment of paja brava hay provides a forage of an average quality comparable to alkali-treated straw, but can be a very useful security forage in the arid Andean highlands for sound feeding strategies of livestock during the frequent periods of scarcity.

This technical alternative seems particularly adapted to the economic conditions of the low-input, subsistence farming systems found in this region, due to the direct availability of raw-materials, a very low technology required and a relatively easy storage (dry area). However, further investigations are needed in order to evaluate its feasibility and effectiveness in the local livestock production systems, particularly in relation to labour force availability, and to determine levels of land-use pressure and management (intensity and frequency of cropping, phenological stage of harvested plants) to insure the sustainability of the resource.

REFERENCES

- AOAC. 1980. *Official methods of analysis* (13th Ed.). Association of Official Analytical Chemists, Washington, DC.
- Alvarez V., 1995. Establecimiento de nuevos bofedales en la zona occidental del Departamento de Oruro. p. 177-184. *In*: D. Genin et al. (Ed.) Waira Pampa un sistema pastoril camelidos-ovinos del altiplano arido boliviano. ORSTOM-CONPAC-IBTA, La Paz, Bolivia.
- Choque, S. 1995. Tratamiento de forrajeras nativas (*Festuca orthophylla* y *Parastrephia lepidophylla*) para la alimentación de corderos. Tesis Ing. Agro., UTO, Bolivia, 112 p.
- Cordesse, R., M. Inesta, and J.L. Gaubert. 1992. Intake and digestibility of four forages by llamas and sheep. *Ann. Zootech.* 41: 70.
- De Rouw, A., J.L. Rajot, and G. Schmelzer. 1998. Effet de l'apport de bouses de zébus sur les composants du rendement du mil, sur les mauvaises herbes et sur l'encroûtement superficiel du sol au Niger. p. 95-112. *In*: A. Biames (Ed.), La conduite du champ cultivé: regards d'agronomes. ORSTOM Editions, Paris, France.
- Genin, D., Z. Villca, and P. Abasto. 1994. Diet selection and utilization by llama and sheep in a high altitude arid rangeland of Bolivia. *J. Range Manage.* 47: 245-248.
- Genin, D., and H.J. Picht. 1995. Condiciones de reproducción de los sistemas de producción pastoriles del altiplano boliviano. p. 225-238. *In*: D. Genin et al. (Ed.) Waira Pampa, un sistema pastoril camélidos-ovinos del altiplano árido boliviano. ORSTOM-CONPAC-IBTA, La Paz, Bolivia.
- Genin, D., and M. Tichit. 1997. Degradability of Andean range forages by llamas and sheep. *J. Range Manage.* 50: 381-385.
- Gihad, E.A., T.M. El-Bedawy, and S.M. Allam. 1981. Comparative efficiency of utilization of untreated and NaOH-treated poor-quality roughages through *in situ* digestion by sheep, goats and buffaloes. p. 327-337. *In*: P. Morand-Fehr, A. Bourbouze, and M. de Simiane (Ed.), Nutrition et systèmes d'alimentation de la chèvre. ITOVIC-INRA, Tours, France.
- Jackson, M.G. 1978. Treating straws for animal feeding. *FAO Animal Production and Health Paper* No. 10, Rome, Italy, 81 p.
- Moss, A.R., D.L. Givens, and J.M. Everington. 1990. The effect of sodium hydroxide treatment on the chemical composition, digestibility and digestible energy content of wheat, barley and oat straws. *Anim. Feed Sci. Tech.*, 29: 73-87.
- Moss, A.R., D.I. Givens, and P.C. Garnsworthy. 1994. The effect of alkali treatment of cereal straws on digestibility and methane production by sheep. *Anim. Feed Sci. Tech.*, 49: 245-259.
- Nolte, M.E., J.H. Cline, B.A. Dehority, S.C. Loerch, and C.F. Parker. 1987. Treatment of wheat straw with alkaline solutions prepared from wood ashes to improve fiber utilization by ruminants. *J. Anim. Sci.*, 64: 669-677.
- Ramirez, R.G., F. Cruz, and C.C. Gonzalez. 1992. Effects of treating corn stover with wood ashes and sodium hydroxide on nutrient digestibility by sheep and goats. *Small Rumin. Res.*, 7: 225-233.
- San Martin, F., and F.C. Bryant. 1989. Nutrition of domesticated South American llamas and alpacas. *Small Rumin. Res.*, 2: 191-216.
- Sundstol, F., and E. Owen. 1984. Straw and other fibrous by-products as feed. *Elsevier* Ed., Amsterdam, Oxford, New York, Tokyo, 604p.
- Tichit, M., and D. Genin. 1997. Factors affecting herd structure in a mixed camelid-sheep pastoral system in the arid puna of Bolivia. *J. Arid Environ.*, 36: 167-180.
- Van Soest, P.J. 1994. Nutritional ecology of the ruminant. O&B Books, Corvallis, 374p.

Harvesting Rainfed Acacia and Atriplex in Northwest Coast, Egypt

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ABSTRACT

Two experiments were carried out in two seasons, 1996 and 1998, to investigate the effect of clipping date and height on forage yield of *Acacia saligna* and *Atriplex nummularia* under rainfed conditions of the Northwest Coastal Zone of Egypt. The fodder shrubs were planted in the 1990/91 winter season, and were not utilized until the starting date of the experiment. *Acacia saligna* shrubs were planted on a site 30 km west of Sidi Barrani, and the other site for *Atriplex nummularia* was 5 km south of Marsa Matrouh. A split-plot design was used for both experiments. Five clipping dates, starting from August until December, was the main treatments of the two experiments. The sub treatments for clipping height were 40, 80, and 120 cm above the soil surface for *Acacia* shrubs, and 20 and 30 cm for *Atriplex*.

Results indicated that the highest forage, dry matter, and crude protein yields were obtained in November and December at clipping height of 80 and 120 cm for *A. saligna*, and at 30 cm for *A. nummularia*. Clipping date or height of *Acacia saligna* did not affect the crude protein and ash content for intake by animals but the crude fiber content increased with increased clipping height. Crude protein and ash content were very low in the remaining *A. nummularia* samples compared to the intake by animals, while the reverse was observed for crude fiber content.

INTRODUCTION

Arid and semi-arid regions account for about 30% of the total global land surface, and could contribute significantly to agricultural production if the constraints limiting production level were removed. Traditionally, the greater part of these regions was used for extensive grazing, under a varying degree of nomadism.

However, sedentation of the nomadic population, introduction of mechanization allowing the cultivation of vast marginal areas, and the construction of water harvesting and management structures have endangered the evolution of many farming system in these regions. This evolutionary process was good in some areas, but it has a harmful, or damaging effect on the biophysical equilibrium of environment in other areas, leading to resource degradation and desertification.

The Northwestern Coastal Zone (NWCZ) of Egypt, with its long history of intensive land use, mainly grazing and rainfed farming, provides a clear example of the impact of man's disruptive action on arid and

semi-arid regions. The NWCZ has the most favorable moisture regime and best biological potential of all Egyptian deserts. Continued uncontrolled grazing, woodcutting, and farming of natural range and marginal lands have, however, induced a process of degradation. This coupled with the harsh environment, uncertain and erratic rainfall, and socio-economic and cultural changes has resulted in an advanced stage of desertification; now, the region is producing at a rate less than its potential.

Acacia saligna a perennial legume shrub is one of the most successful species used in improving range-land soils and sand dune fixation in arid and semi-arid regions. It is a good feed source in desert conditions. The leaves, used fresh or dried into hay, are palatable by livestock. (Skerman, 1977), and due to their high protein content are considered as a forage source for sheep and goats during the dry summer seasons. (Gutteridge, 1991; Tiedman and Johnson, 1992, Kandeel et al., 1994). Seeds can be used as a supplementary feed for sheep and goats. Ibrahim (1981) reported that crushed seeds were fed to sheep without ill effects, and the shrub can be completely grazed off without harming the plants. *Acacia saligna* tolerates all desert's environmental conditions and was successfully grown in saline soils (Sheha, 1984; Zaght et al., 1993).

On the other hand, a shrub of *Atriplex nummularia*, a perennial legume saltbush, can produce under rainfed conditions with good management an average of 3 kg DM/bush/yr, i.e. 3000 to 6000 kg DM/ha/yr of fodder, and about as much fuelwood. In the same line, the productivity of *A. saligna* is comparable to that of *A. nummularia*, but the former requires more water and prefers light to sandy soils. The fodder-to-wood ratio of *A. saligna* is around 50% under good management, similar to *A. nummularia* and *A. halimus* (Le Houerou et al., 1991).

Several studies have been conducted regarding utilization of saltbushes in animal feeding (Hassan and Abd El-Aziz, 1979; El-Shaer and Kandil 1990; and ElShaer, 1990). Saltbushes are generally characterized by moderate crude protein, and high mineral content, particularly Na, K, Cl and Ca concentrations. The stage of growth and maturity considerably affect the nutritive value, palatability, and utilization of *Atriplex* species (El-Shaer, 1995)

MATERIALS AND METHODS

Two field experiments were carried out in 1996-'97 and 1997-'98 seasons to study the effect of clipping date and height on forage yield of unutilized shrubs of *A. saligna* and *A. nummularia*. The shrubs were planted in

1990/1991-winter season on two locations under dry-land conditions of the NWCZ of Egypt. Annual rainfall ranged 85.9-142.5 and 94.2-172.7 mm/year for Matrouh and Barrani area, respectively.

Exp. I: Clipping Date and Height - *A. saligna*

The experiment was located 30 km. west of Sidi Barrany. A split-plot design with five replications was used. Five clipping dates: August, September, October, November, and December, were randomly assigned to the main treatments. The sub-treatments for clipping heights were 40, 80, and 120 cm above the soil surface. Each sub-plot consisted of 10 m² (2 × 5m) planted with one shrub (plant density = 400 shrubs/feddan.)

Seedlings, 6 months of age, were planted in the 1990/1991-winter season. The shrubs were not utilized until 1996 (No cutting or grazing). Every month from August until December, the sub-plots were clipped at heights of 40, 80, and 120 cm above the soil surface, and that time was considered the starting time for the experiments. The experiment was protected from grazing from August of 1996 until December 1998.

After two years for each main treatment, the shrubs were clipped at the designed different clipping heights. Methods of cut and carry outside the farm and grazing by animals was used, with the remains after grazing being weighed. Data were obtained on green and dry forage yields, intake green and dry yields, chemical analysis, and plant heights. Data on fresh and dry forage yields were converted to tons/fed. The yields of each sub-plot were used in the statistical analysis.

Exp. II: Clipping Date and Height - *A. nummularia*

The experiment was located 5 km south of Marsa Matrouh. A split-plot design with four replications was used. Five clipping dates: August, September, October, November, and December, were randomly assigned to the main treatments. The sub-treatments for clipping heights were 20 and 30 cm. above soil surface. Each sub-plot consisted of 20 m² (2 × 10 m) planted with two shrubs. Seedlings, 3 months of age, were planted in the 1990/91 winter season using a spacing of one meter within the row and 10 m between the rows. The areas between rows were planted with barley during the winter seasons. The shrubs were not utilized until 1996. Every month from August until December 1996, the sub-plots were clipped at heights of 20 and 30 cm above the soil surface, and that time was considered the beginning of the experiment. The experiment was protected from grazing.

Two cuts were obtained from the start of the experiment until December 1998. The first cut was obtained in 1997 and every sub-plot was cut and weighed. In the second year (1998) the yields were determined by protecting a number of shrubs and letting the animals graze the remaining shrubs for 3 days. The protected

shrubs were cut and weighed to adjust the true green yield and the green intake.

Data were obtained on green and dry forage yields in the second year, intake green and dry yield, and chemical analysis and plant heights. Data on fresh and dry forage yields were converted to tons/feddan. The yields of each sub-plot were used in the statistical analysis.

For the two experiments, a sample of 1 kg was obtained from each plot in each cut, chopped into small parts about 1-2 cm in size, and dried for 24 hours in a hot-air oven at 70 -80 C. to determine moisture content. The dried samples of each treatment in all replicates were aggregated to form a composite sample for each treatment. The latter samples were ground for chemical analysis. Chemical analysis was carried out according to methods of the Association of Official Agricultural Chemists (1986).

The data obtained was statistically analyzed using the variance of split-plot design method according to Steel and Torrie (1960). Means were compared by using Duncan's new multiple range test as described by Waller and Duncan (1969).

RESULTS

The analysis of variance indicated that clipping date caused significant variations in each of the traits for *A. Saligna*. The highest green and dry forage yields were obtained from clipping dates in December, followed by November and October. The lowest green and dry forage yields were obtained from August clipping. The same trend was obtained from intake green and dry forage yields. Plant height increased gradually from clipping date of August until the December clipping date.

The highest protein yield per feddan was obtained from clipping in December, while the lowest protein yield was obtained from clipping in August. The remaining treatments of clipping times over all heights of clipping were intermediate in protein yields. The analysis of variance indicates that clipping date caused insignificant variations in each of the traits under study in both seasons for *A. nummularia*.

The analysis of variance indicated that height of clipping had a significant effect on all the traits for *A. nummularia*, except plant height. The highest green forage, dry forage, intake green forage, intake dry forage, intake protein yields and plant height were obtained at a clipping height above the soil surface of 80 cm followed by 120 cm. The interaction was not significant for the studied traits, except for intake, green and dry, and protein yields.

The chemical composition data of *Acacia saligna* clipped at different dates are in harmony with those obtained by Skerman (1977), Ibrahem (1981), Sheha (1984), Zaght et al. (1991), Gutteridge (1991), Tiedman and Johnson (1992) and Kandeel et al (1994).

The analysis of variance indicated that varying the height of clipping had a significant effect on the traits under study in the two seasons, except plant height in

the second season of 1998, and intake dry forage yield and intake protein yield. Means of green forage, dry forage, protein yields, plant height, intake green forage and intake dry forage yields were significantly higher when *A. nummularia* was clipped at a height of 30 cm above the soil surface compared to clipping at 20 cm above the soil surface.

The interaction was not significant for any of the studied traits except for intake crude protein yield. These chemical composition data results are in agreement with those obtained by Hassan and Abd El Aziz (1979), El Shaer and Kandil (1990), Le Houerou et al (1991) and El Shaer (1995).

CONCLUSIONS

It could be concluded that:

- The highest forage, dry and crude protein yields were obtained from *A. saligna* in November and December at 80 and 120 cm clipping heights.
- The highest forage, dry and crude protein yields of the 2 years for *A. nummularia* were obtained from in November and December clipping dates, at the clipping height of 30 cm above the soil surface.
- Crude protein and ash contents of *A. saligna* for intake by animals were not affected by clipping date or height, while crude fiber content increased by increasing clipping height.
- Crude protein and ash contents were lower in the remaining *A. nummularia* compared to the intake by the animals, while the reverse of that trend was observed for crude fiber content.

REFERENCES

- Association of Official Agriculture Chemists. 1986. *Official methods of analysis*. 11th Ed. A.O.A.C. Washington, D.C.
- El-Shaer, H.M. 1995. Potential use of cultivated range plants as animal feed in the Mediterranean coastal zone of Egypt. Institut National de la Recherche Agronomique. 31: 15-19.
- El-Shaer, H.M., and H.M. Kandil. 1990 Comparative study on the nutritional value of wild and cultivated *Atriplex hulimus* by sheep and goats in Sina. *Commun. Sci. Develop. Res.* 29: 81-91.
- Gutteridge, R.C. 1991. Agronomic evaluation of tree and shrub species in southeast Queens land. *Fer. Abs.*, 52 (3): 1366.
- Ibrahim, M.K. 1981. Shrubs for fodder production. Advances in food producing systems for arid and semi-arid lands. National Agricultural Research Station, Kenya.
- Kandeel, S.A., A.E. Kherallah, and B.E. Bourthami. 1994. Biomass utilization of juvenil *Acacia cyanophylla* lindl. grown in Egypt. First Intern. Symp. Silviculture of Protection Forestry in Arid Regions and the Agroforestry Potential, ARC. NARP and USAID, Alexandria.
- Le Houerou, H.N., E. Correal, and S. Lailhacar. 1991. New man-made agro-sylvo-pastoral production systems for the isoclimatic Mediterranean arid zone. The Fourth Intern. Cong., Montpellier, France.
- Sheha, M.Y. 1984. Adaptation of plants in Kuwait. 1st Ed., Kuwait Foundation for Sci. Development.
- Skerman, P.L. 1977. Tropical range legumes. FAO. *Plant Production and Protection Publ.* No. 2.
- Steel, R.G.D., and J.H. Torrie. 1960. Principles and procedures of statistics. Mc Graw Hill Book Co. Inc. New York.
- Tiedman, J.A., and D.E. Johnson, 1992. *Acacia cyanophylla* for forage and fuelwood in North Africa. *Agroforestry Systems*, 17: 169-180.
- Waller, R.A., and D.B. Duncan, 1969. Abays rule for the segmmetric multiple comparison problem. *Amer Stat. Assoc. J.* 1485-1502.
- Zaght, M.F., S.S., Tag El Din, and E. Osama. 1993. Guide for important plants of the desert garden. Center of Research Studies Station, King Saud University, Riyadh, Kingdom of Saudi Arabia.

Combating Desertification

Population Impact on Tunisia's Saharan Zone Environment

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INTRODUCTION

Desert ecosystems are characterized by sparsity of life and unpredictability of their environment (Ayyad and El-Kadi, 1982). They are susceptible to a precarious climate, with very low mean annual rainfall (less than 100 mm), large temperature range, and high evapotranspiration. Nevertheless, specialized vegetation could overcome such constraints by developing mechanisms of *adaptation* and *resilience*. However, the severity of the environment becomes more obvious and may lead to an advanced stage of desertification when it is coupled with human pressure, as in the case of many areas of southern Tunisia where the socio-economic situation changes are very important. Socio-economic changes resulted from the State policy of sedentarization of ex-nomad population; launching vast programs of exploiting desert zones with the creation of new irrigated areas based on oases, which exploited underground water resources.

The sedentarization process, which is expressed by concentration of populations around that irrigated areas (Picouet and Sghaier, 1998), has disrupted the traditional land use practices which were based on herding and nomadism from region to another according to rainfall and food availability diet, which ensured a certain equilibrium between the use and the availability of resources. This new life type has negatively affected the natural environment, which has a high fragility towards human intervention. In fact, besides overgrazing, an intensive cutting of ligneous vegetation has developed around the oases, for multiple domestic uses of woody branches and especially for charcoal production.

As a result, some sand-fixative species were degraded or even disappeared from many sites, and quicksand threatens villages and infrastructures even though programs of sand dune fixation were carried out. On the other hand, such activity can be considered as beneficial insofar as selling local charcoal may ensure an important income for the producers and consequently improve the living standard and the social standing of the local population by creating either directly or indirectly other employment (trade, agricultural projects), which may positively affect the natural environment. In fact, some agricultural investments, such as creation of new oases and protection, led to the management of degraded lands.

The present paper intends to analyze the impact of wood exploitation on the natural environment around oases and consequently the living standards in El-Faouar as a representative village community of the Saharan zone in southern Tunisia.

STUDY AREA

The study was carried out within the framework of a national project entitled "*Population dynamics and environment in Tunisian rural areas, DYPEN*". Financed by the *Secrétariat d'Etat à la Recherche Scientifique et à la Technologie* and sponsored collectively by the *Institut des Régions Arides, Centre National de Télédétection, Ecole Supérieure d'Agriculture de Megrane, Institut Sylvo-Pastoral de Tabarka, CRDA Siliana* and the *Institut de Recherche Pour le Développement (France)*. El-Faouar was one from four observatories implemented throughout Tunisia and selected for several assessments. The study area is located in the natural region of Nefzaoua, southwest Tunisia. It constitutes a transition zone between Chott Jerid (saline depression) and the "Grand Erg Oriental".

The region belongs to the Mediterranean-Saharan bioclimate stage, with a mean annual rainfall of 89.4 mm, a mean monthly temperature varying between a minimum of 8.6°C in January and a maximum of 42.2°C in July, and with powerful regular winds (120 days/ year) whose velocity often exceeds 100 km/h, leading to frequent sandstorms. In addition, the region is subjected to under the effect of the very warm wind (sirocco) in summer, causing increasing temperatures and evapotranspiration.

The landscape of El-Faouar has several mobile dune levels. The soils are greatly degraded, mostly skeletal, and very salty in irrigated areas and their surroundings. The vegetal cover is also well degraded too, and is very poor in species composition and diversity. The most abundant species are *Limoniastrum guyonianum*, *Zygophyllum album*, *Halocnemum strobilaceum* (in salt-affected areas) *Retama raetam*, *Hammada schmittiana*, and to a lesser degree, *Ephedra alata* and *Calligonum ssp.* in sandy areas.

Created since the 1950s as sedentarization and fixation zone of the nomads, the oasis of El-Faouar is well-known by far intensive cutting wood of ligneous shrubs in the surrounding steppe. This activity is intensified by population concentration, the growth in energy needs (the winter temperature is very low, reaching even -7°C), and the shrinkage of the transhumance area.

Such situations create two main problems; the first is ecological and is expressed by the deterioration of natural environment and the threat of the biodiversity; the second, is *socio-economic* and is expressed by the necessity of finding alternative solutions for populations living from charcoal by, on one hand, returning the income and other employment's generated by such activity and, on the other hand, providing some

alternative energy sources in order to cover the energetic needs of the ex-nomad populations.

METHODOLOGY

Knowing that we want arrest the impact of the anthropogenic activity on the natural environment (exploitation of wood of ligneous vegetal species around oases in the Saharan zone) and the social well-being (growth of income from charcoal production, and creation of other activities and employment), we attempted to use an integrated approach which takes account, at the same time, of two disciplinary fields; *ecology* and the *socioeconomy*. Consequently, the two following methodologies were associated:

Ecological

Our hypothesis is based on the fact that distance from the village is related to the degree of anthropization. The transect method was applied. Three straight lines leaving of the village of El-Faouar, to the southwest, south, and southeast, were selected for vegetative cover measurement. The selection criteria were based on the frequency of cutting activity and the land accessibility (presence of huge dunes in the other directions). Along each transect, several sampling units (7 at least) were installed where we noted a variation in plant cover, vegetation structure or degree of perturbation (cutting intensity). For each sampling unit, point-sampling was applied for cover and species composition determination. Mean height, mean diameter, and the number of twigs with diameter higher than 5 cm of ligneous vegetation existing within a 50-m radius, were also measured.

Table 1. Household survey by type.

Typology	Total	Sample	%
Marginal farmers	43	4	9.3
Polyvalent Oasian farmers	65	7	10.7
Great shepherds	87	8	9.2
Farmers specialized in date-palm (<i>Deglet Nour</i>)	82	8	9.7
Farmers with family manpower	27	3	11.1
Total	304	30	9.8

Several linear and non-linear regression equation were tested, namely:

$y = a + bx$; $y = a + bx + cx^2$; $y = a + bx + cx^2 + dx^3$;

Where: x = distance from the village of El-Faouar (km); y = % plant cover; % ligneous species cover; height; diameter; and number of twigs. For each equation, the coefficient of determination (R²) was calculated and compared with each other's so that the best fitted to the data are determined.

Socioeconomic

Concerning the socioeconomic aspects, we proceeded by population survey with questionnaires in three near-by household's categories, i.e., according to the wood

and the coal network: the *users*, the *charring* (those who collect the wood and transform it in coal) and the *coal dealers-retailers* in the village.

Two surveys were done involving users. The first, in 1996, touched 456 households, or 23.3% of the whole, and randomly was selected (the village were composed of 1956 households). This survey served for analysis of the demographic and socio-economic aspects of the households and permitted to elaborate a household typology according to the agricultural practices using the multidimensional methods (AFC and CAH). The typology is composed of six different types (Ben Abed *et al.*, 1999), among which only one type was not related to agriculture.

The second survey was made in 1999 and involved a stratified and proportional sub-sample composed of a size of 30 households randomly taken from the five types of 304 farmers (Table 1).

The survey of the charring was done near 10 professional charcoal producers (about 30% of the whole) identified according to the "snow bowls" technique which considers the sensitivity of identification of those practising of such forbidden activity. The selection criteria took into account the superposition the activity fields and the transect of ecological indicators analysis. The coal dealers-retailers survey systematically concerned all the sale points (about 10). Some personal interviews and some focus groups were also held in order to deepen some other aspects in relation to the topic.

RESULTS AND DISCUSSION

Ecological Analysis

The transition from nomadism to a sedentarization system had harmful consequences on natural environment of El-Faouar. Desertification halos appeared around the oasis (Kassah, 1989). Vegetation cover was degraded: it was generally lower than 15%, showing a slight increase with the distance. It varied from 11% at 5 km to 15% at 50 km from the oasis, although the maximum value was recorded at 20 km. This variation was probably due to the dependence of vegetation cover on the degree of anthropization, as expressed by *overgrazing* and *cutting* (Ouled Belgacem and Zaafouri, 1995).

which become less intensive going away from oasis and in the inaccessible zones (vegetation protected by dunes). Concerning species composition, it should be noted that only woody vegetation subject to cutting were taken into account. Some other existing species such as *Halocnemum strobilaceum*, *Zygophyllum album*, *Hammada schmittiana*, and herbaceous species were only grazed.

Limoniastrum guyonianum was the most abundant species. Its cover reached more than 60% at 5 km from the oasis. Although it was frequently subject to cutting, this species is characterized by a high natural regeneration (Nabli, 1989), which is why twigs of each clump were not vigorous and their diameters rarely exceeded 5 cm. The decrease in *L. guyonianum* cover away from the salty soils may be caused naturally, or maybe due the recent strict control of the Forest Service and the gendarmerie, mainly around the village. *Retama raetam* was the second abundant species with an overall cover mean of 20%. The wood is not so appreciated for charcoal and the branches were mostly collected for other domestic uses.

Calligonum comosum and at lesser degree *Ephedra alata* are the most preferred for burning by the charcoal producers and the most subject to cutting. They had completely disappeared within radius of 30 km from El-Faouar oasis and only some sparse individuals subsisted in the inaccessible zones (presence of *barkhanes*). It should be noted that *Calligonum azel*, a highly sand-fixative species, has totally disappeared from El-Faouar as a result of severe selective cutting, since their twigs and even their roots are very appreciated for charcoal production.

Shrubs mean height and mean diameter were relatively very low and did not exceed respectively 1.30 and 2.40 m. In a similar protected area, these parameters may reach 2.60 and 4.20 m, respectively (Ouled Belgacem, 1999). Their variations with distance from the oasis fluctuated from site to site according to the cutting activity and the wood quality. The average number of twigs with diameter > 5 cm, within each clump, was very low and did not generally exceed 5. It increased with the distance and ranged from 3.5 at 5 km to more than 15 at 50 km from the oasis. This variation is dependent on cutting selectivity.

The mathematical relation between vegetation characteristics (cover, each shrub cover, mean height, mean diameter and number of twigs with diameter > 5 cm) and distance from El-Faouar oasis is mostly expressed by the second-degree equation. The mean variation accounted for by distance from oasis ranged from 14% to 93%, with an overall mean of 51%. The remaining variation may be attributed to other factors such as the accessibility of sites and the recent severe control of foresters and gendarmerie, especially around the oasis.

Energy Supply and Demand

The concentration of population in the village and the oasis of El-Faouar has created an important demand in

wood and in coal produced from very appreciated wood for traditional domestic needs. The results of our survey revealed that mean annual consumption of wood from ligneous vegetation and of coal are estimated at 245 and 165 kg/year, respectively, the equivalent of 480 and 323 tons/year for all the village of El-Faouar. The satisfaction of this demand is mostly insured by the local supply either by direct clipping by households themselves or by purchase from professional coalmen. Indeed, the coal supply, as estimated on the basis of quantities seized by Forest Services, increased by the probability of seized (10 %), was evaluated at 840 tons per year. This quantity is very close to that produced by the coalmen, i.e., 900 tons/year (according to Forest Service there are 70 coalmen multiplied by 13 tons/year as the estimated mean quantity produced by one coalman).

By reason of traditions, the majority of inquired households declared that a 50% increase of charcoal prices would not lead them to renounce to the purchase of their needs in charcoal, knowing that the average price per kg of coal is approximately 0.4 US \$. This shows well the degree of attachment of the population to this product so that any incentive policy on the basis of price cannot, alone, minimize the consumption of wood coal.

Wood-Cutting Natural Environment

The impact of cover degradation and the regression of the main psammophile shrub vegetation on the natural environment is expressed by the formation of eolian veils which led progressively to other dune forms, leading to *barkhanes*, the ultimate stage. Wind deflation and accumulation constitute, in fact, a permanent threat to the resources and the infrastructures (Auclair and Zaafouri, 1996).

According to estimations undertaken from our survey, the wood quantity taken from the steppe is about 480 tons /year exploited as crude and 3400 tons transformed into coal (with an output of 25%, the 850 tons of coal need 3400 tons of wood). According to estimations undertaken on an ecological investigation basis (Ouled Belgacem, 1999), one ton of wood of harvested ligneous vegetation would necessitate the exploitation of the equivalents of 7 ha of the steppe. Consequently, the quantity of taken wood per year (3880 tons) caused the degradation of approximately 27,216 ha/year. According to Ouled Belgacem (1999), harvesting one ton of *Calligonum comosum* wood, the species the most appreciated by coalmen, causes the liberation of approximately 60 tons of fixed sand. The mass of the liberated sand, as a result of such activity, would be therefore 232,800 tons/year which will severely threaten the oasis, the village, and the infrastructures. The degradation of 27,216 ha/year leads to the loss of about 816,400-food units (FU)/year (30 FU/ha) is the equivalents of 163,200 \$ (1 kg of barley costs about 0.2 \$).

Harvesting wood from ligneous vegetation of the steppe around the oasis of El-Faouar hardens and

handicaps, without doubt, the effort deployed by Technical Services to struggle against the quicksands which costs about of 130,000 \$/year (Kebili, 1999). Their interventions involved, in 1998 alone, the raising of 12,627 km of tabias, the stabilization of 7,468 ha of sand dunes and the safeguard of 14,165 ha. On the other hand, the development of this activity is not only explained by the attachment of the populations to their traditions but also by the economic profitability of the activity itself for the category of population that they practice. In fact, the income for each coalman is estimated at 5,200 \$/year, a disposable income of 3,400 \$/year (the costs of manpower, transportation, etc. are estimated at 1,800 \$/year). This income can be considered encouraging as compared to that of 1ha of oasis, 2,760 \$/year (Sghaier, 1995) or to the agricultural minimum wage guarantee of about 1,700 \$/year. From there, we can understand the reasons behind the development of such activity despite the expected severe sanctions by the regulation. We can also wonder about the appropriateness to convince people renounce to this safe activity by creating more encouraging alternative activities.

CONCLUSIONS

The study has confirmed that concentration of the ex-nomad population in the Saharan environment, as consequence of oasis creation, expands the anthropic impact on the surrounding steppe. The increase of the demand of wood and charcoal has led to the degradation of the natural environment and the acceleration of desertification. The activity of wood harvesting from ligneous vegetation turns out to be beneficial. We may consequently wonder about the effective means and the economic incentives that can be suggested in order to minimize these effects on the environment.

REFERENCES

- Auclair, L., and M.S. Zaafouri. 1996. La sédentarisation des nomades dans le sud tunisien: comportements énergétiques et désertification. *Cahiers Sécheresse*, 7: 17-24.
- Ayyad, M.A., and H.F. El-Kadi. 1982. Effect of protection and controlled grazing on the vegetation of a Mediterranean desert ecosystem in northern Egypt. *Vegetatio*, 49: 129-139.
- Ben Abed, M.A., M. Sghaier, and N. Bachar. 1999. Typologie des exploitants agricoles dans les observatoires. DYPEN II. Faouar, Menzel Habib, Kroumerie, Bargou. Collectif de Recherche, DYPEN. IRA, Tunisia.
- CRDA, Kebili. 1998. Rapports annuels de l'activité CTV El-Faouar (1996, 1997, 1998).
- Kassah, A. 1989. Sédentarisation des nomades et mise en valeur agricole: Les Ghribs à Réjim Mâtoug. In: *Géographie et Développement* No. 8-9. ORSTOM.
- Nabli, M. 1989. *Essai de synthèse sur la végétation et la phyto-écologie tunisiennes*. Ouvrage collectif, Prog. Flore et Végétation Tunisiennes. Vol. 4-6, 229 p + planches.
- Ouled Belgacem, A. 1999. Aperçu sur l'effet de la mise en défens sur la dynamique de la végétation en zone désertique de Tunisie. *Mémoire de DEA*. Fac. Sci. Sfax, Tunisie. 73 p.
- Ouled Belgacem, A., and M.S. Zaafouri. 1995. Impact de la privatisation des terres de parcours collectifs sur la végétation pastorale en zone désertique tunisienne. In: *Pastoralisme et foncier: impact du régime foncier sur la gestion de l'espace pastoral et la conduite des troupeaux en régions arides et semi-arides*. *Options Méditerranéennes*. Série A. 32: 213-217.
- Picouet, M., and M. Sghaier. 1998. Population dynamics and aridity: an experiment in the arid regions of Tunisia. In: *Population and environment in arid regions*. MAB series. Vol. 19: 265-279.
- Sghaier, M. 1995. Tarification et allocation optimale de l'eau d'irrigation dans les systèmes de production de la région oasienne de Nefzaoua (sud de la Tunisie). *Ph. D. Thesis*. Univ. Gent. Belgique. 234 p + annexes.

The Desert Ecosystem Protective Vegetation Cover in Southern Tunisia

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INTRODUCTION

The Tunisian desert zone is characterized by a harsh and precarious climate, with a mean annual precipitation less than 100 mm, a large temperature range, a frequent winds and a very intensive evapotranspiration (Floret and Pontanier, 1982). The socioeconomic changes as expressed by sedentarization of ex-transhumant populations have bred the regression of rangelands as a result of the development of occasional agriculture, and the quantitative and qualitative degradation of vegetal cover as a result of overgrazing. Climate and man with his animals are the main factors that contribute to the degradation of the natural vegetation and consequently to the acceleration of desertification which constitutes the principal environmental problem in Tunisia. The development of management strategy of a given ecological system is based on the good knowledge of its regeneration capacity in case where it does not reach the ultimate stage of degradation (UNESCO, 1990). Several techniques were applied in Tunisian arid zones for degraded rangelands rehabilitation (Akrimi et al., 1989), such as: *protection, appropriate grazing system, reseeding, planting exotic shrubs, ... etc.*, and they have permitted an encouraging results. However, the effect of these techniques, in desert ecosystems, was not well studied. The present study deals with the evaluation of protection (the easiest technique), from 10 to 12 years, on vegetation cover dynamics in four sites presenting an aridity gradient and located in the natural region of Nefzaoua (south-west of Tunisia).

STUDY AREA

According to Sarfatti (1988), the region belongs to the Mediterranean-Saharan bioclimate stage with a mean annual rainfall of 89.4 mm, a monthly mean temperature varying between a minimum of 8.62 °C in January, a maximum of 42.2 °C in July, and with powerful regular winds (120 days/year) that the velocity often exceeds 100 km/h leading to frequent sandstorms. In addition, the region is under the influence of the very warm wind (*sirocco*) in summer, increasing, thus, evapotranspiration, which may exceed 1158 mm/year.

Four sites, located throughout a region presenting an aridity gradient, were the subjects of an assessment of their vegetation cover dynamics.

- The first is located in the zone of Chareb at 37° 75' latitude north and 7° 54' longitude east. The soil is deep as a result of the alluvial deposit accumulations. The dominant vegetal species are *Arthrophytum scoparia* and *Thymelaea hirsuta*. It is

considered as the most cultivated zone during the rainy years.

- The second site is called Kebili and located at 37° 44' latitude north and 7° 43' longitude east. It is characterized by a gypseous soil, sometimes covered by eolian veils. The main existing species were *Retama raetam*, *Limoniastrum guyonianum*, and *Atractylis serratuloides*.
- The third site is that of Ailet (Jemna) and located at 37° 29' latitude North and 7° 47' longitude East. The soil is very salty and characterized by an accumulation of gypsum at middle depth. The main vegetal species were *Traganum nudatum*, *Suaeda mollis*, and *Zygophyllum album*.
- The fourth site is located at 37° 8' latitude North and 7° 4' longitude East, at El-Faouar. It constitutes a transition zone between Chott Jerid (saline depression) and the "Grand Erg Oriental". The landscape appears as several mobile dune levels. The dominant vegetation species were *Limoniastrum guyonianum*, *Traganum nudatum*, and *Zygophyllum album*.

METHODS

In each site, the evaluation vegetal cover dynamics was made in two plots of an area of 40 x 40 m each. The first was unprotected and considered as control. The second was protected since 1986. The assessments were done throughout three years (1996, '97, and '98) during the vegetation-growing season (Mars-April). In other words, it was question of an evaluation of a 10, eleven, and twelve years protection. During each year and within each plot, point sampling method was applied for cover and species composition measurements (Floret, 1988). The destructive method was used for biomass estimation by clipping all the vegetation existing in 8 x 4 m quadrat (Floret et al., 1983).

RESULTS AND DISCUSSION

The climatic conditions, based on precipitation during the period of investigation which extended throughout three years, were characterized by their irregularity. The quantity recorded during the first year (1996) was relatively very important (247.7 mm) since it was about the triple of the mean annual of the region (89.4 mm). However, the second year (1997) was dry since the quantity of rainfall did not exceed 60 mm, and the third year (1998) was very dry with very low precipitation (36.6 mm) which may negatively affect the development of vegetation, mainly that of therophytes.

The effect of protection on biological spectrum (Raunkiaer, 1934) was expressed by the relative importance of the different biological types. Except the Kebili site, where four types were recorded, only three biological types existed in the sites of Chareb and Ailet. In every case, the biological spectrum is mostly composed of chamephytes, which were favored by protection (47.6% against 38.8% in the control at Chareb and 61.1% against 53.8% at Kebili). Moreover, protection had no effect on spectral composition of El-Faouar (the aridest site) since only chamephytic type was represented.

The second important type was that of therophytes, but it seems that this type is more dependent on precipitation and grazing pressure, which is why annual species were more diverse in the unprotected plots (Floret and Pontanier, 1982). The proportion of phanerophytic type was very low since it was represented by only one specie (*Retama raetam*) in the Kebili site. Hemi-cryptophytes were also slightly influenced by protection probably due to their low pastoral value (as the case of *Peganum harmala* in the site of Chareb).

Concerning vegetal species diversity, the beneficial effect of protection was more obvious in the less arid sites (Chareb and Kebili), especially during the dry year (1998) where the improvements reached 33.3 and 31.5% respectively (Table 1). However, in the driest sites (Ailet and El-Faouar), there was no significant effect of protection on vegetal species richness, probably due to edaphic constraints (high salinity of soils and presence of mobile dunes).

- The *second group* consists of the species which were penalized by protection and were frequent in the unprotected plots. It concerns the species with low economical interests and pastoral value such as *Euphorbia guoniana*, *Peganum harmala*, *Zygophyllum album*, and *Arthrocnemum indicum*. However, the contributions of some other species such as *Argyrolobium uniflorum* (a highly palatable legume species) and at lesser degree *Plantago albicans* decreased in the protected plots of Chareb and Kebili as compared to their contributions in vegetal cover of the unprotected plots. It seems that these species do not tolerate the prolonged protection and relatively prefer the modest grazing capacities (Chaieb, 1989).
- The *third group* involves the species which were indifferent to protection. It concerns herbaceous vegetation both annual and perennials. It looks that they more dependent on precipitation than on management mode (Ayyad and El-Kadi, 1982).

The use of protection turned out, in general, to be beneficial on the total plant cover, even though such effect decreases with the aridity gradient. This technique has led, to an improvement of a mean of 83% at Chareb (the less arid site), 57% at Kebili, 9.5% at Ailet, and 19% at El-Faouar. The improvements were more obvious during the dry years (1997 and 1998). Besides, after 10 years' protection, the evolution of total cover becomes more dependent on the quantity of rainfall. That's why a general decrease of cover was recorded in the different sites throughout the last 2 years of the experiment, which were very dry.

Table 1. Evolution of flora richness in four sites for 3 years.

	1996										1997								1998							
	Protected					Control					Protected				Control				Protected				Control			
	C	K	A	F	C	K	A	F	C	K	A	F	C	K	A	F	C	K	A	F	C	K	A	F		
Ligneous species	11	13	6	4	8	7	6	4	11	13	6	4	7	7	5	3	11	14	6	3	6	7	4	3		
Herbaceous sp.	10	5	5		10	6	5		10	5	4		10	6	4		10	5	3		8	6	3			
Total	21	18	11	4	18	13	11	4	21	18	10	4	17	13	9	3	21	19	9	3	14	13	7	3		

¹C: Chareb; K: Kebili; A: Ailet; F: El-Faouar.

Based on results of species composition measurements of the different sites both in protected plots and in the controls, the comparison of different values of species contributions to total cover permit to detect three main groups:

- The *first group* involves the species which were favoured by protection and more or less disappeared from the unprotected plots. They were mainly the palatable species such as *Helianthemum sessiliflorum*, *Salvia aegyptiaca* and *Arthrophytum schmittianum* in the site of Chareb and *Rhanterium suaveolens* and *Gymnocarpus decander* at Kebili, or the woody species which escaped such as *Limoniastrum guyonianum* in the sites of Kebili, Ailet and El-Faouar.

The beneficial effect of protection on biomass of different sites was also observed. This fact is explained by the big gaps between the estimated biomass in the protected and unprotected plots, since the recorded mean values were respectively the followings: 1311 against 312 kg DM/ha at Chareb, 1622 against 295 kg DM/ha, 860 against 653 kg DM/ha at Ailet, and 414 against 241 kg DM/ha at El-Faouar. These values confirm that the beneficial effect of protection decreases with the aridity gradient. On the other hand, these gaps show again how is severe the human pressure (as expressed mainly by cutting and overgrazing) on the natural environment of Tunisian Saharan zones.

CONCLUSIONS

The present study is a preliminary assessment of the effect of protection on vegetation cover dynamics in four sites located along an aridity gradient of Tunisian Saharan zone. The results show that the use of such technique for degraded land management is relatively beneficial on cover, species composition, diversity, and biomass even though this effect decreases with the aridity gradient. After 10 years' protection, vegetation dynamics is more dependent on precipitation, so that a total decrease of the different studied parameters was recorded throughout the dry years of the experiment.

On the other hand, the effect of protection on the species composition was in favour of chamephytes. We think that the sites had been subjected to such a severe and continuous perturbation that a prolonged protection (12 years) has led to a new equilibrium state which is different to that initially existing. According to Le Houérou (1995), in areas receiving more than 100 mm/year mean precipitation, a less prolonged protection permitted the evolution of shrubby steppe with chamephytes to grass pastures dominated by range species such as *Stipa spp.*, *Aristida spp.*

REFERENCES

- Akrimi, N., M. Chaieb, M. Neffati, and J. Zemzemi. 1989. Synthèse des principaux travaux en matière d'écologie et d'aménagement pastoraux. Actes des travaux de l'atelier national sur les acquis de l'expérience tunisienne en matière d'aménagement pastoral. IRA Medenine et CRDI, p. 8-18.
- Ayyad, M.A., and H.F. El-Kadi. 1982. Effect of protection and controlled grazing on the vegetation of a Mediterranean desert ecosystem in northern Egypt. *Vegetation* 49: 129-139.
- Floret, C. 1988. Méthodes de mesure de la végétation pastorale. *Pastoralisme et développement*. IAV. Hassan II, Rabat/IAM. Montpellier, 157p.
- Floret, C., and R. Pontanier. 1982. L'aridité en Tunisie présaharienne. Climat, sol, végétation et aménagement. *Mémoire de thèses*. Travaux de l'O.R.S.T.O.M., 150, 544p.
- Floret, C., E. Le Floch, and R. Pontanier. 1983. Phytomasse et production végétale en Tunisie présaharienne. *Acta Oecologica. Oecol. Plant. No. 2*, 4(18): 133-152.
- Rankiaer, C. 1934. Plant life forms. Clarendon Oxford, 104p.
- Sarfatti, P. 1988. Il climat del Governatorato di Kebili in Tunisia, p. 23-35. *Rivista di agricoltura subtropicale e tropicale*. Trimestrale Anno LXXXII No. 2, Gennaio-Giugno.

United Arab Emirates' Experience in Combating Desertification

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INTRODUCTION

Desertification and sand migration into cities and urban areas and their subsequent effects on roads and farms are major problems that face many countries, especially the developing ones. Since ancient times the people of the United Arab Emirates (UAE) have practised agriculture and cultivation of land wherever water resources were available. Cultivation of land and addition of new and improved agriculture techniques to transform the land into fertile farms was mainly concentrated close to water wells and oases. Man has built specially designed water supply systems (*Afalj*) to utilize water efficiently, to cultivated land to produce crops of nutritional value.

The emphasis on agriculture and cultivation has paralleled the advance in infrastructure. UAE is the forefront in terms of land cultivation and combating desertification. This has led to the country earning international recognition for its efforts. Increased agriculture and cultivation of land requires wise utilization of the limited natural resources. There are many challenges that the country has to deal with. The most important challenge has been how to use the scarce resource of water in agriculture. Other important challenges include the extreme weather conditions of the country, and the paucity of agriculturally qualified and trained nationals. Despite these adverse conditions, the Government has adopted and financed large projects on developing underground water resources.

For example, the Government has encouraged farmers to implement modern irrigation methods, thereby reducing the amount of underground water they used. The Government has built a number of dams, huge water desalination plants, and water-treatment plants in order to find suitable solutions to problems that farmers face. The Government has also encouraged the utilization and implementation of state-of-the art techniques in agriculture, and has founded a number of modern agriculture research centers in the country, which cooperate with local, regional, and international centers.

Large desert areas have been transformed through irrigation, planting with trees, and finally used for agriculture. These transformation processes of spreading green areas throughout the country have contributed to the sustenance of life in otherwise unlivable areas. The replacement of part of the desert with modern farms has created stable environments for man to live and for cities and villages to flourish. Most of the newly formed farms are considered major sources of both income and food for the farmers. Not only man has benefited from the spread of green areas and farms

around the country, but also these farms have provided a safe haven for wildlife such as birds and animals.

This paper focuses on the major efforts of UAE Government in terms of cultivation of sandy desert areas, and on the different agricultural programs that the Government has adopted to improve and modernize agriculture.

NATURAL CONDITIONS

Geographical Location and Area

UAE is located between longitudes 52°-56° east, and between latitudes 22°-26° north of the equator. The country occupies an estimated area of 77,700 square kilometers, of which 1,113,562 donums of total area has been cultivated in (1998) with field crops and fruits, in addition to areas of tree planting and as forestation within city boundaries.

Table 1. Areas of individual Emirates.

Emirate	Total Area ¹ --- % ---	Area -- km ² --
Abu-Dhabi	86.67	67,340
Dubai	5.0	3,885
Al Sharjah	3.33	2,590
Ajman	0.33	259
Um Al Quuain	1.00	777
Ras Al-Khaimah	2.17	1,683.5
Al Fujairah	1.5	1,165.5
Total	100	77,700

¹Percentage of total area.

UAE lies in the dry zone. The climate is semi-tropical, with long hot summers (temperatures reach 45°C), and relative humidity more than 90%. Evaporation rate is more than 3000 mm per annum, while rainfall is only 100 - 120 mm per annum. The majority of the country's land is considered as sand, extending from Ras Al-Khaimah in the north, to Liwa in Abu-Dhabi in the south. It contains little organic matter and has high levels of calcium carbonate 40%. Agriculture in UAE depends heavily on underground water resources (wells). Valleys and *Aflaj* are also considered resources in limited areas. Treated water effluent is mainly used in the inner city greening programs.

The land in UAE can be divided geomorphologically into four regions:

Oman Mountain

This represents about 24% of the total area of the country. It is composed of limestone in the northern areas

(mountaintops), igneous and metamorphic rocks in the southern areas.

Sandy Desert Region

This represents about 53% of the total area, and mainly consists of sand dunes and sand plains. These regions are rich in minerals such as quartz and lime. Sand dunes near coastal lines are richer in limestone in the northern areas than in the southern areas.

Salt Marshes

This represents about 10% of the total area and is characterized by the presence of salt sediments and by the increased underground water levels. These areas are useless for agriculture because of the salt and subsequent high costs of cultivation.

Plains

This represents an estimated area of 13% of the total area. These plains contain the cultivated areas of the country. The plain of Batinah is a narrow mainly stony strip, which contains high level of calcium carbonate up to 40%. The stony plain extends from the Oman Mountains, and is bordered from the west by sand dunes reaching a width of 15-20 kilometers and a length of more than 100 kilometers.

COMBATING DESERTIFICATION

Particular attention has been paid to improving the quality of life in rural areas and in the equitable redistribution of wealth. Lands have been gifted together with attractive financial grants. Loans to purchase equipment and the provision of technical expertise and practical assistance have resulted in an increase in land under cultivation. The number of farms has increased from 5000 in 1972 to over 20,000 today. Farm production has soared and a high degree of self-sufficiency has now been reached in vegetable, fruit, dairy, and other farm products. The Government of UAE has focused on the process of cultivation of sandy desert areas and transforming them into farms upon which many people can depend for their income and food.

This focus on farming has contributed to settlement of a large group of Bedouin. Until recently (i.e., 1998), the number of farm ownership has increased to 25,212, with a total area of 1,113,562 donums. The country is also focusing heavily on the farmer to encourage him to sustain his lands through providing facilities such as well-drilling, provision of loans, fertilizers, seeds, and equipment at half the market price. Moreover, the Government provides free initial leveling and cultivation of the land. The Government also builds large farms and assists in "greening" the desert by distributing indigenous plants and trees on vast areas of the country. These efforts are directed towards introducing the activities of farming and agriculture to as many people as the Government can reach.

Another benefit from introduction of plants is to stop sand migration (desertification) from spreading, and to approach self-sufficiency. A number of forests have been established throughout the country using a

number of different trees species. This man-made greening process has been very successful in combating desertification, and protection of farms, urban areas, industrial areas, external roads and highways, and in the protection of wildlife. Among the efforts that the country has adopted are the following:

- Building of nurseries to improve and increase local trees and plants like *Prosopis spicigera*, *Acacia tortilis* and *Salvadoran Persia* that can tolerate the extreme local weather conditions and water salinity.
- Introduction of new plants that can cope with the local weather conditions, i.e., *Simmondsia chinensis*.
- Development and propagation of local desert plants such as *Calligonum comosum* and *Haloxylon salicorni*wm, *Cyperus conglomerate* and *Panicum turgidum*.
- Utilization of modern methodologies in prevention of sand dune migration, such as use of asphalt, palm tree leaves, and plastic for wind capturing.
- Foundation of conservation and protection zones for indigenous plants and for developing them locally.
- Foundations of programs to develop and breed rare and endangered animal and bird wildlife.
- Training of nationals in different agricultural techniques and services.

Due to the increasing demand for water, because of the increase in farming, urban, and industrial areas, the Government has focused on developing and conserving the local water resources available. This has been achieved through different projects:

- Surveying of the local water resources.
- Building of a number of dams throughout the country (40 so far).
- Doubling of desalination plants (both from sea and from local wells) to meet the increasing demand on water.
- Building of sewage-water treatment plants.
- Distribution of irrigation systems through specially built modern networks (more than 80% of farms are now irrigated through a modern network of irrigation pipes).
- Education of farmers on the benefits of rationalization of use of water resources.

The Abu-Dhabi Municipality, since its establishment in 1966, has played an important role in land cultivation in the inner city of Abu-Dhabi and its suburbs eastward up to the Al Khatum region and southward to the Western Region. For spreading of green areas to maintain, cultivate, and produce more, the improvement projects have encompassed all the regions under the Municipality's directorate.

These projects have contributed to the mitigation of sand migration into the cities and to the settlement of the Bedouin into villages and cities. Villages, in turn, have expanded more and more due to these agricultural

programs. As a result, sandy deserts have gradually become gardens and farms, rich in organic and mineral components because of the cultivation processes. The total cultivated areas in Abu Dhabi so far is 255,234 hectares, of which 2,354 are green plain areas in the inner city, 232,550 ha of which are considered forests and trees, 19,760 ha are productive farms, and finally 1,065 ha are used for animal feed production. Most of the farms have been established near the Oasis in the heart of the desert.

RESEARCH IN AGRICULTURE AND LAND CULTIVATION

The UAE Government of the has placed a great deal of emphasis on building research stations because of their importance in development and improving the agriculture sector. In addition, establishment of such research and development centers helps in providing a solid basis and a nucleus for agricultural research, utilizing state-of-the-art techniques and methodologies. This, in turn, will improve the efficiency of work, and development of new techniques to confront the challenges, should the need arise. Moreover, these research centers will provide techniques on reducing production costs and improving the quality of the products. These stations will provide for overall development and utilizing resources wisely. The establishment of such stations aims at the introduction of new plant and tree species in the country and experimenting with new species of vegetables, fruits, date palm trees, and animal feed. Also, research and evaluation of the best production machinery. Research at these stations has focused on the following areas.

Irrigation and Water

A number of experiments have been carried out in the different research stations around the country to introduce the latest developments in irrigation systems. This is mainly to rationalize the use of water and fertilizers, and to cut the costs of labor. In addition, research has focused on irrigation and watering of the sandy areas. Drip irrigation has proved successful to water vegetable crops, ornamental trees, and forests. Bubble irrigation has been successful in watering date palm trees and most fruits. Sprinkler systems have been successful in watering field crops and animal fodder.

The irrigation systems have been successful in decreasing the use of the underground water resources and fertilizers. Increased production and improving the quality of the products and reducing labor costs, in addition to the increase in land cultivated, were direct results of adopting these systems. Studies on the water use of many of the crops using mathematical models and direct measurements using lysimeters have been widely performed.

Studies on using soil improvement techniques to decrease the dependence on water and prolonging the fertility of the soils have been carried out, and methods

and materials that increase soil moisture and utilize these methods have proved successful in dry and saline environments. A number of experiments, inside protective housing using hydroponics, have been successful on crops like tomatoes, cucumber, strawberry, and flowering plants.

Studies on the effects of water level on plant development and the use of specialized covering materials to maintain constant soil temperature in arid zones have also been carried out successfully. Studies on the use of black plastic as a soil covering and its effects on the soil and water consumption have been done, as well as of the density of plants on water consumption in Hamraniya research station.

Projects on desalination through condensation using specialized piping systems, then channeling the water to the roots of the plants, have been carried out jointly between Abu-Dhabi Municipality and the Japanese Coboto Company. This project has proved successful in crops whose water needs are relatively moderate and in protected agriculture. A joint project between Abu Dhabi and Mitsubishi Company of Japan to desalinate water using condensation methods using glass-covered tunnels has been agreed upon, but are still in the process of being carried out.

Date Palm Tree Cultivation

Studies on the number of good quality species in the country and on their cultivation both *in vivo* and *in vitro*, and replacing the lesser quality ones in the farms, oases, on the roads, and in the newly cultivated forests, has been done. Farms for genetically engineering plants have been established; these could cultivate male species of the palm trees and then permit choosing the best quality ones to distribute to farms in the country. Studies on the degree of similarity of the species that have been cultivated in the laboratories with the mother parent are being conducted. Studies have been carried out on the success of planting nursery palm trees that were produced in the lab in the same region.

Introduction of techniques on automated planting and conservation of pollen grains has also been used, as well as implementing the latest techniques in collection, conservation, and long-term storage, and packaging of the dates. The 1998 statistics revealed that the number of palm trees in the country has already reached 25 million.

Field Crops and Animal Feed Production

Evaluation and cultivation of different cultivars of Rhodesgrass showed that it was successful as a source of animal fodder. Experiments on 30 species of alfalfa and maize that have been introduced to the country from Oman, Middle East, Europe, and America are being carried out. Studies are being conducted on some of the local desert plants such as *Panicum turgidum* and *Cenchrus ciliaris* to test them as possible sources of animal fodder. Studies are being carried out on the

nutritional value of some of these indigenous grasses with the idea of using them as animal fodder, as well as the possibility of cultivating corn and sunflower.

Preventative Care of Local Plants

Classification and identification of the insects and plant diseases in the country are aspects of preventive care for local plants, as well as testing of insecticides that have high efficiency and lower toxicity. Introduction of natural ways of combating insects such as *Pheromone* and light traps and insulation techniques have been developed.

Fruit Production

New fruit species have been introduced and the degree of success of their cultivation in the country's local climate conditions has been studied. Citrus fruit cultivation and cross breeding have been conducted to develop the best varieties that can withstand the country's climate. The fertilizer requirements of several fruit species are being measured. Tissue-culture techniques

to increase and improve certain species of fruits have been developed along with production of nursery trees of certain species that are virus-free.

Vegetable Production

New vegetables of species have been introduced to get the best marketable value and that can tolerate diseases and can withstand our local climate. Studies on the protective production of vegetables and improving the techniques have begun.

International Cooperation and Joint Projects

UAE has been successful in maintaining solid relations with research centers and agencies locally, regionally, and internationally. This has resulted in a number of joint projects, including the following: Biological control of the date palm weevil project with the Arab Agriculture Development Organization (other joint projects exist); Salt Tolerant Plants Project with the Islamic Development Bank, ICARDA - APRP Project, and Palm Tree Development Project with IFAD.

Stress Physiology

Apple Tree Sensitivity to Early-Season Water Stress

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ABSTRACT

"Empire" apple trees grown in two-sided plexiglas pots were subjected to water stress early in the season during cell division to study the sensitivity of shoot growth, fruit growth, root growth and single-leaf photosynthesis of apple trees to water stress and their recovery after re-watering. The results during the stress period and after re-watering indicated that the sensitivity to water stress, starting with the most sensitive process, is in the following order: shoot growth, fruit growth, photosynthesis, root growth. When water stress developed during the middle of cell-division stage, final fruit size and weight of stressed stress was significantly less than that of the well-watered control trees. But when water stress developed during the end of cell division and beginning of cell-expansion stages, final fruit size and weight of the two treatments were similar.

The results of this study can be used to improve water management in water-limited regions because it integrates the water stress responses of the most important growth and development processes in the apple tree. Water stress is harmful during the fruit cell division; therefore, early-regulated deficit irrigation in dry areas will reduce fruit size and yield. Water stress at the end of cell division did not reduce final fruit size; therefore, regulated deficit irrigation may be used after the stage of fruit cell division.

INTRODUCTION

Water stress affects plant processes differently. The most affected process is the plant expansive growth in cell-dividing fruits and shoots (Hsiao, 1973; Jones et al., 1985; Landsberg and Jones, 1981). Apple fruits are sensitive to water deficit during the cell-division phase because during this phase fruit grow exponentially (Bollard, 1970; Lotter et al., 1985; Lakso et al., 1995), and thus water is needed to build positive turgor to allow for cell-division and expansion. Water deficits during the early cell-division stage can reduce the future capacity of yield, even if plants get an adequate water supply later (Failla et al., 1990; Sritharan and Lenz, 1988) because final size depends on cell number (Goffinet et al., 1995). Apple shoot growth and leaf area expansion are also sensitive to water stress during their growth from full bloom to the end of the shoot growth. Most of the work on water stress for shoot growth agreed that shoot growth and leaf area suffer

the most during this early period (Lotter et al., 1985; Powell, 1976; Sritharan and Lenz, 1988). In addition to shoot growth, trunk growth can be significantly reduced by water stress (Lotter et al., 1985; Assaf et al., 1975; Failla et al., 1992).

The effect of water stress on root growth of apple is not well documented due to the intensive work needed to study root development. Both significant and non-significant effects are reported, and, in some cases, roots were enhanced by water stress (Maggs, 1961; Fernandez, 1992). Unlike root growth, photosynthesis response to water stress is well documented. The reduction in photosynthesis is due to stomatal closure and non-stomatal factors that are related to the increase in ABA level in the leaves that is synthesized either in the leaves or in the roots (Jones, 1983; Sritharan and Lenz, 1989; Downton et al., 1985; 1988; Loveys, 1984; Kramer, 1988; Cornic and Miginiac, 1983; Raschke, 1985; Downton et al., 1987; Gowing et al., 1990).

The effect of water stress on apple growth and development in dry areas has received less attention than expected because apple production is limited mainly to humid areas or to arid areas with abundant inexpensive irrigation water. In Mediterranean climates, water stress during the early season is less likely to occur because, in addition to the low water requirement due to the low evaporative demand, there is usually adequate water from winter precipitation. However, in areas with dry winters, the growing season starts with dry soil and trees depends fully on rain that might not be adequate. This creates a big concern about water stress during the early part of the season. Since apple production is expanding to the dry areas where water stress can develop at any time, the study of water stress effects on apple trees should expand too.

Although the effects of water stress on the above individual growth and developmental processes have been studied, evaluating them simultaneously in one study to assess their relative sensitivity to water stress and their recovery after re-watering, to develop efficient water management, has not received much attention. Therefore, the objective of this study was to monitor shoot, fruit, and root growth, and leaf photosynthesis during the cell-division stage of fruit development to assess their relative sensitivities to water stress and their recovery after re-watering. The hypothesis to be tested was that during cell-division, shoot and fruit growth are similar and more sensitive to water stress than photosynthesis and root growth, and the former have less chance to reach full recovery after water stress is relieved.

MATERIALS AND METHODS

Sixteen 3-year-old 'Empire' (*Malus domestica* Brock.) apple trees, on M9 rootstock, were grown in a Arkport sandy loam soil in two-sided plexiglas pots. The 72-liter two-sided plexiglas pots (80-cm long $\times$ 15-cm wide $\times$ 60-cm high) were made of wood and 0.31 cm clear acrylic sheets (plexiglas) to give a clear view for studying root development. The clear acrylic sheets were fixed into the wood boards and silicone was added for fixing the sheets to the wood. The sheets were connected with threaded rods and fixed with bolts and nuts.

One drainage hole in the pot's bottom was made at one side and covered with plastic screen and gravel. The hole was connected with a pipe to carry the water to a container which could collect the drainage water. Every pot was fixed to two 10-cm high and 50-cm long wood pieces to stabilize the pot and hold the pot over the ground so that drained water can be collected easily.

The two plexiglas sides were covered with 2-cm thick plywood sheets as insulators to protect roots and were braced against the plexiglas to keep the soil shaped. The trunk of each tree was supported by a piece of wood to keep the tree from moving. The pots were covered by waterproof wood shields to prevent rain from getting into the pots.

Fruit diameter was measured with a digital caliper. Sampled fruit weights were calculated from their fruit diameter using correlation equations that were obtained from seasonal measurements of fruit diameter and weight for trees of the same cultivars. After harvesting the treated apple trees, diameters and weights of all fruits were measured.

Shoot length was measured with a meter ruler. Roots on the plexiglas sides were traced with a permanent color marker. Then the root growth was estimated by counting the number of roots that intersected lines of 2-cm grids that covered the whole side of the plexiglas window. The data were expressed as number of intersections per tree. Since the number of root intersections on the plexiglas varied among trees, the later measurement sets were analyzed as a percentage of the first measurement.

Single-leaf gas exchange rates were measured with a Ciras-1 Portable Infrared Carbon Dioxide Analyzer (PP Systems, Haverhill, Mass.) with a 2.5-cm² broad leaf chamber. Inlet and outlet CO₂, temperature and humidity were measured by the analyzer. Photosynthetic photon flux was measured during the gas exchange measurement by a light sensor attached to the leaf chamber. Photosynthesis was calculated by a photosynthesis calculation program provided with the analyzer.

Stem water potential was measured by enclosing selected leaves inside a plastic bag covered with aluminum foil to reflect sunlight, reduce the temperature, and stop transpiration and thus cause stomata to close. An equilibrium between the stem and leaf is reached

after at least 30 minutes (A. Lakso, personal communication). After one hour of enclosing the leaves in the plastic bags, leaves were excised and immediately placed in a pressure chamber Model 3005, Soil Moisture Corp, Santa Barbara, CA) to measure stem water potential. In order to get representative samples for the tree stem water potential, measured leaves were selected from the upper part of the lower half of the tree.

Pre-dawn water potentials were measured by enclosing selected leaves during the night before taking the measurements. Then early in the morning the leaves were excised to measure the water potential using the pressure chamber. The pre-dawn water potential method was used during the 1994 experiment, but this was replaced by mid-day stem water potential method during the major experiment in 1995 since mid-day potentials better represent the stress under evaporative demand when the greatest gas exchange is occurring (Jones, 1990).

Experiments

Trees were transplanted on 6 May 1994 from 20-liter round pots, where they had grown for 2 years, into the two-sided plexiglas pot. Bud-break occurred 2 weeks after planting, about May 20, and full bloom was on June 5. Flowers were hand-pollinated. Trees were fertilized after bud-break and after full bloom. The trees were assigned randomly to stress or control treatments, six trees per treatment, in a completely randomized design.

On 15 June 1994, 10 days after full bloom (DAFB), all trees were watered and fertilized and, on the last day of watering, the trees were assigned to the stress treatment. At this time, all trees were hand-thinned to 12 fruit per tree. All the fruits were monitored, and 12 shoots per tree were marked for measurement. The first measurement of fruit diameter, shoot length, leaf plastochron index (number of nodes with leaves longer than 2 cm) were taken on June 17 (12 DAFB) and then taken weekly. Pre-dawn water potentials, single-leaf gas exchange, and root density were measured on sunny days twice during the stress period. Early stress treatment ended on July 12 (37 DAFB) when stressed trees were re-watered.

In the 1994 experiment, water stress became significant only after 30 days after full bloom (18 days after withholding water from the stress treatment). This slow stress development was due to slow growth and leaf area development of the trees, apparently due to transplant shock. The stress occurred at the end of the cell-division and the beginning of the cell-expansion, thus the most severe stress occurred after fruit cell-division was complete. Fruits, shoots and gas exchange of the control and stressed trees started to show significant differences only around 34 DAFB.

In 1995, trees were moved out of the cold storage on 16 May. Shoots were hand-pruned to stimulate shoot growth and fertilized as needed during the season. Full

bloom was on June 5 and the trees were hand-pollinated on the same day. After initial set, the trees were hand-thinned to 18 healthy fruits per tree. The tree growth was better and the weather at the time of fruit cell division was hot enough to have fast development of water stress during this stage. Eight trees were assigned randomly to each of two treatments, well-watered and stressed treatments, in a completely randomized design. Twelve shoots and fruits per tree were selected for measurement of growth.

Treatments were applied on 15 June 1995 (10 DAFB). The control trees were watered every 3 days after June 15. Shoot length and fruit diameter were measured every 4 days during and after the stress period. Stem-water potentials and single-leaf photosynthesis were measured on two and four leaves per tree, respectively, during sunny days in the middle of the 4-day periods. While shoot and fruit measurements were continued until shoot growth cessation and harvest, while root density and photosynthesis measurements were continued until full recovery after re-watering the stressed trees on the first of July (26 DAFB). After harvest, fruits were weighed and sampled shoots were defoliated to measure their leaf area.

RESULTS

The effects of water stress on shoot, fruit, and root growth, and on single-leaf photosynthesis of apple trees were studied early in the season during the active shoot growth and the cell-division phase of fruit growth. The results are from the 1995 experiment unless indicated. Trees developed water stress within one week of withholding water. Stem water potential of stressed treatment measured at 16 DAFB was 0.2 MPa lower and significantly different from that of the well-watered control (Table 1). At this time shoot and fruit growth, and single-leaf photosynthesis rates of the stressed trees were all significantly affected by water stress when compared to the well-watered control trees.

The measured units were different for all processes. Individual values for the stressed trees were addressed as a percent of the control average for every set of mea-

surements. Then the slopes for the relationships between stem water potentials and the percent of control were compared. These relationships were curvilinear for fruit and linear for shoot and photosynthesis. The slope for shoot was significantly steeper than that for photosynthesis. According to these relationships, shoot growth rate was more affected by water stress than fruit growth rate and photosynthesis. At the end of the first week of stress, root growth of the stressed trees was not significantly different from that of the control. Maximum water stress occurred during the last 6 days of the treatments in which shoot growth rate dropped to a very low level (14% of control) compared to fruit growth rate (34%) and photosynthesis (35%). Root growth was only observed at the end of the stress period, and stressed trees did not have enough moisture.

While photosynthesis and root growth recovered fully after re-watering the stressed trees, shoot growth rate recovered only partially (Table 1). Fruit growth rate of the stressed trees dropped to about 30% of the control during severe water stress. After re-watering, fruit growth rapidly increased until it was very close to that of the control during the first few days after re-watering. Then it dropped back to a significantly lower growth rate for the rest of the season. This effect was seen in the seasonal growth as fruit size of the stressed trees did not reach that of the control for the rest of the season. The difference between the two treatment's shoot length (73%), harvested fruit weight (16%) and diameter (7%) were statistically significant. While the well-watered control trees had 68% of total tree fruits that weighed 150 g per fruit, stressed trees had only 46%. The final leaf area of sampled shoots of stressed trees had a similar reduction to that of final shoot length when compared to the control trees.

Unlike the 1995 experiment, fruit growth rates of stressed trees in 1994 had full recovery after re-watering and thus the same fruit size and weight of the control trees at harvest. In 1995, maximum stress, and thus reduction in fruit growth rates, occurred at 24 DAFB, while in the 1994 experiment it occurred at 35 DAFB at end of cell division.

Table 1. Treatment means of various crop parameters during the stress period and after re-watering.

Days After Full Bloom	Water Potential: Stem		Shoot Growth Rate	Fruit Growth Rate		Leaf Pn Rate	Root Density
	Control	Stressed		Weight	Diameter		
	-----Mpa-----		--g--	--g--	--cm--	-%-	
16	-1.1	-1.3*	68*	86*	88*	77*	
18			62*	63*	74*		71
20	-0.9	-1.5*	55*	53*	63*	39*	
24	-0.8	-1.9*	14*	34*	47*	35*	
28	watered	watered	31*	90	120	107	
32	//	//	41*	90	102		101
39	//	//	48*	97	112		
53	//	//		85*	95*		
73	//	//		84*	96*		
100	//	//		85*	96*		

In addition to the differences between the means of the three measurements taken at different times during the stress period, the individual stressed trees developed different levels of water stress due to variation in leaf area. The results were related to stem water potential using individual tree data. Good relationships between shoot growth rate, fruit growth rate, and stem water potential were found. Shoot growth rates appeared to decline linearly with declining stem water potential. The fruit growth rates, however, responded slightly to mild stress, then stronger to greater stress. The shoot growth rate decreased more than that of the fruit under mild water stress.

DISCUSSION

In apples, shoot growth, fruit growth, and root growth and, photosynthesis were all sensitive to water stress during the fruit cell-division stage. Shoot growth was the most sensitive because shoot growth rate dropped to a very low rate and had only small recovery after re-watering the trees. The differences in fruit weight between the stressed and the control trees after re-watering increased as the season progressed. Water stress reduced the final shoot length more than it reduced the final fruit size. In addition, while the relationship between shoot growth rate and stem water potential was linear, it is curvilinear for that between fruit growth rate and stem water potential. This suggests that shoot growth is more affected by water stress than fruit growth (Failla et al., 1990; Li et al., 1989).

The sensitive reduction in shoot growth rates under water stress can be explained by the high sensitivity of cell-division and expansion of the shoot tips to the reduction in cell turgor caused by water stress (Hsiao, 1973; Landsberg and Jones, 1981) and by the lack of osmotic adjustment (Lakso et al., 1984; Jones et al., 1985; Robinson and Barritt, 1990). Recent work in grapes suggests that water stress reduces cell-expansion by causing some changes in the cell wall properties that reduce its extensibility (Schultz and Mathews, 1993). Fruits at this stage are growing by cell division and do not have active osmotic adjustment, so they were expected to be as sensitive as shoots. The differences in sensitivity between the shoots and fruits may be explained by the differences in water potentials and size of the shoot tips and fruits. Unlike fruits, shoot tips are located at the top of the tree thus shoot tips are expected to be exposed to lower stem water potentials than fruits. Also, shoot tips have a higher ratio of surface area to volume than do fruits, hence, shoot tips might have higher water loss and lower water potentials than fruits.

Fruit growth rate based on fruit diameter of the stressed trees exceeded that of the control during the two weeks after re-watering. However, this higher rate may be an artifact because by the end of the stress period, the stressed fruits were smaller, hence, diameter increases are comparable. Therefore, fruit weight is a better expression of growth. Despite the recovery of fruit growth rate, fruit size and weight were significant-

ly lower than that of the control for the rest of the season. Therefore, the effect of water stress during fruit cell division influenced fruit growth during the rest of the season by apparently reducing cell number and growth potential (Sritharan and Lenz, 1988; Failla et al., 1990; Lakso et al., 1989; 1995). This is because fruit growth rate and final fruit size in 'Empire' apple depends on cell numbers produced during the cell division (Goffinet et al., 1995).

In the 1994 experiment, fruit growth rate and fruit size and weight of stressed trees were reduced significantly during the stress period, but the differences between the stress and control treatments became smaller as the season progressed and disappeared at 85 DAFB. Hence, fruit size and weight were similar for both treatments at harvest. Interestingly, it was found that significant water stress, and thus maximum reduction in fruit growth during 1994, developed at the end of cell division and the beginning of cell-expansion stages, while in 1995 it developed in the middle of the cell-division stage. So, water stress during cell division seems to have greater and season-long effect on final fruit size than stress during cell-expansion. When water stress treatment was compared to the control during a 2-month period starting at 6 weeks after full bloom, Irving and Drost (1987) found no significant reduction in apple tree crop yield.

Under mild water stress, root growth seems to be less affected than shoot and fruit growth, and photosynthesis during the second week of stress period. While shoot and fruit growth, and photosynthesis of the stressed trees at this time was significantly different from that of the control, root growth was not. However, the stress clearly did not stimulate root growth. The very few roots observed on the plexiglas window at the end of the stress period could be due to soil shrinking that caused an air space between the plexiglas inner surface and the dry soil. Hence, the roots may be forced to grow toward the middle of the pots. In any case, full recovery in root growth was obtained after one week of re-watering the stressed trees suggesting that root growth was less affected than shoot and fruit growth.

In this study, stress developed within one week due to the high evaporative demand of the air and rapid canopy development. Under such rapid stress development, the mature leaves apparently do not have time to osmotically adjust (Lakso et al., 1984; Jones et al., 1985). In addition to the fast development of stress, photosynthesis was measured under high temperature conditions so the trees were under multiple stresses. The fast development of water stress combined with high temperature can explain the fact that the reduction in leaf photosynthesis of the stressed trees occurred faster than would be expected in field-growing trees, which have slower stress development (Lakso, 1986). Despite this reduction in photosynthesis, it recovered fully 3 days after re-watering. Hence, the effect of water stress on photosynthesis should not be long lasting.

Implications for Irrigation and Water Management

The growing season in some dry areas starts with no soil moisture due to the dry winter. So understanding the effect of water stress on growth and development of apple trees during the early part of the season is very important because the final yield and fruit size depends on the cell-division at this time (Goffinet et al., 1995). Understanding the response of these processes to water stress can help avoid yield losses and to develop irrigation management methods with high water-use efficiency. The results of this study can be used to improve water management in water-limited regions because it integrates the water stress responses of the most important growth and development processes in the apple tree.

Water stress is harmful during the fruit cell division; therefore, early-regulated deficit irrigation in dry areas will reduce fruit size and yield. Water stress at the end of cell division did not reduce final fruit size; therefore, regulated deficit irrigation may be used after the stage of fruit cell division.

REFERENCES

- Assaf, R., I. Levin, and J. Bravdo. 1975. Effect of irrigation regimes on trunk and fruit growth rates, quality and yield. *J. Hort. Sci.* 50: 481-493.
- Bollard, E.G. 1970. The physiology and nutrition of developing fruits. In A.C. Hulme (Ed.) *The biochemistry of fruits and their products*. Academic Press, London. 1: 387-425.
- Cornic, G., and E. Miginiac. 1983. Non-stomatal inhibition of net CO₂ uptake by abscisic acid in *Pharbitis nil*. *Plant Physiol.* 73: 529-533.
- Downton, W.J.S., B.R. Loveys, and W.J.R. Grant. 1988. Non-uniform stomatal closure induced by water stress causes putative non-stomatal inhibition of photosynthesis. *New Phytol.* 110: 503-510.
- Downton, W.J.S., W.J.R. Grant, and B.R. Loveys. 1987. Diurnal changes in the photosynthesis of field-grown grapevines. *New Phytol.* 105: 71-80.
- Failla, O., C.P. Treccani, and I. Mignani. 1990. Water status growth and calcium nutrition of apple trees in relation to bitter pit. *Sci. Hort.* 42: 55-64.
- Failla, O., G. Zocchi, C. Treccani, and S. Cocucci. 1992. Growth development and mineral content of apple fruit in different water status conditions. *J. Hort. Sci.* 67: 265-271.
- Fernandez, R.T. 1992. Physiological responses of young apple trees on three rootstocks to drought stress. *Ph. D. Thesis*. Michigan State Univ. East Lansing, MI.
- Goffinet, M. C., T.L. Robinson, and A.N. Lakso. 1995. A comparison of 'Empire' apple fruit size and anatomy in unthinned and hand-thinned trees. *J. Hort. Sci.* 70: 375-387.
- Gowing, D.J.G., W.J. Davies, and H.G. Jones. 1990. A positive root-source signal as an indicator of soil drying in apple. *J. Exp. Bot.* 41: 1535-1540.
- Hsiao, T.C. 1973. Plant response to water stress. *Ann. Rev. Plant. Physiol.* 24: 519-570.
- Irving, D.E., and J.H. Drost. 1987. Effects of water deficit on vegetative growth fruit growth and fruit quality in Cox's Orange Pippin apple. *J. Hort. Sci.* 62: 427-432.
- Jones, H.G., A.N. Lakso, and J.P. Syvertsen. 1985. Physiological control of water status in temperate and subtropical fruit trees. *Hort. Reviews* 7: 301-344.
- Jones, H.G. 1983. *Plant and microclimates: A quantitative approach to environmental plant physiology*. Cambridge Univ. Press, Cambridge, U.K.
- Kramer, P.J. 1988. Changing concepts regarding plant water relations. *Plant and Cell Environ.* 11: 565-568.
- Kramer, P.J. 1983. *Water relations of plants*. Academic Press, New York.
- Kriedemann, P.E. 1968. Photosynthesis in vine leaves as a function of light intensity, temperature and leaf age. *Vitis* 7: 213-220.
- Lakso, A.N., A.S. Geyer, and S.G. Carpenter. 1984. Seasonal osmotic relations in apple leaves of different ages. *J. Amer. Soc. Hort. Sci.* 109: 544-547.
- Lakso, A.N., L. Corelli Grappadelli, J. Barnard, and M.C. Goffinet 1995. An expolinear model of the growth pattern of the apple fruit. *J. Hort. Sci.* 70: 389-394.
- Lakso, A.N., T.L. Robinson, and R.M. Pool. 1989. Canopy microclimate effects on patterns of fruiting and fruit development in apples and grapes. p. 263-274. In C.J. Wright (Ed.) *Manipulation of fruiting*. Butterworths, Boston.
- Lakso, A.N., and F. Lenz. 1986. Regulation of apple tree photosynthesis in the autumn by temperature. p. 34-37. In A. Lakso, and F. Lenz (Ed.) *Regulation of photosynthesis in fruit trees*, N.Y. State Agric. Exp. Sta. Special Publ., No. 34.
- Landsberg, J.J., and H.G. Jones. 1981. Apple orchards. In T.T. Kozlowski (Ed.) *Water deficits and plant growth*. Vol. VI, p. 419-469. Academic Press, New York.
- Li, S.H., J.G. Huguet, P.G. Schoch, and P. Orlando. 1989. Responses of peach tree growth and cropping to soil water deficit at various phonological stages of fruit development. *J. Hort. Sci.* 64: 541-552.
- Lotter, J. De V., D.J. Beukes, and H.W. Weber. 1985. Growth and quality of apples as affected by different irrigation treatments. *J. Hort. Sci.* 60: 181-192.
- Loveys, B.R. 1984. Abscisic acid transport and metabolism in grapevine (*Vitis vinifera* L.). *New Phytol.* 98: 575-582.
- Maggs, D.H. 1961. Changes in the amount and distribution of increament induced by contrasting watering, nitrogen, and environmental regimes. *Ann. Bot.* 25: 353-361.
- Powell, D. 1976. Continuous measurement of shoot extension and stem expansion in the field. *J. Exp. Bot.* 27: 1361-1369.

- Raschke, K., and R. Hedrick. 1985. Simultaneous and independent effect of abscisic acid on stomata and photosynthesis in whole leaves. *Planta*, 163: 105-118.
- Robinson, T.L., and B.H. Barritt. 1990. Endogenous abscisic acid concentrations vegetative growth and water relations of apple seedlings following PEG-induced water stress. *J. Amer. Soc. Hort. Sci.* 115: 991-999.
- Schultz, H.R., and M.A. Matthews. 1993. Growth osmotic adjustment and cell-wall mechanics of expanding grape leaves during water deficits. *Crop Sci.* 33: 287-294.
- Sritharan, R., and F. Lenz. 1989. The effect of long term water stress and fruiting on photosynthesis and transpiration in apple. *Gartenbauwissenschaft* 54: 150-154.
- Sritharan, R., and F. Lenz. 1988. Effects of water stress in apple I. Effect of water supply on flower formation and fruit set of the apple cultivar "Golden Delicious". *Gartenbauwissenschaft* 53: 223-226.

Reduced Water Potential, Temperature and Boron on Germination of Two Hot-Desert Plants

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ABSTRACT

Seeds of *Lagonychium farctum* and *Calotropis procera* were germinated under different treatment combinations of reduced water matric potential (ψ_m), temperature (T) and boron (B) concentration. The effect of each of the single factors on radicle emergence was greatly modified by the level of other factors in both plants, referring to the strong interaction among the factors. This was more pronounced in the elongation of the radicle and hypocotyl in both. This affects seedling development, where hypocotyl elongation particularly controls the projection of cotyledonary leaves above the soil surface (hence utilizing radiant energy) in such seeds. This interaction is also reflected on dry matter allocation from the storage tissue to such growing seed organs.

Although all single factors and their interactions had highly significant effects on radicle emergence in both plants, ψ_m plays the dominant (governing) role in this respect. However, temperature has the sub-dominant role in the respect in *Lagonychium* (together with $\psi_m \times T$ interaction), whereas B (together $T \times B$ interaction) has the sub-dominant role in *Calotropis*. Temperature and ($\psi_m \times T$) had greater control on radicle and hypocotyl elongation in *Lagonychium*, whereas B and ($\psi_m \times B$) had greater control in *calotropis*. Greater differences in the role of single factors and interactions were reflected in dry matter allocation to growing seed organs. The impact of interactions on the success of seedling establishment, and comparably in plants to be cropped in such habitats, is discussed.

INTRODUCTION

In arid and semi-arid regions, seed germination of desert plants is controlled by various environmental factors such as *water stress*, *temperature*, and *nutrients*, which operate together simultaneously. In absence of interfering factors, the drop in water potential due to osmoticum results in decreased water uptake by whole seeds or its organs, a progressive delay in germination, and an increasing percentage of seeds which fail to germinate (Horak and Sweat, 1994). Therefore, different temperature optima for germination and radicle growth may indicate separate regulation mechanisms for germination and radicle growth and may be important to seed survival in natural habitats.

The role of single factors or their interactions depends on the levels of each factor, seed organ and

phase of germination (El-Sharkawi and Farghali, 1987). In this respect, the crop plant seeds are influenced more by water potential rather than by temperature (El-Sharkawi and Springuel, 1977), and thus adapted to temperature. Those of desert plants are adapted to reduced-water potential (El-Sharkawi and Farghali, 1985). Likewise, the rate of imbibition of such seeds is influenced by the ambient temperature and solution water potential (Battaglia, 1993).

Boron (B) is deficient in desert soils. The amendment of B to seeds during germination could be beneficial in the improvement of germination characteristics in arid and semi-arid areas. The concentration of B in young seedlings is inherently sensitive to sudden changes in B uptake caused by factors such as changes in soil moisture (Riley et al., 1994). The present work aimed at studying the combined effects of different temperatures (T) matric water potentials (ψ_m) and supplied B on the characteristics of seed germination (radicle and plumule emergence and radicle-and hypostyle elongation as well as dry matter allocation) in two hot-desert plants.

MATERIALS AND METHODS

Mature seeds investigated were: (i) *Calotropis procera* (Aiton) W.T. Aiton, a tree-like weed abundant in sandy soils of inland Egyptian deserts. (ii) *Lagonychium farctum* (Banks & Sol.) Bobrov., a leguminous perennial under-shrub, both being abundant in arid desert habitats (Kharga Oasis, 700 km south of the Mediterranean Coast).

Lagonychium farctum seeds were subjected to etching in sulphuric acid (30 minutes) followed by rapid and extensive washing in tap and distilled water, and then blotted dry. Seeds were then treated with 10-3 ($\mu\text{g.L}^{-1}$) mercuric chloride solution and washed thoroughly with sterilized distilled water, blotted dry, were placed on chemically-pure filter paper in sterilized glass Petri dishes (11 cm in diameter). Each dish contained 10 seeds supplied with 15 ml of treatment solution and germinated in constantly dark incubators at planned constant incubation temperatures. Incubators with air circulation which allow for control of temperature between 15 and 35 C (± 2 C) were used.

Matric Water Potential: Boron, Incubation Temperatures

Effect of decreased matric water potential (ψ_m) on seed germination was simulated by using aqueous polyethylene glycol (PEG-6000, Union Carbide Corp, USA)

solutions as media for germinating seeds. PEG solutions were prepared by dissolving certain amounts of carbowax 6000 according to pre-constructed calibration curves (El-Sharkawi and Springuel, 1977), in half-strength nutrient solution prepared according to Hoagland and Arnon (1950), to obtain certain levels of ψ_m ranging between -0.24 and -1.54 MPa.

Another series of solutions of half strength Hoagland nutrient solution having the same water potentials (ψ_m), and amended with different B (as H_3BO_3) ion concentrations (0, 1.0, 2.5, and 4.0 ppm) were prepared representing the effective optimal physiological range.

Unstressed, B-untreated seeds (0 MPa, 0 ppm B) were referred to as "control" with respect to any treatment combination (stress or B). However, B-treated plants, whether stressed or unstressed, were always compared with B-untreated plants (B deficiency) at any stress level.

The two plants varied in their tolerance to increasing matric stress. Radicle emergence in *Calotropis* seeds succeeded at $\psi_m = 0$ to -0.88 MPa and in *Lagonychium* at 0 to -1.32 MPa. The test temperatures for *Calotropis* seeds were 20, 25, and 30°C, while for *Lagonychium* seeds tests, were run at 15, 25, and 35°C.

Measurements of Germination Characteristics

Radicle emergence and elongation (and hypocotyl) are often considered a criterion for germination success and seedling establishment under natural arid and semi-arid conditions. The present study gives special attention to these parameters. Also, on reaching maximum germination (22 days), both radicle and hypocotyl were excised, and their fresh and corresponding dry weights were determined. The same was done for the remaining part of the seed (storage tissue) exclusive of the testa. The dry weight for each organ is expressed as percentage of the total dry weight of germinating seeds for each treatment combination.

Statistical inferences necessary to evaluate the relative role of single factors and their interactions in germination phases included analysis of variance and coefficient of determination, η^2 (El-Sharkawi and Springuel, 1977).

RESULTS

Radicle Emergence

Generally, at different temperatures, both in the presence or absence of B, imposed water stress caused significant decreases in radicle emergence in the seeds under investigation. In *Calotropis*, stress caused a significant decrease in the emergence of radicle initiated at relatively moderate stress levels ($\psi_m = -0.44$ to -0.51 MPa) at different temperatures. Presence of B shifted this initiation in decreasing emergence to a lower stress level ($\psi_m = -0.24$ MPa). Over a wide range of temperature (20-30°C), radicle emergence was negligibly affected by temperature change.

However, addition of B resulted in an enhancement of radicle emergence, especially at relatively high temperatures (30°C) over a wide range of ψ_m compared to B-deficient plants. The effective concentration of B in this respect was 1.0 and 2.5 ppm at 20 and 30°C, respectively. High temperature interacting with imposed stress resulted in failure of emergence at $\psi_m = -0.88$ MPa. While the effect of low temperature and B magnifies the effect of stress on decreasing emergence (radicle emergence = 0%).

Similar to *Calotropis*, the radicle emergence in *Lagonychium farctum* occurred, under a wider optimal temperature range (15-35°C). Decreasing ψ_m significantly decreased radicle emergence, which is initiated at moderate stress levels ($\psi_m = -0.64$ to -0.88 MPa) at 25 and 35°C, and this is shifted to high ψ_m levels (-0.24 to -0.44 MPa) at extreme temperatures (15 and 35°C), especially with increasing B concentration (2.5-4.0 ppm). However, B at 4 ppm caused significant increase in emergence % specifically at high temperature (35°C).

Although different B-treatments improved germination, especially at 25°C over a wide range of stress (-0.24 to -1.32 MPa), the reverse was true at low temperature where addition of B decreased germination percentage. The same held true at high temperature, but the decreased effect was restricted to high stress levels only (-0.64 to -1.26 MPa). Boron increased emergence at $\psi_m = 0$ to -0.51 MPa with the effective B concentration 2.5 to 4 ppm (at 35°C). Both extreme temperatures and relatively high B levels apparently caused germination inhibition at low water potentials. ($\psi_m = -1.17$ to -1.26 MPa).

Analysis of variance indicated that all single factors (ψ_m , T and B) and their interactions had highly significant effects on the emergence of the radicle in *Calotropis* and *Lagonychium*. Water stress (ψ_m) was the major factor which dominantly affected the emergence of radicle in *Calotropis* and *Lagonychium* ($\eta^2 = 0.84$ and 0.77, respectively). Boron and the interaction (T $\times$ B) in *Calotropis*, temperature (T) and the interaction ($\psi_m \times T$) in *Lagonychium* equally sub-dominantly affected radicle emergence.

Radicle Elongation

The effect of temperature on radicle elongation in *Calotropis* was pronounced, especially at relatively low temperature (20°C). Maximum elongation took place at relatively high temperature (30°C) and under reduced water potential rather than in the absence of moisture stress. Radicle elongation, however, significantly decreased in response to imposed matric stress. Boron significantly increased radicle elongation at all temperatures. The magnitude of its effect was dependent on both temperature and ψ_m level. The effective (optimum) concentration in this respect was 2.5 ppm. The optimum temperature for radicle elongation under B

deficiency was 25 °C. This optimum shifted to 30 °C at low water potentials. Maximum radicle length was attained with 2.5-ppm B. Higher B concentration (4 ppm) suppressed radicle elongation, particularly at sub- and supra-optimal temperatures.

The reverse was true at the optimum temperature. This indicates that B application reduces the sensitivity of radicle elongation to both extreme temperature and reduced water potential and hence it promotes seedling developing. Both single factors and their interactions had highly significant effects on radicle elongation. Water potential is the major effective factor in this respect. The effects of temperature, B and their interactions with ψ_m were sub-dominants to ψ_m .

Radicle elongation in *Lagonychium* was strongly affected by temperature. Maximum elongation took place at 35 °C regardless of stress, except at ψ_m lower than -0.88 MPa where maximum elongation was at 25 °C. Matric stress, however, had a general significant decreasing effect on elongation at all temperatures. Boron treatment (particularly at 1 ppm) improved radicle elongation over a wide range of matric stress. Its effect at low temperature (15 °C), however, seems not to exist. Boron treatment and temperature change slightly affected the decreasing effect of matric stress on radicle elongation, which signifies that interaction between the three effective factors ($\psi_m \times T \times B$) is rather weak. The effects of the three single factors (ψ_m , T and B), as well as, their binary or tri-factorial interactions, however, are highly significant. The importance value, η^2 of such factors and their interactions expressing the relative contribution of each in affecting radicle elongation show that both ψ_m and T nearly equally affect elongation. The interaction ($\psi_m \times T$) contributes 25% of the total effect on elongation ($\eta^2 = 0.25$).

Hypocotyl Elongation

Since both *Calotropis* and *Lagonychium* have epigeal-type of germination, elongation of the hypocotyl is important in raising the cotyledonary leaves above ground and hence starting photosynthetic activity and supplying carbon metabolites to the radicle.

In *Calotropis*, a significant decrease in elongation of hypocotyl with reduced ψ_m initiated at -0.24 MPa was observed overall the experimental temperature range 20-30 °C. Presence of B retarded the decreasing effect of stress on elongation, especially at low temperature (at 20 °C with 2.5-4 ppm B). Generally, high temperature yielded an increase in elongation of hypocotyl. The optimum temperature for hypocotyl elongation was 30 °C, and it was less sensitive to low temperature compared to radicle elongation.

Application of B improved hypocotyl elongation (the effective B concentration 1 ppm at both 20 and 25 °C). However, high temperature required higher effective B concentration. Increasing B concentration (2.5-4 ppm) reduced hypocotyl elongation, especially at extreme temperatures, especially at high stress levels.

The effect of stress on elongation of the hypocotyl in *Lagonychium* was similar to *Calotropis* overall the experimental temperature ranges and under different B concentrations. Thus, there was a significant decrease in hypocotyl elongation initiated at relatively high ψ_m levels (-0.24 MPa) under different temperatures and B levels.

Similar to the radicle, temperature change played a role in elongation of the hypocotyl. Elongation was greatly reduced at low temperature (15 °C) and increased with increasing temperature. Presence of B had limited or negligible (retarding) effect on the elongation of hypocotyl at low temperature. At 25 °C, B concentrations induced enhancement in hypocotyl elongation over a wide range of ψ_m (-0.24 to -1.32 MPa). The effective B concentration was 2.5 ppm. At low ψ_m levels, B concentration of 4 ppm was most effective. At high temperature stimulation of hypocotyl elongation by B was noticed at moderate ψ_m levels (-0.44 to -0.88 MPa).

Most single factors and their interactions had highly significant effects on the hypocotyl elongation of the investigated plants. Water stress (reduced ψ_m) was the dominant factor (judged by η^2 values) which predominantly affected the elongation of hypocotyl in both plants. Temperature (T) sub-dominantly affected the elongation of the hypocotyl in *Lagonychium*, while in *Calotropis* it was sub-dominantly affected by the interaction ($\psi_m \times T$).

Dry Matter Content

Dry matter allocation to both radicle and hypocotyl was estimated as percentage of total weight of germinating seeds to indicate the degree of buildup of structural materials in the two main parts of the embryonic axis. At 20 °C, the allocation of stored material to the embryonic axis of *Calotropis* decreased with increasing B concentration and matric stress. Generally, the hypocotyl had a large share of dry matter over a wide range of temperatures and ψ_m levels.

Therefore, the radicle and hypocotyl compete for dry matter depleted from the storage tissue, especially in response of B. The presence of B increased the share of radicle at all temperatures studied, especially at relatively low water stress. Also, the depletion of reserve materials from the storage tissue was maximum at 30 °C with 1 ppm in contrast to other B concentrations. This may be due to decreased respiration under stress and/or increased hydrolysis and translocation of depleted materials from the storage tissue.

Stress induced a significant increase in dry matter allocation to the radicle initiated at relatively low ψ_m (0 to -0.44 MPa) at different temperatures. Similar to the radicle, stress induced a significant increase in dry matter gained by the hypocotyl, which was initiated at $\psi_m = -0.24$ MPa.

All single factors and their interactions had highly significant effects on the dry matter allocation to the

radicle and hypocotyl (except with $\psi_m \times B$ interaction). Stress had the predominant effect in this respect ($\eta_2 = 0.68$ and 0.80 , respectively). The effect of the interaction ($\psi_m \times T \times B$) is sub-dominant.

In *Lagonychium*, regardless of B concentration, the reserve material in the storage tissue was slightly depleted at low temperature (15°C) and high water stress levels. High temperature (35°C) induced more depletion from the storage tissue to the embryonic axis of the germinating seeds particularly at low and moderate stress levels. The hypocotyl had a larger share of dry matter (39.7% of total seed content) than the radicle (15%), in both born deficient and B-supplied seeds. At moderate temperature (25°C), more accumulation in the embryonic axis of B-treated seeds took place at higher stress levels ($\psi_m = -1.32$ MPa) compared to their analogues of B-deficient plants.

Treatment with B increased both radicle and hypocotyl share of dry matter at relatively high temperature over a wide range of ψ_m in contrast with B-deficient plants. Generally, the dry matter accumulation in both embryonic organs significantly decreased with imposed stress. This decrease was initiated at high ψ_m levels and low temperature, and this initiation shifted toward moderate stress levels and higher temperature range (25 – 35°C). At moderate and higher temperatures, application of B reduced the sensitivity of the hypocotyl to water stress and the initiation of this significant decrease shifted to moderate stress levels compared to low B concentration (1 ppm).

The single factors and their interactions had highly significant effects on the dry matter content in the different seed organs (no significant effect of the $\psi_m \times B$ interaction in case of hypocotyl of *Lagonychium*) had the predominant effect on the dry matter accumulation in both radicle and hypocotyl. However, $\psi_m \times B$ interaction had the predominant effect on the content of the storage tissue, while the effect of temperature on the contents of the embryonic axis was sub-dominant. The tri-factorial interaction had the sub-dominant effect in the case of the storage tissue.

DISCUSSION

Radicle emergence in the seeds investigated was significantly affected by reduced matric water potential (ψ_m), temperature change (T) and B addition to the incubation medium. In the absence of interacting factors (ψ_m and B), temperature change had no effect on the emergence percentage of the radicle. This signifies that *the germinating seeds had a wide optimal temperature range* (El-Sharkawi, 1992; Blank et al., 1994). Although minor decrease in water potential (low water stress) in the incubation medium had little effect on further development of stress extreme levels inhibited seed germination (regardless of temperature or B effects). This may be due to inhibition (or decreasing) water uptake (Dell, 1992).

However, the magnitude of water stress effect on the emergence percentage (failure or decrease) was temperature- and B-dependent. Whereas increasing matric stress at extremely high or low temperature (20 and 30°C in *Calotropis* and 15 and 35°C in *Lagonychium*), especially at high B levels (2.5–4.0 ppm) accentuated its deleterious effect on radicle emergence. This interference by temperature or B shifted the threshold stress levels at which emergence of radicle fails to lower potentials (being in favour of germination) may be due to increasing sensitivity to reduced water potential at extreme temperatures.

The undesirable deleterious effects induced by high B-application levels or the emergence percentage may be due to: 1) impairment of membrane permeability at high B concentration (Mateo et al., 1987), 2) additive (synergistic) effects of the intrinsic factors (El-Sharkawi et al., 1989), and 3) non-absorption of B due to imposed matric water stress up to particular levels (Shu et al., 1994). Contrarily, low B-application levels resulted in higher emergence percentage of the radicle in the experimental seeds and reduced the sensitivity of its emergence to imposed stress (Shikhova and Limarenko, 1994).

This improving effect of B addition on the emergence percentage is attributed to the fact that 1) B maintains membrane integrity, stability and functions (Mateo et al., 1987), and 2) B addition reduces (or prevents) accumulation of phenolic compounds which may inhibit or suppress growth processes (Al-Yousif et al., 1994). Stress significantly reduced length of both radicle and hypocotyl in the two plants studied. Contrary to radicle emergence, the elongation was more affected by temperature. The length of both organs in *Calotropis* and in *lagonychium* was strongly reduced under low temperature.

However, *Lagonychium* was more sensitive to low temperature compared to *Calotropis*. This means that the length of germinating seed organs in desert plants is markedly affected by low temperature (El-Sharkawi and Farghali, 1985; Nykiforuk, 1994). However, increasing temperature to the optimal level was associated with increasing seedling growth, where improved microclimatic conditions, just by increasing soil temperature, led to faster emergence and better seedling establishment (Anda and Pinter, 1994).

Boron application had an important role in increasing the embryonic axis length and enhancing the development of root hairs, consequently increasing water-absorbing surface (El-Sharkawi et al., 1997). Such effects may have taken place as follows: 1) Boron application reduced the sensitivity to high temperature in both plants through shifting the optimum for elongation of radicle and hypocotyl to higher temperature; increased B uptake with increasing temperature may be the result of altered membrane permeability and increased activity of B in the uptake solution (Brown and Hu, 1993). 2) In *Calotropis*, particularly radicle length was significantly higher at high temperature at

(ψ_m) = -0.24 Mpa. 3) Boron treatment tended to reduce the sensitivity of hypocotyl elongation to imposed water stress in both plants particularly at extreme temperatures.

High B-level (2.5 to 4 ppm) had an inhibitory effect on the elongation of embryonic axis in *Calotropis* and in *Lagonychium* at extreme temperatures, particularly at high stress levels which may be due to: the synergistic effect of extreme temperature on elongation (White et al., 1990), and supra-optimal supply of B (Liang and Shen, 1994), or impeding imbibition and swelling of the thin cuticle and surface waxes resulting in a lower absorption, hence, a lower B content (Shu et al., 1994).

Boron application enhanced dry matter accumulation in the embryonic axis, particularly in the radicle of the investigated seedlings. *This indicates that B treatment improved growth and counteracted (diminished) the deleterious effects of imposed matric stress.*

However, this effect was temperature-dependent, where B levels from 2.5-4.5 ppm reduced the sensitivity of the hypocotyl dry matter content to imposed matric stress at high temperature (25-35 °C). The stimulatory effect of B on the dry matter accumulation could be due to its involvement in cellular biosynthesis of proteins, sugars, phenolic acids and transport by membranes (Schon and Blevins, 1990; Shen et al., 1993).

Values of the determination coefficient (η^2) indicate that matric water potential (ψ_m) had the dominant effective role in different germination phases (emergence, elongation, and dry matter allocation to the embryonic axis). However, the interaction $\psi_m \times T$ had the same role in the case of the depletion of dry matter from the storage tissue in both *Calotropis* and *Lagonychium*. Summation of values for the effect of B and the interactions in which it is involved (B: B $\times$ T and $\psi_m \times T \times B$), which refers to the total role played by B in radicle emergence of the experimental seeds indicates that *Calotropis* radicle was most affected by B application while that of *Lagonychium* was least affected. This signifies that *Lagonychium* is more adapted, indicating a difference among desert plants toward micronutrient requirement. Therefore, recognizing the demands of crop plants for such element should be important since its effect is not singly but in interaction with both (ψ_m), and T. (e.g., wheat, El-Sharkawi et al., 1999).

REFERENCES

- Al-Yousif, F.S., Al-Wahaibi, M.H., and El-Hirweris, S.D. 1994. Influence of boron concentrations on some metabolites of date palm and sorghum seedling. *J. Plant Nutr.* 17: 1037-1052.
- Anda, A., and L. Pinter. 1994. Sorghum germination and developments as influenced by soil temperature and water content. *Agron. J.* 86: 621-624.
- Battaghta, M. 1993. Seed germination physiology of *Eucalyptus delegatensis* R.T. Baker in Tasmania. *Aust. J. Bot.* 41: 119-136.
- Blank, R.R., J.A. Young, E. Martens, and D.E. Palmquist. 1994. Influence of temperature and osmotic potential on germination of *Allenrolfea occidentalis* seeds. *J. Arid Environ.* 36: 339-347.
- Brown, P.H., and H. Hu. 1993. Boron uptake in sunflower squash and cultured tobacco cells: Studies with stable isotope and ICP-MS. *Plant & Soil* 156: 147-150.
- Dell-Aquial, A., and J.D. Bewley. 1989. Protein synthesis in axis of polyethylene glycol treated pea seeds and during subsequent germination. *J. Exp. Bot.* 40: 1001-1007.
- El-Sharkawi, H.M. 1992. Temperature effects on germination of some crop plant seeds under two types of stress. In C.G. Kuo (Ed.) *Proc. Inter. Symp. "Adaptation of Food Crops to Temperature and Water Stress"*. Academia Sinaica Taipei, Taiwan, August 8-13.
- El-Sharkawi, H.M., and K.A. Farghali. 1985. Interactive effects of water potential and temperature in the germination of seeds of three desert perennials. *Seed Sci. Technol.* 13: 265-283.
- El-Sharkawi, H.M., and K.A. Farghali. 1987. Interactive effects of nitrogen, water stress and temperature in the germination of *Bauhinia* seeds. *Phyton*, 27: 139-153.
- EL-Sharkawi, H.M., K.A. Farghali, and S.A. Sayed. 1989. Interactive effects of water stress, temperature and nutrients in the seed germination of three desert plants. *J. Arid Environ.* 17: 307-317.
- EL-Sharkawi, H.M., K.A. Farghali, and S.A. Sayed. 1997. The role of boron in morphological and anatomical development of the radicle in two desert plants. *Conf. Biol. Jordanian Soc. Biol. Sci.*, 8-11 Nov. 1997.
- El-Sharkawi, H. M. K.A. Farghali, and S.A. Sayed. 1999. Growth characteristics of *Triticum aestivum* L. roots under different treatment combinations of boron, matric water potential and temperature. *Seed Sci. & Technol.*, 27: 1-11.
- El-Sharkawi, H.M., and I.V. Springuel. 1977. Germination of some crop Plant seeds under reduced water potential. *Seed Sci. & Technol.* 5: 677-688.
- Hoagland, D.R., and D.I. Arnon. 1950. The water culture method for growing plants without soil. *Calif. Agric. Exp. Sta. Cir.* 347-352.
- Horak, M.J., and J.K. Sweat. 1994. Germination, emergence and seedling establishment of buffalo gourd (*Cucurbita foetidissima*). *Weed Sci.* 42: 358-363.
- Liang, Y., and Z. Shen. 1994. Interaction of silicon and boron in oil seed rape plants. *J. Plant. Nutr.* 17: 415-425.
- Mates, P., F. Martinez, I. Bonilia, E. Fernandez Valinte, and E. Sanchez Maeso. 1987. Effects of high boron concentrations on nitrate utilization and photosynthesis of blue-green algae *Anabaena* PCC 7119 and *Anacystis nidulans*. *J. Plant Physiol.* 128: 161-168.

- Nykiforuk, G.L., and A.M. Johnson-Flanagan. 1994. Germination and early seedling development under low temperature in canola. *Crop Sci.* 34: 1047-1054.
- Riley, M.M., A.D. Robson, G.A. Dellar, and J.W. Gartrell. 1994. Critical toxic concentrations of boron are a variable in barley. *J. Plant Nutr.* 17: 1701-1719.
- Schon, M.K., and D.G. Blevins. 1990. Foliar boron applications increase the final number of branches and pods on branches of field grown soybeans. *Plant Physiol.* 92: 602-607.
- Shen, Z., Y. Liang, and K. Shen. 1993. The effect of boron on the nitrate reductase activity in oil seed rape plants. *J. Plant Nutr.* 16: 1229-1239.
- Shikhova, N.S., and I.V. Limarenko. 1994. Effect of boron on seed germination and growth of *Picea ajanensis* and *Populus koreana*. *Lesovedenie*, 0: 13-21.
- Shu, Z.H., G.H. Dberly, and E.E. Cary. 1994. Mobility of foliar-applied boron in one-year-old peaches as affected by environmental factors. *J. Plant Nutr.* 17: 1243-1255.
- White, P.J., H.D. Cooper, M.J. Earnshaw, and D.T. Clarkson. 1990. Effects of low temperatura on the development and morphology of rye (*Secale cereale*) and wheat (*Triticum aestivum*). *Ann. Bot.* 66: 559-566.

Soil Salinity Effects on Yield and Nutrient Concentrations of Some Fruit Species

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ABSTRACT

The effects of soil salinity on yield and nutrient element contents of date palm, olive, and grapevine were studied in a 2-year field trial. Geographic soil database for Ibbshwai District was built in ILWIS-GIS system, where the main soil characteristics were stored. A salinity map for the area was created through reclassification capabilities of GIS, tested, and updated through a conventional field check. Queries, followed by field check, were done to select similar soils despite their salinity status.

The fruit yield declined by 4.5, 4.6, and 5.7% for each unit increase in soil salinity above 4.5, 2.2, and 2 dS.m⁻¹ for date palm, olive, and grapevine, respectively. The results place date palm in a highly tolerant category, olive in moderately tolerant, and grapevine in moderately sensitive category. The Na and Cl concentration in the leaflets of date palm leaves of olive and petioles of grapevine increased as soil salinity increased. The net return of the fruit production was reduced by 4.6, 5.4, and 7.1% with each unit increase in soil salinity above 3.7, 2.2 and 2.1 dS/m for date palm, olive, and grapevine, respectively.

INTRODUCTION

Among the principal soil environmental conditions which can limit successful production or even survival of fruit-bearing species is soil salinity. Differences among fruit species in response to salinity are reported (Bernstein, 1965; Hassan and Abou El Azayem, 1990), and these differences are important for selecting plants adapted to salinity conditions (Hassan and Catlin, 1984). Soil salinity, especially in arid environments, causes great losses to agriculture by lowering the yield of various crops, and also causes productive land to be withdrawn from agriculture. The ever-increasing demand for agricultural products requires a re-assessment of the production potential of low-quality land and water resources (Epstein et al., 1980).

Although the species considered here respond similarly to osmotic effects of salts on water relations, they differ considerably with regard to specific effects (Bernstein, 1965). Both Na⁺ and Cl⁻ ions are predominantly responsible for specific-ion toxicity. The effect of salinity on fruit species have been investigated with pot culture in the greenhouse (Hassan and Abou El Azayem, 1990). However, there is little information on the effect of salinity on yield of fruits trees species in

the field. Since salt tolerance data for the most fruit trees species are neither conclusive nor available to adequately predict yield under field conditions, therefore a 2-year field study was initiated to determine the effect of soil salinity on yield, nutrient element contents in leaves and net return for fruit crops of three fruit species grown under increasing levels of soil salinity under field conditions.

The integration of aerial photography, remote sensing and geographic information systems techniques has proved to be effective and successful tools in environmental studies and soil mapping. The use of geographic soil database in a GIS, however, considerably enhances the possibilities of satisfying users' needs through the capabilities of data processing, data interpretation, map overlaying, map crossing, re-classifying, modeling and building-decision scenarios (Zinck and Valenzuela, 1990).

MATERIALS AND METHODS

Location map of orchard fields in Ibbshwai District was created with the help of maximum likelihood supervised classification of Landsat TM satellite image (July, 1991). Classification was done using ILWIS-GIS system. The resultant map was verified and corrected with the help of the topographic sheet and field check.

A geo-pedologic soil map was established with the help of aerial photograph interpretation (scale 1:40000) following the geo-pedologic approach (Zinck, 1989). A conventional soil survey was made to investigate the different mapping units and to represent them with modal soil profiles. Twenty-five soil profiles were examined along different transects in the area, and were sampled and analyzed for the main soil characteristics. The resultant soil map was projected over a recent topographic base map with scale 1:50000 (Egyptian General Survey Authority, 1995).

The map was digitized into ILWIS-GIS system where the main soil characteristics were stored in a geographic soil database. Reclassification based on salinity attribute was done, and a salinity map of the area was created. More detailed salinity survey was done (within areas cultivated with orchards around Ibbshwai town) using grid method of 500-m intervals, and a final salinity map was created.

Comprehensive queries were made to identify areas similar in their qualities despite salinity status and cultivated with orchards. These areas were investigated for the three fruit species studied.

A 2-year field study was conducted in main areas of the three fruits species at Ibshwai District, Fayoum, Egypt during 1997 and 1998. The locations for each fruit tree species were selected according the soil survey studies carried out before the experimental work. Eleven, 13, and 12 locations for date palm, olive, and grapevine, respectively, were selected for this study because of their similarity in soil characteristics. The soil samples were taken to represent the soil solum to a depth of 0-60 cm for each plot, and analyzed for the main soil characteristics. Three representative soil profiles were made for the three fruits areas, morphologically described in the field, and classified as loamy, mixed, thermic, Typic Torrifluvent, (Soil Survey Staff, 1996).

The soils from the experimental selected plots were deep productive, well drained, with medium texture, slightly to moderately calcareous and with low organic matter contents. The electrical conductivity of the saturated soil paste extract (ECe) was determined each year on the selected soil samples from each plot before and after the experimented work, following the procedures of Page et al. (1982).

The present study was carried out on date palm "Sewy" cultivar at 11 selected plots according to their soil salinity levels (from 4.5 to 15.4 dS/m). The trees were 25-years old and planted at 7 m apart. The female spathes for all the selected date palm trees were pollinated just after their opening by male strands collected from one seedling date palm tree. "Agizi Shami" cultivar of olive trees was used at 13 selected plots according to their soil salinity levels, which ranged from 1.7 dS/m to 17.9 dS/m. The trees were 12-years old and planted at 6 m apart. "Local Fayoumy" grapevine cultivar was used, and 12 selected plots according to their soil salinity levels, which ranged from 1.3 dS/m to 15.73 dS/m, were used in this study. The vines also were 12-years old.

Cultural practices from each fruit species were the same as in the all locations following the recommendations of Egyptian Ministry of Agriculture. The selected trees of each fruit species appeared healthy, and no symptoms of nutrient deficiencies were detected. All trees were under clean cultivation methods. Tree production within each treatment was harvested as they matured because salinity affects the maturation rate. Yield was determined and expressed as tons/acre and relative yield was calculated.

The mature fully expanded leaflets of date palm; leaves of olive and petioles of grapevine were sampled, weighed and then dried at 70°C for 24 hr. for analysis of sodium and chloride. Sodium was determined using a flamephotometer after dry-ashing samples overnight at 500°C (Page et al., 1982). Chloride was extracted from ashed samples with hot water and titrated with standard silver nitrate solution according to Page et al. (1982).

A nested analysis of variance design was used for each fruit species. The least significant difference was used to compare the averages of the parameters. All

data were statistically analyzed using the procedures outlined by Snedecor and Cochran (1980).

The economic analysis was done for the combined data of the 2-years for each fruit species. Net returns (return after costs) were determined. Total return was calculated as the sum of the product of the amount of fruits for each fruit species multiplied by the corresponding prices obtained from various sales companies in Fayoum Governorate. Costs of the product were obtained from the growers.

RESULTS AND DISCUSSION

The soils showed no sign of stresses or significant variability except for salinity stress. The only recorded effective stress factor in the soils studied was the ECe. In the present study, the variation in soil ECe values was considered to be the main factor affecting yield, growth and element contents of the studied fruit species.

The model of van Genuchten and Hoffman (1984) was used to statistically analyse the total yield for each fruit species experiments. Yield was significantly reduced as salinity increased (Fig. 1). Yield measured at lower salinity were found to be similar to the average commercial yield in Fayoum Governorate, i.e., 125, 6.4 and 6 tons/acre for date palm, olive, and grapevine, respectively. However, like most crops, yield vary depending on climate, soil conditions, and cultural practices.

The combined data for the two years indicate a threshold (maximum ECe without yield reduction or when yield starts to decline) of 4.5, 2.2, and 2 dS.m⁻¹ and a yield decline of 4.4, 4.6, and 5.7% for date palm, olive, and grapevine, respectively, for each unit increase in soil salinity above the threshold (Fig. 1). Relative yield (Yr) for any ECe exceeding the threshold of 4.5, 2.2 and 2.0 dS.m⁻¹ for date palm, olive and grapevine, respectively, can be calculated with the equation. According to salt tolerance classification of Mass and Hoffman (1977), the present results place date palm in highly tolerant category, olive in moderately tolerant, and grapevine in moderately sensitive category.

Net return was reduced by 4.6, 5.4, and 7.1% with each unit increase in soil salinity above 3.7, 2.2, and 2.1 dS.m⁻¹ for date palm, olive, and grapevine, respectively (Fig. 2). Two intersecting straight lines were used: a horizontal line with zero slope and a concentration-dependent line plotting net return versus salinity, and its slope indicates the net return reduction percentage per unit increase in soil salinity. The intersection point designates the threshold, i.e., the maximum soil salinity that does not reduce net return below that obtained under non-saline conditions. The relative net return for any ECe exceeding the threshold value for each cultivar can be calculated with the equations in Fig.5.

Soil salinity increased the contents of Cl and Na in the leaflets of date palm, leaves of olive and the

petioles of grapevine. Both Na and Cl accumulation under increasing salinity were reported for date palm (Hassan, 1991), olive (Hassan et al., 1990), grapevine (Prior et al., 1992), and other crops (Rush and Epstein, 1976, 1981). The Na concentration was at least five-fold higher than Na in petioles of grapevine grown at soil salinity of 15.73 dS/m. Leaf photosynthesis was strongly and negatively correlated with Cl concentration (Prior et al., 1992). The ability of plant to produce and survive at high levels of salinity depends on the capacity to establish an equilibrated osmotic gradient between soil-roots and shoots and to exclude salt ions from active plant tissues (Greenway and Munns, 1980).

It can be concluded that the results obtained, as well as the net return of the fruits trees species studied in relation to different soil salinity levels, have implications for not only for local conditions in Egypt, but also for other locations which have similar ecological conditions.

REFERENCES

Bernstein, L., 1965. Salt tolerance of fruit crops. *USDA Agric. Info. Bull.* 292, 8p.
Egyptian General Survey Authority, 1995. 1:50000 series. *NH36-E1d and NH36-E2c*.
Epstein, E., J.D. Norlyn, D.W. Rush, R.W. Kingsbury, D.B. Kelly, and G.A. Cuninghame. 1980. Saline culture of crops: A genetic approach. *Science*. 210: 399-404.
Greenway, H., and R. Munns. 1980. Mechanisms of salt tolerance in nonhalophytes. *Ann. Rev. Plant Physiol.* 31: 149-190.
Hassan, M.M. 1991. Comparative studies on salt tolerance of date palm seedlings. *Proc. Intern. Conf. Plant Growth, Drought and Salinity in the Arab Region*. December, 1988, Egypt.
Hassan, M.M., and A. Abou El-Azayem. 1990. Differences in salt tolerance of some fruit species. *Egypt. J. Hort.* 17: 1-8.

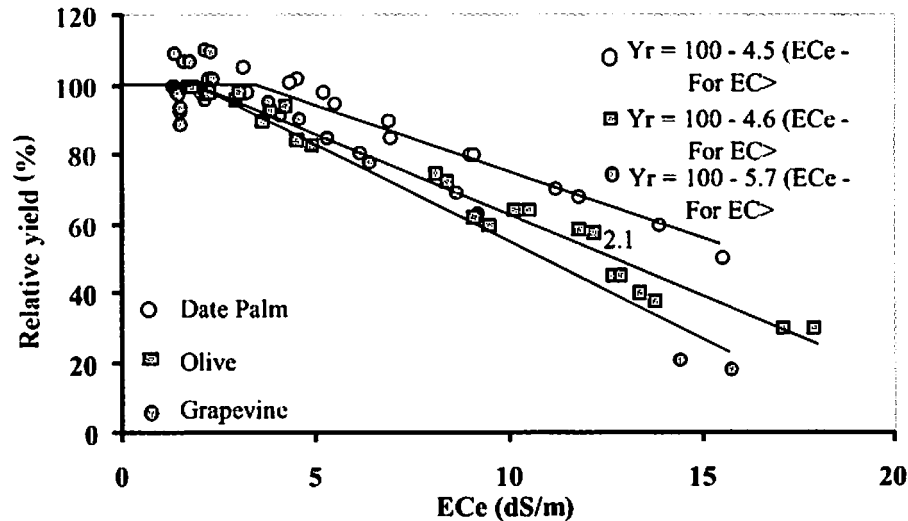


Fig. 1. Relative fruit yield of three fruits species as a function of increasing soil salinity (data of two seasons, 1997, 1998).

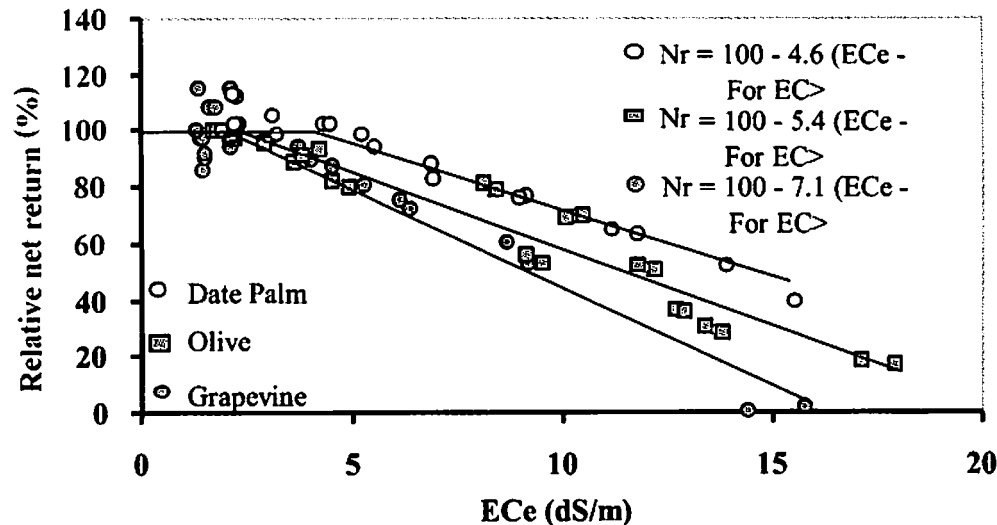


Fig. 2. Relative net return of three fruits species as a function of increasing soil salinity (data of two seasons, 1997, 1998).

- Hassan, M.M., and P.B. Catlin. 1984. Screening of Egyptian apricot *Prunus armentace L.* seedlings for response to salinity. *Hort. Science*, 19: 43-245.
- Hassan, M.M., S.A. Seif, and A.A. Abou-Arab. 1990. Salt tolerance of some olive cultivars. *J. Agric. Sci. Mansoura Univ.*, 15: 737-743.
- Page, A.I., R.H. Miller, and D.R. Keeney (Ed). 1982. Methods of soil analysis Part II, Chemical and microbiological methods. 2nd Ed. Amer. Soc. Agron., Madison, Wisconsin, USA.
- Prior, L.D., A.M. Grieve, and B.R. Callis. 1992. Sodium chloride and soil texture interaction in irrigated field grown Sultana grapevines. 2. Plant mineral content, growth and physiology. *Aust. J. Agric. Res.* 43: 1067-1083.
- Rush, D.W., and E. Epstein. 1976. Genotypic response to salinity: Differences between salt-sensitive and salt-tolerance genotypes of tomato. *Plant Physiol.*, 57: 162-166.
- Rush, D.W., and E. Epstein. 1981. Comparative studies on the sodium, potassium and chloride relations of a wild halophytic and a domestic salt-sensitive tomato species. *Plant Physiol.*, 68: 1308-1313.
- Snedecor, G.W., and W.G. Cochran. 1980. Statistical methods. 7th Ed., Iowa State Univ. Press, Iowa, USA.
- Soil Survey Staff. 1996. Keys to soil taxonomy. 7th Ed., USDA, National Resources Conservation Service, USA.
- Van Genuchten, M. Th., and G.J. Hoffman. 1984. Analysis of crops salt tolerance data. In: Shainberg and Shalhevet (Ed). Soil salinity under irrigation: Process and Management. Studies 51, Springer-Verlag, New York, USA.
- Zinck, J.A., 1989. Physiography and soils, *Lecture notes*, ITC, Enschede, The Netherlands.
- Zinck, J.A., and C.R. Valenzuela. 1990. Soil geographic database: structure and application examples. *ITC Journal*. 3: 270-293.

Salinity Stress on Potato as Modified by Calcium Application

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ABSTRACT

The trials were designed to evaluate the effect of calcium nitrate for reducing the injurious effect of saline water irrigation on growth and productivity of potato plants, cv. "Diamant". Seed tubers were planted in pots (30-cm dia.) into sandy soil at Ain Shams University, Faculty of Agriculture, for two spring seasons (1997 and 1998). Sea salt (Rashidi) at 4000 ppm concentration was used, and salt treatments were started 30 days after planting. Calcium (Ca^{+2}) concentrations (0.25, 0.5, 1, and 2 g/plant) were added as calcium nitrate for plants treated with saline water irrigation (4000 ppm). The results indicated that irrigation with saline water negatively affected all plant growth parameters such as plant length, number of leaves, total leaf area, dry/fresh weights of haulm and tubers, chlorophyll content, and yield. Average yield of potato plants were 375, 225, 287, 358, 439, and 269 g/plant for the treatments: control (4000 ppm salt) and Ca^{+2} at 0.25, 0.5, 1, 2 g/plant with salt. Using Ca^{+2} at lower concentrations reduced the harmful effects on plant growth and productivity of potato plants, while the highest level of Ca^{+2} (2 g /plant) under saline conditions reduced productivity of potato plants.

INTRODUCTION

Potato, *Solanum tuberosum* L., is the fourth most important crop in the world after wheat, maize and rice. It is considered as one of the most important vegetable crops grown in Egypt, where it grows under different environmental conditions. High soil salinity or saltiness is a widespread condition in arid and semi-arid areas and along low-lying seacoasts. Wherever irrigation is practised, excessive amounts of soluble salts in the irrigation water or soil may cause a salinity hazard. The degree of salinity may be so low that it only affects the most sensitive crops or so high that few, if any, crops can be grown. Different crops vary widely in their tolerance to salinity. Therefore, information on salt tolerance is often valuable in deciding which crops to grow under existing conditions (Cramer and Spurr, 1986).

Excessive salt concentration, however, tends to make the soil moisture less available to plant roots (Maas and Hoffman, 1977). Even if a saline soil is kept moist at all times, the limited availability of water will result in stunted plants. The saltier the soil solution, the less readily available is the soil water and the more stunted the plant (Bernstein, 1975). Salt-affected soils make up a substantial portion of the world's land area, including approximately 33% of the irrigated soils (Epstein et al., 1980).

Efforts have been made to control salinity by technological means: *reclamation, drainage, use of high leaching-fractions, and application of soil amendments*. An additional approach to the problem is to utilize the large genetic potential of many crop species and select more salt-tolerant crops (Epstein et al., 1980; Boyer, 1982). Selection and breeding for salt tolerance in a particular crop species would be facilitated if we could identify and understand the mechanisms of salt tolerance and toxicity for that species (Cramer et al., 1985).

Calcium is an important factor in maintenance of membrane integrity and ion-transport regulation. It has been shown that Ca^{+2} is essential for $\text{K}^{+}/\text{Na}^{+}$ selectivity and membrane integrity (Epstein, 1961; Lauchli and Epstein, 1970; Hanson, 1984). Elevated Ca^{+2} concentrations in the nutrient solution mitigated the adverse effects of NaCl on bean plants by inhibition of Na^{+} uptake (LaHaye and Epstein, 1969; Greenway and Munns, 1980) and reduction in leakage of membranes (Leopold and Willing, 1984). La Haye and Epstein (1969) clearly postulated that the $\text{Ca}^{+2}/\text{Na}^{+}$ interaction takes place at the plasmalemma. These authors suggested that Na^{+} acted by displacing Ca^{+2} from membranes, leading to increased membrane permeability and intracellular Na^{+} concentrations.

The limited supply of good quality irrigation water, particularly in the arid and semi-arid regions, is the most important factor against agricultural expansion, it creates a severe problem to plant-production. This problem is accompanied by the fact that most of the irrigation water is saline (Maas and Hoffman, 1977; Blum, 1988). This work was conducted in order to investigate some alternatives for the grower to overcome such unfavorable conditions prevailing in arid and semi-arid region such as Egypt.

MATERIALS AND METHODS

This experiment was designed to test the effect of saline water irrigation and calcium nitrate on the growth and productivity of potato plants, cv. Diamant. The experiment was carried out for spring seasons, 1997 and 1998 at Ain Shams University, Faculty of Agriculture. Seed tubers were planted in pots (30-cm dia.) in sandy soil. Sea-salt (Rashidi) was used at a concentration of 4000 ppm. Chemical analysis of Rashidi salt sample used in the trials was 0.2% Ca^{+2} , 43.8% Na^{+} , 0.74% K^{+} , 3.66% HCO_3^{-} and 50.2 % Cl^{-} . The salt treatments were started 30 days after planting the seed tuber.

Seed tubers were planted on January 15th, 1997 and 1998. Harvesting date was April 20th, 1997 and 1998, for the two planting seasons. Potato plants were

irrigated every 2 days and treatments were fresh water (226 ppm), Rashidi salt (4000 ppm), and Ca⁺² concentrations (0.25, 0.5, 1.0, and 2.0 g /plant with salt treatment). Calcium treatments were added as calcium nitrate (19% Ca⁺²). Haulm (leaves and stems) and tubers were harvested and dried at 70°C for 4 days and weighed to determine dry weight. Analysis of variance was conducted according to Snedecor and Cochran (1980).

The following measurements were recorded: plant length (cm), number of leaves, total chlorophyll content, total leaves area (cm²), haulm dry weight, fresh weight ratio, tubers dry weight, fresh weight ratio, specific gravity, and total tubers weight/plant.

RESULTS

All results are shown in Table 1. Plant length was decreased with irrigation of saline water (4000 ppm) compared to the control. Plant length was increased with increasing Ca levels used under irrigation of saline water. Using Ca⁺² with saline water mitigated the effect of salinity on plant length in general. The low concentration of Ca⁺ (0.25 g) reduced the effect of salinity, but was still significantly lower than control. The best concentrations in reducing the effect of salinity on this parameter were 0.5 and 1.0 Ca⁺²g/plant. Plant length was decreased with using high level of Ca⁺² compared to the control. Plant length of treatments (control, salt 4000 ppm, salt with 0.25, 0.5, 1.0, 2.0 g Ca⁺²/plant) were 39, 30, 33, 35, 37, and 26 cm, respectively. These differences were significant.

Table 1. Plant parameter in response to salt and Ca⁺² treatments.

Variable	Treatments						
	Control	Salt Alone	Salt plus Ca, g/plant				Significance
	226 ppm	4000 ppm	0.25	0.5	1.0	2.0	
Plant Length, cm	38	30	33	35	37	26	xx
Leaves/Plant, no.	79	52	62	69	76	48	xx
Chlorophyll Content	35.6	25.5	27.3	30.1	35.4	24.7	xx
Leaf Area, cm	886	423	646	485	856	324	
Dry: Fresh Weight of Haulms	12.0	10.0	10.4	11.0	11.8	9.0	N.S
Dry: Fresh Weight of Tubers	18.4	16.0	16.2	17.2	18.0	16.5	N.S
Specific Gravity	14.0	16.2	14.2	13.0	12.4	10.0	N.S
Total Soluble Solids	4.5	5.8	5.2	4.1	3.6	2.1	N.S
Yields/Plant, g.	375	225	287	358	369	169	xx

Similar trends were obtained for number of leaves, total chlorophyll content, total leaf area in the two successive spring seasons. Leaf numbers of treatments control, salt 4000 ppm, salt with 0.25, 0.5, 1.0, 2.0 g Ca⁺²/plant were 79, 52, 62, 69, 76, and 48 leaves/plant, respectively, in the two spring seasons. These differences were statistically significant. Total chlorophyll content of control, salt 4000 ppm, and salt treatments with 0.25, 0.5, 1.0, and 2.0 g Ca⁺²/plant were 35.6, 25.5, 27.3, 30.1, 35.4, and 24.7 g, respectively, in the two spring seasons. These differences were statistically significant.

The total leaf area of treatments control, salt 4000 ppm, salt with 0.25, 0.5, 1.0, 2.0 g Ca⁺²/plant were 886, 423, 485, 646, 856, and 324 cm², respectively, in the two seasons. The effects of different Ca levels under saline on haulm and tuber fresh weight to dry weight ratio of potato plants in the two spring seasons, and indicated no significant differences of treatments. Similar results obtained for the specific gravity and total soluble solids of tubers of potato plants.

The effects of different levels of calcium under saline on the yield of potato plant in the two spring seasons were statistically significant. Yield of potato plant was decreased with irrigation of saline water (4000 ppm) compared to the control. Yield of potato plant was increased with increasing Ca levels under irrigation of saline water. Meanwhile, yield of potato was decreased with using high level of Ca under irrigation of saline water. Moreover, yield of potato plant of treatments, control, salt 4000 ppm, salt with 0.25, 0.5, 1.0, 2.0 g Ca⁺²/plant were 375, 225, 287, 358, 369 and 169 g/plant, respectively, in the two spring seasons.

DISCUSSION

Salinity and/or water stress are common factors negatively affecting plant growth of vegetables such as potato (Bilski et al., 1988; Levy, 1992). Indeed, both vegetative and yield data show this fact. Plant length was affected significantly in an adverse way by the increases in salt concentration. This can be explained by the osmotic effect of salinity on cell enlargement which reflected on stem length (Greenway, 1961,

1963). The shorter stem usually comes from short internode length because of smaller cell size (Meiri and Poljakoff-Mayber, 1967). This explains why there was significant differences in number of leaves with the salt concentration used. Leaf area was also reduced by salinity, which can be explained as a result of lowering leaf water potential (Levy et al., 1988), hence reducing leaf cell expansion, and the latter was visually translated to smaller leaf area.

The negative effects of salinity on plant growth and production is a function of the relationship between dry matter production (photosynthesis) and water content

(related to water uptake and transpiration) in plant tissue (Tyree and Javris, 1982; Cosgrove, 1986). The two components of this relationship, dry matter and water, are independent (Frensch and Hsiao, 1994) and very much affected by conditions during growth, such as electric conductivity (EC) in the root zone (or irrigation water). This explains the reduction in fresh and dry weight of foliage. As a result of the osmotic effect of salinity, total soluble solids (TSS) increased in the tubers (Levy et al., 1988).

As a general trend, irrigation with saline water negatively affected all plant growth parameters such as plant length, number of leaves, fresh and dry weights of foliage and tubers. However, using Ca^{+2} reduced these harmful effects on plant growth (Kent and Lauchli, 1985; Bilski et al., 1987). This was clear in all growth parameters in this experiment. The improving effect of Ca^{+2} on growth under saline conditions may be explained in a way that root hairs were able to maintain higher levels of membrane-associated Ca^{+2} when exposed to high concentrations of NaCl (Cramer et al., 1985). In fact, it is essential to have Ca^{+2} of selective permeability, i.e., membrane integrity (Hanson, 1984; Leonard and Hepler, 1990; Poovaiah and Reddy, 1993). This helps in improving plant growth performance under saline conditions.

However, this improving effect of Ca^{+2} was true only with the low concentrations (0.5 and 1.0 g Ca^{+2} /plant). Higher concentrations (2.0 g Ca^{+2} /plant) did not show the same improving effect. This may come from the fact that increasing Ca^{+2} concentration to this level contributes more to elevating the EC rather than reducing the harmful effect of NaCl.

It can be concluded from this experiment that the negative effect of salinity on plant growth and productivity can be overcome by application of Ca^{+2} . However, the positive effects of some of the concentrations used in this study suggested that the most proper and recommended amount of Ca^{+2} would be finally determined based on soil type and economic factor. This means that this kind of applications will be mainly used in the newly reclaimed land where most of these soils are sandy and saline. A final conclusion on Ca^{+2} is that Ca^{+2} doesn't show its improving effects unless stress conditions exist.

REFERENCES

- Bernstein, L. 1975. Effect of salinity on plant growth. *Ann. Rev. Phytopathol.*, 13: 295-312.
- Bilski, J.J., D.C. Nelson, and R.L. Conlon. 1988. The response of four potato cultivars to chloride salinity, sulfate salinity and calcium in pot experiments. *Am. Potato J.* 65: 85-90.
- Bilski, J.J., D.C. Nelson, A. Maianu, and R.L. Conlon. 1987. Response of potatoes and related wild species to salinity. *Amer. Potato J.* 64(8): 431.
- Blum, K. 1988. Plant breeding for stress environments. Boca Raton, FL, USA: CRC Press, Inc. 223 p.
- Boyer, J.S. 1982. Plant productivity and environment. *Science* 218: 443-448.
- Cosgrove, D.J. 1986. Update on cell walls: How do plant cell walls extend. *Plant Physiol.* 102: 1-6.
- Cramer, G.R., and A.R. Spurr. 1986. Responses of lettuce to salinity. I. Effect of NaCl and Na_2SO_4 on growth. *J. Plant Nutr.* 9(2): 115-130.
- Cramer, G.R., A. Lauchli, and V.S. Polito. 1985. Displacement of Ca^{+2} by Na^{+} from the plasmalemma of root cells. *Plant Physiol.* 79: 207-211.
- Cramer, G.R., and A.R. Spurr. 1986b. Responses of lettuce to salinity. II. Effect of calcium on growth and mineral status. *J. Plant Nutr.* 9(2): 131-142.
- Epstein, E. 1961. The essential role of calcium in selective cations transport by plant cells. *Plant Physiol.* 36: 437-444.
- Epstein, E., J.D. Norlyn, D.W. Rush, R.W. Kingsburg, D.B. Kelley, G.A. Cunningham, and A.F. Wrona. 1980. Saline culture of crops: a genetic approach. *Science* 210: 399-404.
- Frensch, J., and T.C. Hsiao. 1994. Transient responses of cell turgor and growth of maize roots as affected by changes in water potential. *Plant Physiol.* 104: 247-257.
- Greenway, H. 1961. Plant response to saline substrates. II. Chloride, sodium and potassium uptake and translocation in young plants of *Hordeum vulgare*, during and after a short sodium chloride treatment. *Aust. J. Biol. Sci.* 39: 57.
- Greenway, H. 1963. Plant response to saline substrates. III. Effect of nutrient concentration on the growth and ion uptake of *Hordeum vulgare* during NaCl stress. *Aust. J. Biol. Sci.* 16(3): 616-628.
- Greenway, H.R., and R. Munns. 1980. Mechanisms of salt tolerance in non-halophytes. *Annu. Rev. Plant Physiol.* 31: 149-190.
- Hanson, J.B. 1984. The function of calcium in plant nutrition. p.149-208. In: P.B. Tinker, and A. Lauchli (Ed.) *Advances in Plant Nutrition*, Vol.1. Praeger, New York.
- La Haye, P.A., and E. Epstein. 1969. Salt toleration by plants: enhancement with calcium. *Science* 166: 395-396.
- Lauchli, A., and E. Epstein. 1970. Transport of potassium and rubidium in plant roots: the significance of calcium. *Plant Physiol.* 45: 639-641.
- Leonard, R.T., and P.K. Hepler. 1990. Calcium in plant growth and development. *Amer. Soc. Plant Physiol.* Rockville, Md.
- Leopold, A.C., and R.P. Willing. 1984. Evidence for toxicity effects of salt on membranes. p. 67-76. In: R.C. Staples, and G.H. Toenniessen (Ed.) *Salinity tolerance in plants: strategies for crop improvement*. John Wiley and Sons, New York.
- Levy, D. 1992. The response of potatoes (*Solanum tuberosum* L.) to salinity: plant growth and tuber yields in the arid desert of Israel. *Isr. J. Bot.* 120: 547-555.
- Levy, D., E. Fogelman, and Y. Itzhak. 1988. The effect of water salinity on potatoes (*Solanum tuberosum*

- L.*): physiological indices and yielding capacity. *Potato Res.* 31(4): 601-610.
- Maas, E.V., and G.J. Hoffman. 1977. Crop salt tolerance: current assessment. *J. Irrig. Drain. Div. Proc. Amer. Soc. Civil Eng.* 103: 115-134.
- Meiri, A., and A. Poljakoff-Mayber. 1967. The effect of chloride salinity on the growth of bean leaves in thickness and in area. *Isr. J. Bot.* 16: 115-123.
- Poovaiah, B.W., and A.S.N. Reddy. 1993. Calcium and signal transduction in plants. *CRC Crit. Rev. Plant Sci.* 12(3): 185-211.
- Snedecor, G.W., and W.G. Cochran. 1980. *Statistical Methods*, 7th (Ed.), Iowa State Univ., Press. Ames, Iowa, USA.
- Tyree, M.T., and M.G. Javris. 1982. Water in tissue and cells. *In: Encyclopedia of Plant Physiology: Physiological Plant Ecology II. Water relations and carbon assimilation (NS)*, 12 B. (O.L. Lange, P.S. Nobel, C.B. Osmand, and C.B. Ziegler, (Ed.) Springer Verlage, Berlin/New York, 36-77.

Expert Systems and Modeling

Stability Analysis for Bread Wheat Genotypes in Egypt

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ABSTRACT

Two field experiments were carried out during the two successive winter seasons (1989/90 and 1990/91) at El-Sharkeia Governorate at two different locations, i.e., El-Khatteer desert area (Fakkus, sandy soil), and Om El-Zain Village, Zagazig, which represents clay soil. In each experiment, 15 genetically diverse bread wheat genotypes were tested in RCBD with four replications.

Significant values of mean squares for genotypes and genotype $\times$ environment interaction for number of spikes m^{-2} and number of grains/spike suggested that genotype were genetically differed for these characters. Regarding number of spikes/ m^2 , regression values were below 1.0 for genotypes Giza 157, Sakha 61, Giza 160, Giza, 163; Sakha 8 $\times$ Hattari 33. This provides a measure of greater resistance to environmental change (above average stability), and therefore increasing specificity of adaptability to low-yielding environments. Concerning number of grains/spike, the genotype Giza 164, Sakha 69, Sakha 8 $\times$ Hattari 51, Giza 157 $\times$ Hattari 23, and Sakha 8 $\times$ Hattari 48, were highly responsive to change in environmental conditions and performed well in favorable environments.

The wheat genotypes Sakha 61, Sakha 92, Giza 157, Sakha 8 $\times$ Hattari 33, Sakha 8 $\times$ Hattari 46, Giza 157 $\times$ Hattari 14, and Giza 157 $\times$ Hattari 23, were the most stable genotypes under the conditions of the present study for 1000 - grain weight.

For grain yield (ardab/feddan), regression coefficients below 1.0 were obtained for wheat genotypes Giza 163, Sakha 92, Giza 157, Sakha 61, Sakha 8 $\times$ Hattari 33, Sakha 8 $\times$ Hattari 48, and Giza 157 $\times$ Hattari 14, suggesting greater resistance to environmental changes (above average stability) and therefore increasing specificity of adaptability to low-yielding environments.

INTRODUCTION

Wheat is one of the major crops in Egypt and world on the basis of cultivation. Since its multiple usage in human consumption. The wide gap between population and limited area devoted to wheat cultivation, including newly reclaimed area make it necessary to develop wheat cultivars which would be accepted well in both clay and sandy soil conditions.

The aim of several breeding programs is to select genotypes that are consistently high-yielding over a wide range of environments. This selection is usually not efficient due to the contribution of genotypes $\times$

environment interaction components, i.e., the failure of genotypes to have the same relative performance in different environments. For selecting the most stable genotypes over different environments and those performing well under specific environments, stability analysis developed by Finley and Wilkinson (1963) was applied in several studies.

Finlay and Wilkinson (1963) studying the adaptation of 277 barley varieties grown in replicated trials for many seasons at three locations in South Australia, found that any variety with a low value of B_i (coefficient of regression) may be considered as a stable one. Jatasra and Paroda (1979) evaluated ten wheat genotypes in six environments and found significant effect of genotype environment interactions and the parameter of stability, b_i , was positively correlated with the mean performance of spike emergence and plant height.

El-Ghawas et al. (1984) in Egypt reported that wheat genotypes, Giza 157 and the introduced line 578, were characterized by yield stability of high performance over all environments. Also, Bassiouny (1985), in Egypt, evaluated 24 wheat genotypes under five levels of N-fertilization. He stated that highly significant differences in grain yield, 1000-grain weight, number of grains/spike, number of spikes/ m^2 , and plant height were detected. Highly significant variety $\times$ environment (linear) interaction was detected when tested against pooled deviation for the studied traits, indicating that these traits of the different wheat genotypes responded differently to varied environments.

Shukla (1986) stated that some authors have found that regression parameters accounted for a considerable amount of the interaction between genotype and environment, while others have found that these parameters account for only a small amount of such interactions and the regression parameters have been found to vary considerably from trait to another.

Ramogasa (1988) reported that the most stable components were 1000-grain weight and harvest index in bread wheat and number of productive tillers/plant and 1000-kernel weight in durum wheat. The least stable characters were total number of tillers/plant and number of spikelets/spike. Selim (1989) indicated that the most stable components of wheat were number of spikes/ m^2 , spike length, and spike grain weight; the least stable character was number of days-to-50% heading.

The aim of this research was to calculate stability parameters for yield contributing characters of 15 wheat genotypes under two locations in Egypt, i.e., El-Khattara and Om El-Zain.

MATERIALS AND METHODS

Two field experiments were carried out during the two successive winter growing seasons 1989/90 and 1990/91 at Zagazig Governorate in two different locations, i.e., El-Khattara desert area (Fakkus), which represents sandy soil, and Om El-Zain village, Zagazig, which is considered a clay soil. In each experiment, 15 genetically diverse bread wheat genotypes were tested. The pedigree and origin of the studied wheat genotypes are presented in Table 1.

Wheat grains were drilled in six-rowed plots, with 3-m long and 1.2 m width (plot area 3.6 m²), with a seeding rate of 50 kg/feddan. Sowing dates in both seasons were 28 and 29 November, in El-Khattara and Om El-Zain, respectively. Randomized complete block design with four replications was used at each location. Sprinkler irrigation was used in El-Khattara whereas surface irrigation was used at the Om El-Zain location. Fertilizer application and the recommended agriculture practices were performed at proper time at the two locations.

B_i = Regression coefficient for the i^{th} variety on I_j ,
 I_j = Environmental index at the j^{th} environment,
 s_{ij} = Deviation from regression of the i^{th} variety at the j^{th} environment.

The types of response were summarized as follows:
 $B = 1.0$ indicates average stability; when it is associated with high mean yield, the genotypes have general adaptability, while the genotypes are poorly adapted to all environments when this value is associated with low mean yield.
 $B > 1.0$ indicates that the genotypes are sensitive to environmental change (below average stability) and have greater specificity for adaptability to high-yielding environments.
 $B < 1.0$ indicates that the genotypes have greater resistance to environmental change (above average stability) and therefore increasing specificity of adaptability to low-yielding environments.

Table 1. Pedigree and origin of the studied wheat genotypes.

No.	Genotype	Pedigree	Origin
1	Giza 162	Vcm/cm "s"/7c13/Kal/Bb	Egypt
2	Giza 157	Giza 155 × Pi 62 ⁴ × LR 64 ² × TZpp × Knott 11	Egypt
3	Sakha 61	INIA-RL 4220 × 7c/YR "s"	Egypt
4	Sakha 8	INDUS × NORTEIN "S" pk 3418	Egypt
5	Sakha 69	INIA RL 4220 × 7c/YR "s" Cm 15430- 25 - 05	Egypt
6	Giza 164	KVZ/Buha "s"//Ka 1/Bb	Egypt
7	Sakha 92	Napo 63/Inia 66//Wern "S"	Egypt
8	Giza 160	Chenab 70//G. 155	Egypt
9	Giza 163	T. aestivum/Bon//Cno/7c	Egypt
10	Sakha 8 × Hatri	F5 85/86 No. 33	Lines from crosses
11	Sakha 8 × Hatri	F5 85/86 No. 46	Egyptian × German
12	Sakha 8 × Hatri	F5 85/86 No. 48	Spring wheat
13	Sakha 8 × Hatri	F5 85/86 No. 51	Shandaweel wheat
14	Giza 157 × Hatri	F5 85/86 No. 14	program.
15	Giza 157 × Hatri	F5 85/86 No. 23	//

Statistical Analysis

The obtained data for each experiments, i.e., in each location, were statistically analyzed according to the method outlined by Steel and Torrie (1980).

Stability Index

Stability indices for the wheat genotypes studied were calculated according to Finlay and Wilkinson (1963). This model described as follows:

$Y_{ij} = u + d_i + B_i I_j + s_{ij}$

Where:

- Y_{ij} = Yield of the i^{th} variety in j^{th} environment.
- u = Mean yield of all varieties at two sites.
- d_i = Yield deviation of i^{th} variety.

RESULTS AND DISCUSSION

Stability Analysis

Stability parameters for yield and yield component, i.e., number of spikes/m², number of grains/spike, and 1000-grain weight of the studied wheat genotypes under the different environments were computed using Finlay and Wilkinson (1963) model. Considering the two locations and the 2 years as four environments, the analysis of variance indicated significant mean squares for genotypes and genotype × environment, suggesting that genotypes differed genetically for the characters studied.

Number of spikes/m²

The data presented in Table 2 indicated that the Sakha 92 variety had a regression coefficient value equal to one, indicating average stability. When this value is associated with high mean yield, the variety has general adaptability. On the other hand, when this is value associated with low mean yield, the variety is poorly adapted to all environments. Regression values above 1.0 obtained for wheat genotypes, Giza 162, Sakha 8, Sakha 69, Giza 164, Sakha 8 × Hattari 48, Sakha 8 × Hattari 14, and Sakha 8 × Hattari 46, revealed that these genotypes were sensitive to environmental changes (below average stability), and thus they should be grown in a specific environment. Table 3 shows significant mean squares for genotypes, environment, and genotype × environment suggesting that genotypes were genetically different for number of spikes/m². In addition, such genotypes differed in their response to environmental condition, which could be considered adequate to specify the performance of each genotype to the varying environment.

Wheat genotypes Giza 157, Sakha 61, Giza 160, Giza 163, and Sakha 8 × Hattari 33 had a regression coefficient below 1.0. This provides a measure of greater resistance to environmental change (above average stability) and therefore increasing specificity of

adaptability to low-yielding environments. Apparently, the number of spikes is the most influential yield component, and breeding for more spikes and stability for this trait will yield stable, high-yielding genotypes. These results are supported by the findings of Luthra et al. (1979) and Chaubey and Sastry, (1981).

Grains/Spike

There was a wide range of variation in values of regression coefficient among wheat genotypes (Table 2). Besides, significant interactions between genotypes and environment were also detected, as shown in Table 3. The genotypes, Sakha 69, Giza 164, Sakha 8 × Hattari 48, Sakha 8 × Hattari 51, and Giza 157 × Hattari 23, were highly responsive to change in environmental conditions and performed well in favorable environments. However, the regression coefficient values and of the genotypes Giza 162, Giza 157, Sakha 61, Sakha 8, Sakha 92, Giza 160, Giza 163, Sakha 8 × Hattari 33, Giza 157 × Hattari 14 and Sakha 8 × Hattari 46, (0.97, 0.95, 0.91, 0.96, 0.97, 0.95, 0.99, 0.92, 0.96) suggested that these genotypes failed to respond to improved environments, consequently they yielded relatively well under low-yield environments. Similar conclusions were observed by Anand et al., (1972), Luthra et al. (1977), and Chaubey and Sastry (1981).

Table 2. Stability parameter of individual genotypes for yield and yield components.

Genotype	Spikes/m		Grains/Spike		1000-Grain Weight		Grain Yield	
	Mean	b value	Mean	b value	Mean	b value	Mean	b value
					--g--		-ardab/feddan-	
Giza 162	287	1.03	51.5	0.97	49	1.06	13.8	1.00
Giza 157	267	0.99	50.2	0.95	43	0.93	13.0	0.93
Sakha 61	268	0.96	48.2	0.91	44	0.95	12.5	0.90
Sakha 8	281	1.01	50.8	0.96	48	1.03	14.3	1.03
Sakha 69	290	1.04	59.9	1.13	52	1.12	15.4	1.11
Giza 164	285	1.02	53.9	1.02	49	1.06	14.5	1.04
Sakha 92	279	1.00	51.5	0.97	43	0.94	13.2	0.95
Giza 160	276	0.99	50.4	0.95	47	1.01	14.6	1.05
Giza 163	271	0.97	52.2	0.99	47	1.02	13.4	0.96
Sakha 8 × Hattari 33	274	0.98	48.7	0.92	43	1.94	12.9	0.93
Sakha 8 × Hattari 46	281	1.01	52.7	0.99	45	0.98	13.9	1.00
Sakha 8 × Hattari 48	281	1.01	54.6	1.03	44	0.94	13.8	0.99
Sakha 8 × Hattari 51	282	1.01	56.2	1.06	47	1.02	14.6	1.05
Giza 157 × Hattari 14	287	1.03	51.0	0.96	44	0.95	13.2	0.95
Giza 157 × Hattari 23	281	1.01	54.6	1.03	44	0.96	14.3	1.03

Table 3. Mean squares of the analysis of variance for yield and yield components.

Variance	Degrees of Freedom	Spikes -No./m ²	Grains -No./spike	1000-Grain Weight --g	Grain Yield ardab/feddan
Genotype (G)	14	622.3100**	146.9200**	144.14**	10.36**
Environments (E)	3	173666.4000**	1118.0100**	838.13**	188.15**
G × E	42	342.7900**	20.6100**	7.23n.s	1.98n.s
Heterogeneity	14	7.7100n.s	12.1850n.s	201.285**	15.467**
Deviation	28	510.3200**	24.8220*	84.797**	4.763**
Pooled error	168	110.55196	18.7537	10.762125	1.837

Thousand-Grain Weight

Data presented in Table 2 indicated that there was a wide range of variation in the values of regression coefficients among wheat genotypes, while Table 3 indicated that no significant mean squares for $G \times E$ interaction was observed. This indicates that the wheat genotypes under study did not differ in their response to environmental conditions.

The wheat genotypes Giza 162, Sakha 8, Sakha 69, Giza 164, Giza 160, Giza 163, and Sakha 8 $\times$ Hattari 51, were the most sensitive ones, and should be highly responsive to change in environmental conditions and perform consistently better in favorable environments.

However, wheat genotypes Giza 157, Sakha 61, Sakha 92, Sakha 8 $\times$ Hattari 33, Sakha 8 $\times$ Hattari 48, Giza 157 $\times$ Hattari 23, Giza 175 $\times$ Hattari 14, and Sakha 8 $\times$ Hattari 46, failed to response under improving environments, consequently they yielded relatively better in low-yield environments and relatively poorer in high-yield environments.

Grain Yield

The results given in Table 2 revealed that the regression values differed from one genotype to another, indicating that these genotypes differed in their performance from location to location. Wheat genotypes Giza 162 and Sakha 8 $\times$ Hattari 46 had regression coefficient values equal to one indicating an average stability. The mean performance of these varieties was associated with b value, suggesting that mean performance and b value were related to each other.

Wheat genotypes Sakha 8, Sakha 69, Giza 164, Giza 160, Sakha 8 $\times$ Hattari 51, and Giza 157 $\times$ Hattari 23, had a regression coefficients value above 1.01, indicating that these were highly sensitive to environmental change (below average stability) and greater specificity of adaptability to high-yielding environments.

Regression coefficients decreasing below 1.0 were obtained for wheat genotypes Giza 157, Sakha 61, Sakha 92, Giza 163, Sakha 8 $\times$ Hattari 33, Sakha 8 $\times$ Hattari 48, and Giza 157 $\times$ Hattari 14 suggesting greater resistance to environmental change (above average stability) and therefore increasing specificity of adaptability to low-yielding environments.

It could be concluded that yield is a polygenic trait and is composed of many component characters, the most important ones being the number of spikes/plant

or unit area, number of grains/spike and grain weight; these have high correlation with grain yield (Anand et al., 1972; Luthra et al., 1977; 1979; Chaubey and Sastry, 1981).

REFERENCES

- Anand, S.C., H.S. Aulakh, and S.K. Sharma. 1977. Associations among yield component in dwarf wheat. *Indian J. Agric. Sci.* 42: 935-938.
- Bassiouny, A.H.M. 1985. Studies on yield potentiality in wheat. *Ph.D. Thesis*, Fac. Agric., Zagazig Univ., Egypt.
- Chaubey, J.S., and V.D. Sastry. 1981. Stability analysis of yield and yield components in some Indian and Mexican varieties of wheat. *Indian J. Agric. Sci.* 51: 611-614.
- El-Ghawas, M.I., A.M. Abdel-Halim, A.M. Esmail, and A.N. Abdel Hakeem. 1984. Estimating the stability parameters for comparing agronomic wheat varieties and their implication in breeding programs. 2nd Conf., ARC, Giza, 9-11 April.
- Finlay, K.W., and G.N. Wilkinson. 1963. The analysis of adaptation in plant breeding programs. *Aust. J. Agr. Res.* 14: 742-754.
- Jatasra, D.S., and R.S. Paroda. 1979. Stability for synchrony traits in wheat. *Indian. J. Genet. & Plant Breeding* 39(3): 378-383.
- Luthra, O.P., S.N. Karkab, and R.K. Singh. 1977. Genotypes environmental interactions and ranking of varieties in wheat. p. 22-25. 3rd Intern. Congress Society for the Advancement of Breeding, Canberra, Australia.
- Luthra, O.P., R.K. Singh, and S.N. Karkab. 1979. Stability analysis of tall and dwarf cultivars of wheat. *Agric. Res. Rural Rev.* 2: 27-33.
- Romagosa, I., and L. Roy. 1988. Yield component stability in *T. aestivum* L. and *T. turgidum* var. *durum*. *Cereal Res. Comm.* 16 (1-2): 77-84.
- Selim, M.S.M. 1989. The performance and stability of wheat varieties under different seeding rates. *Ph. D. Thesis*, Fac. Agric., Zagazig Univ., Egypt.
- Shukla, G.K. 1986. Use of regression approach in the analysis of genotyp-environmental interaction. *C F. Plant Breeding Abst.* 56(1): 10-12.
- Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd Ed. McGraw-Hill Book Co., New York.

Green Cowpea Productivity in Sandy Soil with Different Organic Manures

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ABSTRACT

To investigate productivity characters of cowpea green yield (*vigna sinensis*) cv. Cream 7, under sandy soil conditions at the Experimental Farm of El-Bossaily region, Behera Governorate, two field experiments were carried out in 1998 and 1999 seasons, each experiment included eight treatments; seven representing different combinations of cattle and chicken manure fertilizers, i.e., 30 + zero, 25 + 5, 20 + 10, 15 + 15, 10 + 20, 5 + 25, zero + 30 m³/feddan, respectively, in addition to the control treatment (recommended mineral fertilizer). All organic manure treatments were better than the control with respect to vegetative and reproductive growth characters as well as pod nutritional characters, except for fruit earliness. However, 10 m³ cattle manure + 20m³ chicken manure/feddan treatment was superior, indicating the most favorable effects of chicken manure, followed by cattle manure.

INTRODUCTION

Cowpea (*vigna sinensis*) is one of most important leguminous vegetable crops grown in Egypt. Potential pollution with overuse of chemical fertilizers because a concern. Thus, attempts were made to solve problems of chemical fertilization. Organic farming represents a move towards an alternative system of agriculture.

Many investigators have shown that nitrogen (N) application to cowpea plants increased plant growth, dry matter content, yield and its quality as well as the nutritional value of seeds (Kumar and Pillai, 1981; Hassan et al., 1989; Farrag, 1991). The growth of pea green pod yield and its components, as well as seeds quality and the nutritional value of seeds, were significantly increased by increasing the rate of chicken manure (Abd-Allah, 1998). Application of organic manures significantly increased the yield of cowpea; the increase amounted to 17 and 29% at the rate of 5 and 10 tons/feddan farmyard manure (FYM), while the addition of poultry manure at 3, 5, and 10 ton/feddan increased the yield by 22, 29, and 39%, respectively. The maximum increase of cowpea production was recorded by a combination of treatments. The percentage increases were 46 and 45% at the ratios of 1: 1 and 3: 1 over control (Abd-Elfattah and Saleh, 1999)

MATERIALS AND METHODS

Two field experiments were carried out at the Experimental Farm of El-Bossaily region, Behera

Governorate, in 1998 and 1999 seasons. Cowpea (*vigna sinensis*) cv. Cream 7, was sown in 15th Feb. Drip irrigation with 6,000 drippers/feddan was used. Each dripper served two plants on both sides, thus 12,000 plants were included in each feddan.

Each experiment included eight treatments representing different combinations of cattle and chicken manure (CM), in addition to the control treatment as follows: control (recommended mineral and 10 m³ cattle manure i.e., FYM), 30 m³ (FYM) +zero m³CM/feddan, 25 m³ FYM +5 m³ CM, 20 m³ FYM+10 m³ CM/feddan, 15 m³ FYM+15 m³ CM/feddan, 10 m³ FYM+20 m³ CM/feddan, 5 m³ FYM+25 m³ CM/feddan, and Zero FYM +30 m³ CM/feddan.

The eight treatments were randomly distributed in a randomized complete block design with four replicates. The chemical analysis of the organic fertilize is shown in Table 1. Sixty days after sowing, a random vegetative sample of five plants was taken for determination of growth characters, i.e., plant height, leaf and branch numbers, leaf area, and leaf and stem dry weights. At harvest, 105 days from sowing, green pod yield was estimated, i.e., pod number per plant, average pod weight, in addition to pod nutritional value of carbohydrates, total soluble solid, and total titratable acidity.

Green pod content of total carbohydrates was determined spectrophotometrically as glucose after acid hydrolysis. The reagent used was phenol sulphuric acid. Total acidity and total soluble solids percentages were determined using the titration method against 0.1 N NaOH and an Abbe refractometer, respectively (A.O.A.C., 1975). Statistical analysis was carried out according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Data Presented in Table 2 indicated that all organic fertilizer treatments, i.e., mixture of farmyard and chicken manure exceeded the control and produced higher vegetative growth. Such effects were shown in both seasons. The highest growth characters measurements were recorded with FYM (10 + 20 (CM) m³/feddan), except for the 5 m³ FYM + 25 CM treatments. Growth characters, i.e., stem height, leaf and branch number, leaf area, and leaf and stems dry matter followed the same pattern of response to fertilizer treatments.

Table 1. Chemical analysis of the organic manures.

Contents	Cattle	Chicken	Contents	Cattle	Chicken
N, %	1.65	3.26	Cu, ppm	36	32
P, %	0.51	0.74	Pb, ppm	4.1	7.1
K, %	0.96	1.52	Ni, ppm	3.2	5.4
Fe, ppm	3895	4322	EC, dS/m	9.7	9.6
Mn, ppm	373	211	PH	7.3	7.6
Zn, ppm	79	117	Organic mater, %	21.2	39.2

Table 2. Organic fertilizers vs. cowpea vegetative growth and dry matter.

No.	Treatment	Stem	Leaf	Branch	Leaf	Dry Matter	
		Height			Area	Leaves	Branches
		-cm-	No./plant	No./plant	cm ² /plant	--g/plant--	
-----First Season-----							
1	Control	63	19	3.3	1726	10.2	8.2
2	30 m ³ FYM alone	60	17	2.0	1415	9.7	7.3
3	25 m ³ FYM+5 m ³ CM	67	19	2.6	1560	12.1	9.7
4	20 m ³ FYM+10 m ³ CM	73	22	4.0	1853	13.6	10.5
5	15 m ³ FYM+15 m ³ CM	82	26	4.6	1987	16.7	13.0
6	10 m ³ FYM+20 m ³ CM	95	30	5.3	2326	17.0	16.2
7	5 m ³ FYM+25 m ³ CM	87	27	5.0	2263	16.8	14.9
8	Zero FYM+30 m ³ CM	79	25	4.6	1886	15.0	12.5
	L.S.D. 5 %	13	3	0.4	65.18	2.1	2.0
-----Second Season-----							
1	Control	65	20	3.0	1842	10.6	7.6
2	30 m ³ FYM alone	62	18	2.0	1528	10.0	4.4
3	25 m ³ FYM+5 m ³ CM	71	21	3.3	1823	13.4	8.2
4	20 m ³ FYM+10 m ³ CM	74	22	4.0	1875	13.7	10.3
5	15 m ³ FYM+15 m ³ CM	85	27	4.6	2165	16.9	12.9
6	10 m ³ FYM+20 m ³ CM	98	30	5.6	2430	17.6	16.4
7	5 m ³ FYM+25 m ³ CM	90	29	5.0	2264	17.5	14.8
8	Zero FYM+30 m ³ CM	82	26	4.6	1975	15.8	13.0
	L.S.D. 5 %	12	3	0.5	72.36	2.3	2.4

Control = 10 m³ cattle manure + 300 kg ammonium sulfate (20.5% N)+ 300 kg calcium superphosphate (16.5% P₂O₅) + 150 kg potassium sulphate (48% K₂O).

Organic manure is a rich and slow-release fertilizer, and a clean product of peas could be obtained. Usage of organic fertilizer such as chicken manure in sandy soil improves the soil texture. The structural improvement can encourage the plant to have a good root development by improving soil aeration, which leads to higher yield and good quality (Borin et al., 1987; Browaldh, 1992).

It could be concluded from data in Table 3 that increasing the ratio of chicken manure in the fertilizer up to 20 m³/feddan improved cowpea plant productivity and produced the highest fruit yield. However, the lowest yield accompanied the control and/or 30 m³ FYM/feddan treatments in both seasons. The same trend was found in both seasons with respect to number of pods per plant and average pod number (Table 2) and green-pod yield per plant.

The highest nutritional value of pods (Table 3), i.e., total carbohydrates and total soluble solids percentage, as well as titratable acidity, were shown in plants

receiving 10 m³ FYM + 20 CM/feddan in both seasons. Such measurements were lowest with 30 m³/feddan of FYM and/or the control. Results obtained indicated the favorable effect of chicken manure on cowpea plants productivity. This result might be due to the role of organic manure for continuous supply of nutrients, for improving some physical properties of soil, and for increasing water retention than that for chemical fertilizers (Abd-El-Moez et al., 1995; Abd-El Fattah et al., 1996).

REFERENCES

- Abd-Allah, A.M. 1998. The growth of peas, green pods yield and their quantity as affected by organic, N and K fertilizers. *Egypt. J. Appl. Sci.* 13: 292-311.
- Abd-Elfattah, A.M.R. Abd-El-Moez, and M.H. Ghali 1996. Impact of various organic wastes on physico-chemical properties of sandy soil and nutrients content in Broad bean. *Egypt. J. Appl. Sci.* 11: 124-139.

Table 3. Organic fertilizers: cowpea yield and its components and pod nutritional value of green pods.

	Treatment	Pods No./plant	Pod Weight ----g----	Total Soluble Solids -----%-----
-----First Season-----				
1	Control	16.5	7.1	5.3
2	30 m ³ FYM alone	12.3	6.8	5.4
3	25 m ³ FYM+5 m ³ CM	17.6	7.3	5.8
4	20 m ³ FYM+10 m ³ CM	19.1	7.6	5.9
5	15 m ³ FYM+15 m ³ CM	23.2	9.2	6.5
6	10 m ³ FYM+20 m ³ CM	29.2	11.3	7.5
7	5 m ³ FYM+25 m ³ CM	26.2	10.1	7.0
8	Zero FYM+30 m ³ CM	22.1	8.1	6.2
	L.S.D. 5 %	4.1	2.0	0.6
-----Second Season-----				
1	Control	17.0	7.0	5.2
2	30 m ³ FYM alone	13.6	6.7	5.3
3	25 m ³ FYM+5 m ³ CM	17.9	7.3	5.7
4	20 m ³ FYM+10 m ³ CM	20.3	7.8	5.9
5	15 m ³ FYM+15 m ³ CM	24.5	9.4	6.4
6	10 m ³ FYM+20 m ³ CM	30.2	10.5	7.3
7	5 m ³ FYM+25 m ³ CM	27.3	10.3	7.1
8	Zero FYM+30 m ³ CM	23.0	8.3	6.2
	L.S.D. 5%	4.3	2.2	0.6

Control = 10 m³ cattle manure + 300 kg ammonium sulfate (20.5% N)+ 300 kg calcium superphosphate (16.5% P₂ O₅) + 150 kg potassium sulphate (48% K₂O).

Abd-Elfattah, A., M.R. Abd-El-Moez, and A.L. Saleh. 1999. Improvement of cowpea production using organic farming system. *Egypt. J. Appl. Sci.* 14: 231-237.

Abd El-Moez, M.R., M.H. Ghali, and A. Abd-Elfattah. 1995. Conditioning of a sand soil by organic wastes and its impact on N-concentration and yield of broad bean. *Zagazig J. Agric. Res.* 22: 1145-1155.

O.A.C. 1975. Official Methods of Analysis, 12th Ed. Association of Official Analytical Chemists, Washington, D.C.

Borin, M., C. Giupponi, and F. Osele. 1987. The effect of organic and mineral fertilizer and soil type on potato tuber formation. *Information Agrario.* 43: 91-92.

Browaldh, M. 1992. Influence of organic and inorganic fertilizers on common bean (*Phaseolus vulgaris* L.) grown in a P-fixing Mollic Andosol. *Biol. Agric. Hort.* 9: 87-104.

Farrag, M.M. 1991. Response of cowpea to weed control, plant density, and nitrogen fertilization rates. *Minia J. Agric. Res. Dev.*, 13: 435-459

Gomez, K.A., and A.A. Gomez. 1984. Statistical procedures for agriculture research. 2nd Ed., Wiley Inter. Sci. Publ.

Hassan, M.A.M., M.M. Farrag, and T.M. Moharram. 1989. Response of Cowpea to inoculation with rhizobium and nitrogen fertilization rates. *Minia J. Agric. Res. Dev.* 11: 1615-1638.

Kumar, B.M., and P.B. Pillai. 1981. Effects of N, P, and K on the yield of cowpea variety p. 118. *Afric. Res. J. Appl. Krala*, 17: 194-199.

Response of Tomato Hybrids to Organic Fertilizer under Newly Reclaimed Soils

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ABSTRACT

Tomato seedlings (*Lycopersicon esculentum*, Mill) were transplanted at the experimental farm of the Bossialy region, Behera Governorate, in 1998 and 1999 seasons, to investigate the response of some tomato hybrids to organic fertilizer. Ain Shams-2, Dokki-2, and CL-150 hybrids were used in the study. Three fertilizer treatments were used, i.e., control (30 m³ organic fertilizer + recommended rates of the mineral fertilizer) and 45 m³ organic fertilizer + half of the recommended rates of the mineral fertilizer, and 60 m³ organic fertilizer. Results obtained showed the superiority of Dokki hybrid, followed by Ain Shams-2 for vegetative growth and yield characters, except for average fruit weight. However, CL-150 was the least. Increasing organic fertilizer rates improved vegetative growth characters, flowers and fruits numbers as well as fruit acidity and ascorbic acid contents; however, average fruit weight decreased.

INTRODUCTION

Increasing yield production is a major aim of researchers. However, soil fertility maintenance is of importance with respect to physical, chemical, and biological properties. Moreover, reducing environmental pollution through clean agriculture, i.e., organic fertilizers usage is an objective. However, sandy soils have insufficient organic matter contents as well as low macro and micronutrients.

Organic manure increase vegetative growth characters of tomato plants, i.e., plant height, leaves and branches number, and leaf area and dry matter contents as well as early and total yield and its components (Verlodt and Kamoun, 1982; Hilman and Suwandi, 1989; Fattahallah, 1992a;b).

Increased tomato yield produced by organic + mineral compounds is greater than those produced by mineral and fertilizers applied at the similar rates (Rankovet et al., 1979); sugar levels and ascorbic acid contents in tomato fruits are highest with adding organic fertilizer. Moreover, organic fertilizer gave high number of small fruits (Hasegawa, 1989; Fattahallah, 1992b).

Adding organic manure to pepper plants at 25 or 50 m³/feddan as farm yield manure with chemical fertilizers at 60 or 120 kg N/Feddan, generally, gave superior plant height, number of leaves, branches, dry weight of different plant organs, leaves area and pigments,

vitamin C, titratable acidity, and TSS of fruits.

However, this effect was varied and depended on different growth stages and variation of pepper genotypes (Midan, 1995).

Thus, this work aimed at determining the optimum organic fertilizer level for tomato plants in sandy soil, and to assess the response of some newly produced tomato hybrids to such conditions.

MATERIALS AND METHODS

Two successive field experiments were carried out at the Experimental Farm of the Bossialy region, Behera Governorate. Tomato seedlings (*lycopersicon esculentum*, Mill) were transplanted on 15 February in 1998 and 1999 seasons. Ain Shams-2, Dokki-2, and CL-150 tomato hybrids were used in the study. Three fertilizer treatments were applied. Thus, the experiment included nine treatments representing the interaction of the three hybrids with three fertilizer treatments. The split-plot design, with four replicates was used, with the hybrids being in the main plots and the fertilizer treatments in the sub-plots. Fertilizer treatments were as follows:

Control, 30 m³ organic fertilizer, i.e., cattle manure + recommended rates of the mineral fertilizer of the experimental region, (400 kg ammonium nitrate, 200 kg superphosphate, and 150 kg potassium sulphates/feddan).

45 m³ organic fertilizer, i.e., cattle manure + half of the recommended rates of the mineral fertilizer.

60 m³ organic fertilizer, i.e., cattle manure Chemical analysis of used organic manure was as follows: 1.65 N, 0.51 P and 0.96 K percentage, 3895, 373 and 79 PPM of Fe, Mn, and Zn, respectively.

Tomato plants were transplanted 50 cm apart in rows of 1.5 m width. Drip irrigation system was used at 6000 drippers/feddan.

A vegetative sample was randomly taken 45 days after transplanting for plant height, leaf and branch numbers, leaf area and dry matter determinations. At harvest, yield parameters, fruit yield per plant; average fruit weight for both early and total yields were recorded. Fruit vitamin C content (mg/100 g juice), total acidity, and total soluble solids (TSS) were determined in the fruit juice, using phenolphthalein as an indicator and the 2.6 - dichlorophenol indolphenol, the titration method against 0.1 N NaOH, and an Abbe refractometer, respectively (A.O.A.C., 1975).

Data were subjected to statistical analysis, and treatments means were compared using the least significant

difference (L.S.D) method at 5% level according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Data presented in Table 1 indicated that increasing organic matter rates up to 45 m³/feddan significantly improved vegetative growth and dry matter content of tomato, in both seasons. However, the higher organic fertilizer rate, i.e., 60 m³/feddan did not show a positive influence on growth characters, i.e., plant height, leaf and branch numbers, leaf area, and leaf and stem dry matter content.

Dokki-2 hybrid was superior to other ones with respect to all growth characters, while Ain Shams-2 hybrid was the lowest in both seasons. Data also indicated that the best combination treatment was Dokki-2 hybrid with 45 m³ organic fertilizer + half of the recommended mineral fertilizer/feddan for all growth characters in both seasons. However, vegetative growth of tomato was least with Ain Shams-2 treatment receiving 30 m³ organic fertilizers + the recommended rates of mineral fertilizers/feddan. Such stimulatory effect of organic fertilizers on tomato growth was also shown by Verlodt and Kamoun (1982), Hilman and Suwandi (1989), and Fattahallah (1992a,b).

Fruit yield, i.e. fruits numbers per plant was significantly increased due to organic fertilizer application up to 45 m³/feddan (Table, 2).

However, average fruit number was decreased, the results confirmed in both seasons. Generally speaking, both early and total yield were higher with higher fertilizer addition in both seasons.

Vitamin C and of total soluble solids contents were increased due to organic fertilizer application up to 45 m³/feddan whereas fruit acidity was decreased.

Data also revealed that the highest fruit number was obtained with CL-150 hybrid receiving 60-m³ organic fertilizer/feddan. However, total fruit yield with best fruit quality characters was achieved with Dokki-2 hybrid treatments. Results obtained were in agreement with Rankov et al., (1979), Hasegawa (1989), and Fattahallah (1992b) with tomato, and Midan (1995) with pepper plants.

REFERENCES

- A.O.A.C., 1975. Official methods of analysis 12th Ed. Association of Official Analytical Chemists, Washington, D.C.
- Fattahallah, M.A. 1992a. Response of tomato to various irrigation regimes in relation to farmyard manure fertilization. Plant growth and some chemical constituents. Menofiya J. Agric. Res. 17: 1263-1283

Table 1. Organic and inorganic fertilizer vs. vegetative characters and dry matter of different tomato hybrids.

Treatments Hybrid	Fertilizer ¹	Plant Height	Leaves	Branches	Leaf Area	Dry Matter	
						Leaves	Stems
First Season							
		-cm-	No./plant	No./plant	cm ² /plant	--g/plant--	
Ain Shams-2	1	37	30	5.0	735	15.2	12.1
	2	45	39	6.7	893	19.5	14.0
	3	43	37	6.3	854	19.3	13.9
Dokki-2	1	41	33	6.2	885	16.8	12.8
	2	49	46	7.5	923	20.3	14.4
	3	46	40	7.0	897	19.8	14.3
CL-150	1	38	32	5.8	786	15.7	12.3
	2	46	39	6.8	870	19.6	14.3
	3	46	38	6.3	853	19.4	14.2
L.S.D. 5%		3.12	2.72	0.93	47	1.6	1.2
Second Season							
Ain Shams-2	1	33	26	4.8	637	14.1	10.8
	2	43	35	6.5	765	18.2	13.1
	3	41	33	6.2	733	17.8	12.9
Dokki-2	1	39	30	5.3	720	15.4	12.6
	2	47	45	6.5	812	19.8	13.9
	3	45	40	6.3	796	18.9	13.4
CL-150	1	38	30	5.6	710	14.6	11.2
	2	45	36	6.8	793	17.3	12.8
	3	44	36	6.3	763	17.0	12.5
L.S.D. 5%		3.32	2.86	0.84	39	1.1	1.1

¹Fertilizer treatments: 1). control (30 m³) cattle manure/feddan + recommended rate of mineral fertilizers. 2). 45 m³ cattle manure/feddan + half of the recommended rate of mineral fertilizer 3). 60m³ cattle manure/feddan only.

Table 2. Organic and inorganic fertilizers vs. yield and its components, and fruit chemical composition of tomato hybrids.

Hybrid	Fertilizer ¹	Fruits /plant	Fruit Weight	Early Yield	Total Soluble Solids
		No.	First Season -g-	-kg/plant-	%
Ain Shams-2	1	34.6	127	0.47	5.53
	2	40.5	120	0.54	5.97
	3	43.1	108	0.53	6.21
Dokki-2	1	38.0	135	0.56	5.82
	2	43.2	129	0.67	6.21
	3	47.0	112	0.63	6.31
CL-150	1	39.4	108	0.42	5.71
	2	46.2	101	0.50	5.99
	3	50.6	83	0.49	6.03
L.S.D. 5%		2.01	4.31	0.06	0.311

			Second Season		
Ain Shams-2	1	32.1	132	0.43	5.73
	2	39.7	125	0.51	6.12
	3	40.6	110	0.52	6.00
Dokki-2	1	36.1	137	0.59	6.00
	2	43.2	127	0.62	6.32
	3	46.9	114	0.63	6.35
CL-150	1	39.0	112	0.41	5.61
	2	45.5	100	0.47	6.02
	3	48.3	85	0.48	6.10
L.S.D. 5%		2.36	5.17	0.07	0.29

¹Fertilizer treatments: 1). control (30 m³) cattle manure/feddan + recommended rate of mineral fertilizers. 2). 45 m³ cattle manure/feddan + half of the recommended rate of mineral fertilizer 3). 60m³ cattle manure/feddan only.

Fattahallah, M.A. 1992b. Response of tomato to various irrigation regimes in relation to farmyard manure fertilization. 2. Yield and fruit quality. *Menofiya J. Agric. Res.*, 17: 1327-1351.

Gomez, K.A., and A.A. Gomez. 1984. Statistical procedures for agriculture research. 2nd Ed., Wiley Inter. Sci. Publ. pp 357-423.

Hasegawa, K. 1989. The use of fossil-shell fertilizer and its efficiency. 6. A comparison of fertilizer efficiency and the effect on quality in field tomatoes. *Agric. Hort.*, 64: 68-72.

Hilman, Y., and Suwandi. 1989. Effect of different kinds and rates of FYM on the tomato cultivar Gondol. *Bulletin Penelitian Horticultura*, 18: 33-43.

Midan, S.A. 1995. Response of some promising pepper genotypes to different cultural treatments. *M. Sc. Thesis*. Fac. Agric. Menofiya Univ. Egypt.

Rankov, V., G.A. Dimitrov, N. Kostadinov, and D. Atanasova. 1979. Effect of organic-mineral fertilizers on the vegetative and reproductive characteristics of tomatoes in pot experiments. *Gradinarska i Lozarska Nauka* 16: 87-92.

Verlodt, H., and S. Kamoun. 1982. The influences of bag size and the addition of rotted FYM on a tomato crop in growing bags on a substrate of marine grass, *Posidnia oceanica*. *Acta Hort.* 126(1): 263-272.

Wheat Genotype Adaptation to Nitrogen Deficiency under "New Lands" in Egypt

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ABSTRACT

Nutrient deficiency limits crop yields in almost all newly reclaimed areas in Egypt. Twelve wheat genotypes; two landraces, seven bread wheat, and three durum wheat genotypes, were evaluated in El-Bustan desert at two nitrogen (N) levels, 70 and 240 kg ha⁻¹. Grain yield response index (GYRI) was calculated to classify wheat genotypes into four groups; (i) ER, efficient and responsive, (ii) ENR efficient and non-responsive, (iii) NER, non-efficient and responsive, and (iv) NENR, non-efficient and non-responsive.

The results indicated that N fertilizer significantly increased grain yield and biomass yields from a mean of 1.7 to 2.8 and 6.0 to 8.9 t ha⁻¹ under low and high N levels, respectively. There was also a progressive increase in number of tillers bearing spikes, number of kernels per spike, and 1000-kernel weight with increasing N supply. Increasing harvest index and plant height was also detected.

There were substantial differences between entries in their response to increasing N fertilizer rate. The GYRI separated the genotypes into four groups: ER (LR 9, Sakha 69, Gemmeiza 5, and Gemmeiza 7), ENR (LR 20, Sakha 93, and Gemmeiza 9), NER (Bani Suif 2, and Bani Suif 3) and NENR (Giza 164, Giza 168, and Sohag 2). From a plant breeder's point of view, genotypes falling in the ER group are most desirable because they produce high yield at both low and high N levels. Genotypes under group ENR are also desirable because they produce higher yields at low N levels.

This study indicates that there are considerable differences between wheat genotypes in their ability to take up nutrients from deficient soils. Breeding for N-efficiency could consist of the selection and breeding of genotypes adapted to low nutrient availability in the soils, and with a high efficiency in the utilization of N fertilizer applied.

INTRODUCTION

Most crop species do not grow well on soils of low fertility status. Applying more fertilizers could modify soil fertility, but costs of applying fertilizers counteract the increase in crop production. Nitrogen (N) is required in relatively large quantities for crop production, as compared to other essential nutrients. However, N-use efficiency by crop plants is low (50% of that applied to the field). Consequently, excess N not absorbed by plants may be leached out and cause environmental pollution

(Fageria and Baligar, 1993). On the other hand, low soil fertility cannot be completely offset by adaptation of crop cultivars (Mortvedt, 1976).

Although inorganic and organic forms of soil modification abound, and cultivars differ in their ability to utilized soil and fertilizer N (Messmer *et al.*, 1984; Sinclair and Horhe, 1989). Therefore, incorporation of superior extracting capabilities into selected cultivars that will grow well with better N-use efficiency may be very profitable and sustainable. However, using appropriate screening methodology, selection of well-defined sites, and evaluation of the yield expected over a range of environments are important for getting meaningful results (Hamblin *et al.*, 1980).

Despite significant growth in Egyptian wheat production, the country is currently importing about 50% of its wheat (Abd El-Ghani *et al.*, 1994). Moreover, the absolute increases in population and the growth of per capita incomes will add substantially to food demands. To increase domestic food supply, Egypt is reclaiming new lands and developing systems besides the old lands in the main Nile Valley, taking in to account the limited resources. Therefore, current emphasis should be on optimizing yield relative to available resources, especially with the broadening environmental regulations.

Low water availability, imbalanced soil fertility, terminal heat stress, and salinity characterize these newly reclaimed lands, so that increasing productivity per unit of both water and land could be a vital objective. This will require better soil moisture retention, sufficient nutrients, and good varietal adapted characteristics. There is genetic potential available to increase yield, but the emphasis should be oriented towards improving germplasm which is efficient in using water and fertilizers, as well as environmental conditions. The objective of this investigation is to evaluate some wheat genotypes under N-deficient soils, with emphasis on their variability in N response.

MATERIALS AND METHODS

Two field experiments were conducted in 1997-'98 and 1998-'99 to study the influence of N fertilization on grain yield of some wheat genotypes under stress nutrient conditions at El-Bustan area on newly reclaimed soils. Twelve wheat genotypes selected from local wheat varieties were included (Table 1). This site is sandy with pH 7.4, low available N (NO₃-N on 0.7-1.0 ppm) as well as the organic matter (0.7 %), and phosphorus at 24-39 ppm.

Table 1. List of wheat genotype studies.

Entry No.	Name and Pedigree	Entry No.	Name and Pedigree
1	LR 9 (bread wheat landrace)	7	Gemmeiza 5 (GM. 5)
2	LR 20 (bread wheat landrace)	8	Gemmeiza 7 (GM. 7)
3	Sakha 69 (S. 68)	9	Gemmeiza 9 (GM. 9)
4	Sakha 93 (S. 93)	10	Beni Suif 2 (BNS. 2) (durum wheat)
5	Giza 164 (G. 164)	11	Beni Suif 3 (BNS. 3) (durum wheat)
6	Giza 168 (G. 168)	12	Sohag 2 (SHG. 2) (durum wheat)

Two N levels, 70 and 240 kg N ha⁻¹, were used to create low and high soil fertility environment, respectively. The planting date was during the last week of November, and the harvest day was in the first week of May in both seasons. The experimental plot consisted of 6 rows, each 3.5-m long, and 20-cm apart. The seeding rate was calculated to plant about 350 seeds m⁻² according of each genotype kernel weight. All recommended agricultural practices except the studied inputs were applied. The experimental design was a randomized complete block with three replications.

The number of tillers bearing spikes was counted approximately two weeks prior to harvest. At ripening, 2 m from each of the two center rows was harvested to determine biomass and grain yield. Number of kernels per spike was counted in five random spikes, and kernel weight was determined from 1000 random kernels. Grain Yield Response Index (GYRI) was calculated according to Fageria and Barbosa Filho, (1981) as follows:

$$GYRI = \frac{Yield\ under\ high\ N - yield\ under\ low\ N}{High\ N - low\ N}$$

Using this index, four groups may be considered: Non-efficient and non-responsive (NENR), Non-efficient and responsive (NER), Efficient and responsive (ER), and Efficient and non-responsive (ENR).

RESULTS AND DISCUSSION

Nitrogen deficiency limits increasing crop yield in almost all newly reclaimed soils in Egypt. Significant differences ($P < 0.01$) were detected among the genotypes studied. The differences were evident also in both high and low N levels. Nitrogen fertilizer has played a leading role in increasing wheat productivity in Egypt over the past two decades (Hemissa et al., 1984; E. Sadek, 1990; Abd El-Ghani et al., 1994). Our results indicated that N fertilizer significantly increased yields from a mean of 1.7 to 2.8 t ha⁻¹ under 70 and 240 kg N ha⁻¹, respectively. There was also a progressive increase in number of tiller-bearing spikes, number of kernels per spike, and 1000-kernel weight with increasing N supply. Achieving higher biomass and harvest index (HI) was also consistent under high N levels (Feil, 1992).

Nutrient-efficient cultivars are defined in terms of the ratio of economic yield per unit of supply (Fageria, 1992). Therefore, screening methodology for mineral efficiency should differentiate between efficiency and responsiveness (Blum, 1988). In general, efficiency is defined as the ability to grow well at a low concentrations of the available nutrient. On the other hand, responsiveness is defined as the ability to respond to an increasing concentration of the available nutrient.

Our results indicated that there were significant differences between entries in their response to increasing N fertilizer rate. Grain yield response index (GYRI) separated the genotypes into four groups: (1) ER ("LR 9", "S. 69", "GM 5", and "GM 7"), (2) ENR ("LR 20", "S. 93", and "GM 9"), (3) NER ("BNS 2" and "BNS 3"), and (4) NENR ("G. 164", "G. 168", and "SOH. 2") over the two growing seasons.

Consequently, the genotypes falling in the ER group are the most desirable from the plant breeder's point of view because they produce relatively higher yield at both the low and the high N levels. The entries under group ENR are also desirable because of their high yields under the low N level. The most interesting findings were that the entries under the groups ER and ENR possessed significantly higher harvest index under both high and low N levels, except Gemmeiza 9. Several investigations found that the main determinate of grain yield increase has been higher harvest index achieved (Loss and Siddique, 1994; Slafer et al., 1994).

On the other hand, the durum wheat genotypes were very sensitive to reducing N levels. They were less efficient than the most bread wheat genotypes in utilizing lower N applications under low fertile soil. However, the studied durum wheat genotypes were higher than or similar to the bread wheat genotypes in grain yield under higher N level. The results showed also that the landrace entries LR 9 and LR 20 exhibited less reduction in yield under reduced N level indicating that the value of focusing on landraces as an efficient gene pool to incorporate adaptation to harsh environments (Fedak, 1985; Srivastava et al., 1988).

In this study, there were considerable differences between the wheat genotypes in their ability to take up nutrients from deficient soils. Possibly the most striking and widespread interaction in agricultural production is the ability of high-yielding varieties to respond markedly to fertilizers, which is the main characteristic of the modern varieties and the basic reason for the r

high productivity (Black, 1966). Breeding for N-efficiency could consist of the selection and breeding of genotypes adapted to low nutrient availability in the soils, and with a high efficiency in the utilization of N fertilizer applied (Cox et al., 1985; 1986). On lands affected by nutrient deficiencies, three important components of technology for improving yield should be considered; *improved genotype, improved management of both land and crop, and good use of fertilizer.*

This study indicates that exploitation of genetic variability on nutrient response in wheat crop could be an important step in optimizing its productivity under lands with inherent nutrient deficiency. Future breeding and selection should be of an inter-disciplinary nature to use the appropriate screening methodology, which leads to identify genotypes with the desired adaptability, which leads to identify genotypes with the desired adaptability to marginal lands. On lands affected by nutrient deficiencies, higher yields could be obtained through better management practices and by using more efficient cultivars with better utilization of inputs.

REFERENCES

- Abd El-Ghani, A. M., A.A. Gomaa, A.M. Abd El-Shafi, Enayat H. Ghanem, O.S. Khalil, R.A. Abo-Eleneien, and A.M. Eissa. 1994. Differential development of wheat production. *Assiut J. Agric. Sci.* 25(2): 39-58.
- Black, C.A. 1966. Crop yields in relation to water supply and soil fertility. p. 177-206. *In: Plant environment and efficient water use* W.H. Pierre, D. Kirkham, J. Pesek, and R. Shaw (Ed.). Am. Soc. Agron., Madison, WI.
- Blum, A. 1988. Plant breeding for stress environment. CRC Press, Boca Raton, Florida.
- Cox, M. C., C.O. Qualset, and D.W. Rains. 1985. Genetic variation for nitrogen assimilation and translocation in wheat. I. Dry matter and nitrogen accumulation. *Crop Sci.* 25: 430-435.
- Cox, M.C., C.O. Qualset, and D W Rains. 1986. Genetic variation for nitrogen assimilation and translocation in wheat. III. Nitrogen translocation in relation to grain yield and protein. *Crop Sci.* 16: 737-740.
- Fageria, S., and M.P. Barbosa-Filho. 1981. Screening rice cultivars for higher efficiency of phosphorus absorption. *Pesq. Agropec. Bras. Brasilia.* 16: 777-782.
- Fageria, S., and V.C. Baligar. 1993. Screening crop genotypes for mineral stress. Proc. "Workshop on Adaptation of Plants to Soil Stresses". Aug. 1-4. Univ. Nebraska, Lincoln. Intsormil Publ. No. 94-2.
- Fedak, G. 1985. Alien species as sources of physiological traits for wheat improvement. *Euphytica.* 34: 673-680.
- Feil, B. 1992. Breeding progress in small grain cereals: comparison of old and modern cultivars. *Plant Breeding* 108: 1-11.
- Hamkblin, J., H.M. Fisher, and H.E. Ridings. 1980. The choice of locality for plant breeding when selecting for high yield and general adaptation. *Euphytica.* 29: 161-168.
- Hamissa, M.R., A.S. Gomaa, R.A. Abo-Elenein, A.M. Abdel-Shafi, A. Hammam, E. El-Aggouri, H. Ghanem; K.F. Hagazi, M.S. Salah, and R.A. Mitkees. 1984. Response of the new varieties. Conf. ARC, Giza, 9-11 April.
- Loss, S.P., and K.H.M. Siddique. 1994. Morphological and physiological traits associated with wheat yield increases in Mediterranean environments. *Adv. Agron.* 52: 229-276.
- Messmer, M.J., R.J. Lampert, and R.H. Hageman. 1984. Classification of certain N traits as criteria for the identification of productive maize genotypes. *Crop Sci.* 24: 605-610.
- Mortvedt, J.J. 1976. Soil chemical constraints in tailoring plants to the problem soils. 2. Alkaline soils. Proc. "Workshop on Plant Adaptation to Mineral Stress in Problem Soils". Beltsville, Maryland. Nov. 22-23.
- Sinclair, T.R., and H. Horie. 1989. Leaf nitrogen, photosynthesis, and crop production use efficiency: A review. *Crop Sci.* 29: 90-98.
- Slafer, G.A., and H.M. Rawson. 1994. Sensitivity of wheat phasic development to major environmental factors: a reexamination of some assumptions made by physiologists and modelers. *Aust. J. Plant Physiol.* 21: 393-426.
- Srivastava, J.P., A.B. Damania, and L. Pecetti. 1988. Land races, primitive forms, and wild progenitors of durum wheat - their use in dryland agriculture. *In: Proc. "Seventh Int. Wheat Genetics Symposium", Vol. I, Cambridge.*

Soil Heat Transmission at Giza Agrometeorological Station

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ABSTRACT

The temperature of soil is important for a number of reasons, mainly because it is one of the limiting factors to root growth. Knowledge of soil temperature is useful in determining the suitability of planting sites, length of growth seasons, and periods of most rapid growth. In the present paper, the maximum and minimum of daily soil temperature at different depths (2, 5, 10, and 20 cm) at El-Giza station were analyzed and discussed. These data also were correlated with the screen-air temperature at 1.5 meters above the ground. A general idea is also given of the transmission of soil heat from three fields (dry, moist, and grass). Also, thermal diffusivity of the three fields at different depths has been calculated.

INTRODUCTION

Soil temperature is influenced by the environment close to the ground surface and is one of the important factors that control the above atmosphere, microbiological activities, and processes involved in plant production. The rate of organic matter decomposition and the mineralization of organic forms of nitrogen increase with temperature; consequently, the amount of organic matter is greater in soil with lower temperatures. (Villalbando and Biswas, 1994). The temperatures required for temperate crops are typically lower than for tropical crops. The best germination occurs at soil temperatures from 21° to 35° C (Peacock and Heurich, 1984). Smith (1943) showed that a significant amount of moisture could be transferred in the soil due to a temperature gradient. Movement is from warm to cold areas. It was described as mainly a capillary movement due to changes of surface tension, although often assisted by evaporation-condensation exchange, particularly with drier soils.

Data and Station

This work was performed on data of daily maximum and minimum dry soil temperature at depths of 2, 5, 10, and 20 cm, and maximum and minimum air temperatures at the Giza station for the period 1962-'64. Also, the monthly average for maximum and minimum soil temperature at these depths for moist soil and a grass field from 1961-'65 was considered.

Giza agrometeorological station is located inside the experimental fields of the Agricultural Research Center at Giza (latitude 30° 03', and longitude 31° 12', altitude

21 m above sea-level). The station lies about 3 km to the south of Cairo and 1 km west of the Nile. The top-soil at Giza is permeable clay of more than 1.5 m depth, while the sub-soil varies from clay loam to loam. Due to the irrigation of the nearby fields, the depth of the watertable is frequently raised from its normal value of 2-3 m to 1-1.5 m.

Soil temperature was measured in three plots within the station field, each plot representing a different soil treatment, as follows: *Dry*, bare soil; *Moist*, bare soil, kept as near as possible to field capacity; and *Grass*, soil with a short vegetation cover, also kept as near as possible to field capacity.

Each plot was about 400 m² in area, the bare-soil plots (each 20 × 20 m) lying to the north of the vegetated plot (40 × 10 m), with the dry plots to the east and the moist plot to the west. The vegetated field (*Lippianodiflora*) was irrigated daily in summer and about twice weekly in winter. The bare wet field was irrigated daily in summer and every other day in winter to keep the soil at about field capacity. The *Lippia* was kept to about 5 cm high in summer, but in winter, because of reduced growth rate, it was usually only about 1-2 cm high. Also, the thermometers were oriented east-west in the measuring site (Omara, 1971).

The soil thermometers for depths 2, 5, 10, and 20 cm were the large bent-stem ones (fuse-type) with oblong bulbs of about 1-cm diameter. The scales of these thermometers faced upwards so that they could be read without disturbance to the site.

METHODOLOGY

In this study, PC package SYSTAT 1990 was used to obtain the simple line regression equation of y (daily maximum or minimum dry soil temperatures at different depths) on x (daily maximum or minimum air temperature) as the following equation

$$y = a + bx \dots\dots\dots (1)$$

Also, a multiple regression equation y on x_1 (daily maximum air temperature), x_2 (daily minimum air temperature) as the following equation:

$$y = a_1 + b_1 x_1 + c x_2 \dots\dots\dots (2)$$

Where: a , b , are coefficients of liner regression and a_1 , b_1 , and c , are coefficients of multiple regression.

Thermal Diffusivity

The processes of heat conduction through a layer of soil have been outlined in Gloyne and Aomes, (1981).

Soil is not a true solid but consists of individual particles and aggregates together with air and water. The conductivity of a soil block is not constant but depends upon: Conductivity of the particles of soil material, Size of the particles of soil material, Compacting of the mixture, and Soil moisture.

In agriculture, it is temperature changes rather than heat flow which are so important for the below-ground parts of plants, and this determined by

$$a = k / \rho c \dots\dots\dots (1)$$

Where: *a* is thermometric conductivity, *k* is heat conductivity, and *ρ c* is volumetric heat capacity.

The relationship between the three variables (temperature, time, and depth) have given rise to three methods of diagrammatic representation as given in Gloyne and Oames, (1981), in the third vertical axis is for depth, horizontal for time, at this study using two variables the temperature and depth only.

Calculating Thermal Diffusivity

Using the following approach, Suppose *A* (*Z*₁) = amplitude (i.e., half rang) at depth *z* (1), *A* (*Z*₂) = amplitude (i.e. half rang) at depth *z* (2), and *z* (2) > *z* (1), then:

$$A(Z_2) = A(Z_1) \times e^{-(z_2-z_1) \times w/2a} \dots\dots\dots (2)$$

Where: *W* is the angular velocity = 2/*p*, where *p* is the period of daytime (60×60×24 = 86400 Sec), and *a* is the thermal diffusivity, but:

$$D = (2a/w)^{1/2} \dots\dots\dots (3)$$

Where: *D* is the damping of the depth by amplitude. From (3) and (2), then

$$A(Z_2) / A(Z_1) = e^{-(z_2-z_1) / D} \dots\dots\dots (4)$$

Where: *A* (*Z*₂), *A* (*Z*₁), *Z*₂, and *Z*₁ are the measurement data. Then we can calculate the *D* value from Equation 4 and *a* from Equation 3 (Peacock and Heunrich, 1984).

RESULTS AND DISCUSSION

Figure 1 illustrates the average monthly daily values of air temperature and soil temperature at different depths. From this, we notice that little or no deviation between the soil temperatures under the ground during cold seasons, while in a warm seasons, a large deviation exists. The trend of these temperature shows that the values of temperature decreased from 2 to 20 cm. The figure also illustrates that all values of soil temperature at different depths are usually higher than the air temperature at 1.5 m aboveground. In addition, the air temperature and the other temperatures have the same trend during the year.

Average monthly duration of maximum air temperature at maximum dry soil temperature of depths 2, 5, 10, and 20 cm at 5, 9, 13, and 17 respectively, have been plotted (Fig 2). It can be seen that maximum dry soil temperature at depth 20 cm, "TXS20", is below the maximum air temperature, "TXA", at all months except the summer season. Also, the maximum dry soil temperature at depth 10 cm "TXS10" is below the maximum air temperature "TXA" at winter season only where the other months above this value. It may be due to the shortening of day length effectively by the later rising and earlier setting of the sun and also due to other parameters related to heat transformation such as wind speed and cloudiness. The correlation coefficient between maximum air temperature and maximum dry soil temperature at different depths was about 0.55 for all data.

The correlation coefficient between maximum temperature at depth 2 cm, "TX2", and maximum air temperature is minimum, and is 0.31 August, it is due to phenomenon of fog in the morning to each day at this month from Omran (1979).

Average monthly duration of minimum air temperature "TNA" and minimum dry soil temperature of depths 2, 5, 10, and 20 cm, "TNS2, TNS5, TNS10, TNS20", has been plotted in Fig. 3. Minimum dry soil temperature at depth 2, 5, 10, 20 cm and minimum temperature had good agreement.

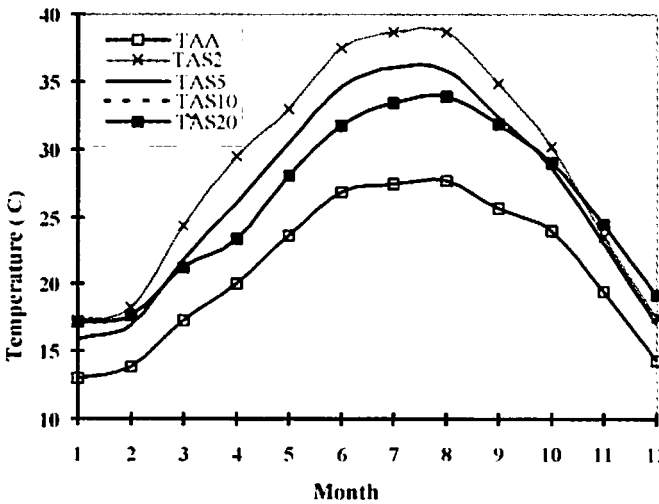


Fig. 1. Average mean air temperature (TAA) and average mean dry soil temperature at depths of 2, 5, 10, 20 cm (TAS2 - 20) for Giza station, 1962-'64.

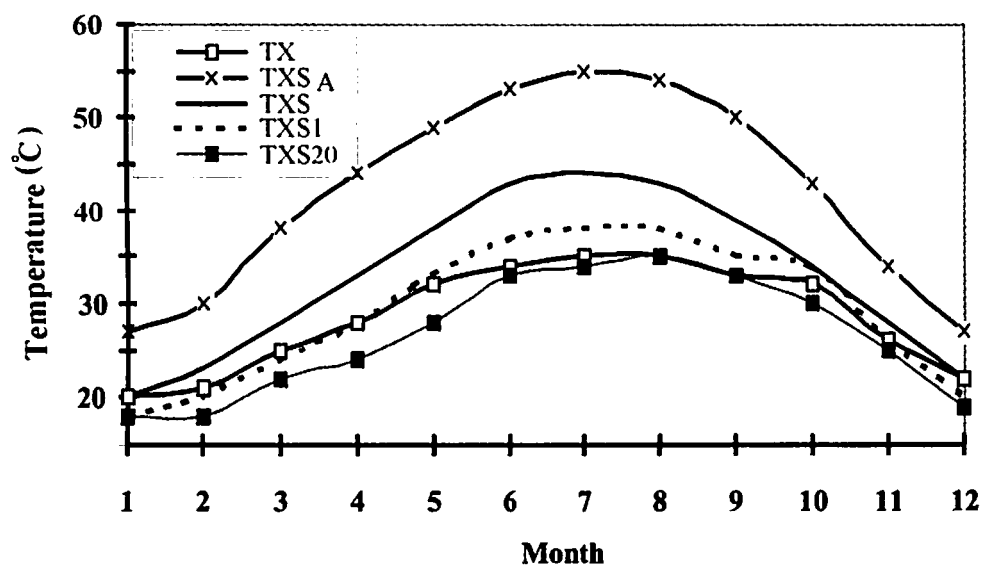


Fig. 2. Average maximum air temperature (TXA) and maximum dry soil temperature at depths of 2, 5, 10, 20 cm (TXS2 - 20) for Giza station, 1962-'64.

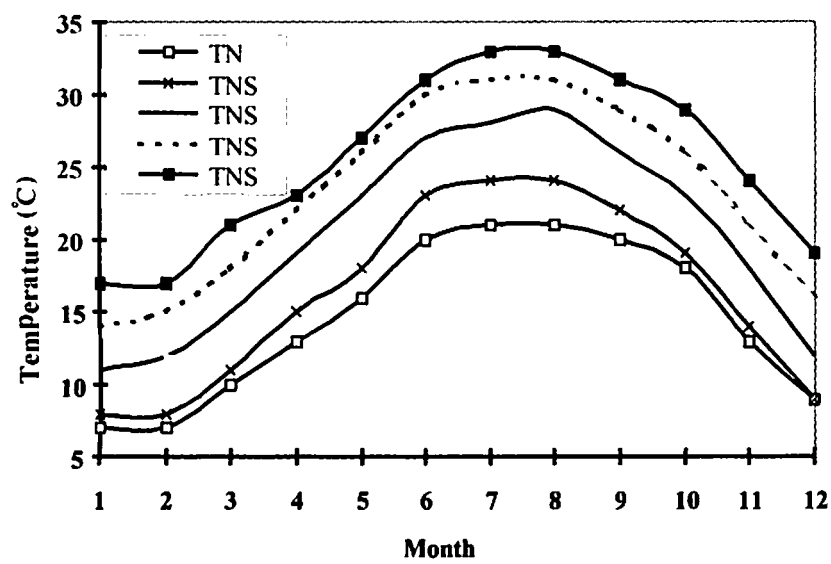


Fig. 3. Average minimum air temperature (TNA) and average minimum dry soil temperature (TNS) at depths of 2, 5, 10, 20 cm (INS1 - 5) for Giza station, 1962-'64.

The correlation coefficient between average minimum air temperature and minimum dry soil temperature at 5 cm depth had a maximum value of 0.86. Also, a minimum value at 20 cm depth was 0.59.

The three plots show widest temperature difference from each other in their mean annual amplitude for different depths; the amplitude of 2 cm depth of dry soil plot was three times greater than the grass soil plot.

Values for diffusivity (D) and albedo (a) during the period (1961-'65) for a sand dry, moist and grass field in Giza were tabulated (Table 1). There were differences in D values and in a for each field because of the difference in properties for each field. On other hand, the albedo, the amount of absorbed of solar radiation, and the thermal diffusivity were different from one surface to another.

Table 1. Thermal diffusivity for three field conditions at Giza station (1961-1965).

Depth (cm)	Dry		Moist		Grass	
	Distance --cm--	Rate -cm ² s ⁻¹ -	Distance --cm--	Rate -cm ² s ⁻¹ -	Distance --cm--	Rate -cm ² s ⁻¹ -
2 - 5	4.2	0.00065	9.6	0.0033	6.8	0.0017
5 - 10	6.4	.0015	11.6	0.0048	8.3	0.0025
10 - 20	6.7	0.0016	10.9	0.0043	8.5	0.0026

CONCLUSIONS

The average monthly daily data for each of air temperature at 1.5 m and at different depths (2, 5, 10, and 20 cm) had the same trend for all seasons. The correlation between air temperature and the temperature at depths 5 cm was the best. The correlation between minimum air temperature and the minimum temperatures at different depths was better than the corresponding data for maximum. The thermal diffusivity for moist soil plot were three times greater than for the dry soil plot, due to the different the surfaces and the amount of absorbed solar radiation. The data in the paper are of value when estimating the temperature of the soil at different depths using the corresponding ambient air temperature.

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REFERENCES

- Gloyne, R.W., and J. Aomes. 1980. *Lecture Notes for Training Class 11 and Class 111. Agricultural Meteorological Personnel*, WMO. No. 551.
- Peacock, J.M., and G.M. Heunrich. 1984. Light and temperature responses in sorghum, in agrometeorology of sorghum and millet in the semiarid tropics. p. 143-158. *Proc. "International Symposium"*. ICRISAT, Patancheru, India.
- Omara, A.A.. 1971. Diurnal and annual temperature patterns in a soil at Giza subjected to three treatments. *Meteorological Research Bulletin*, 3(2), Cairo, Egypt.
- Omran, M.A.H. 1979. A diagnostic study of abnormal stability conditions over the Middle East. *M.Sc.*, Cairo Univ., Egypt.
- SYSTAT, 1990. The system for statistical, computer language. SYSTAT, Inc. 1800, Evanston, IL, U.S.A.
- Smith, W.O. 1943. Thermal transfer of moisture in soils. *Trans. Amer. Geophysical Union*.
- Villalbando, J.F., and B.C. Bisuias. 1994. Practical use of agrometeorology data and information for planning and operational activities in agriculture. World Meteorological Organization, Agricultural Met. CAgm Report No. 60 WMo/TD. Geneva, Switzerland.

Renewable Energy

Estimating Diffuse Solar Radiation in the Arab World: Eastern Region

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ABSTRACT

The number of stations that measure diffuse radiation is very low in the Eastern Region of the Arab World. In a project for making an atlas for solar energy sponsored by the Arab League Educational, Cultural, and Scientific Organization, 25 stations for measurements of diffuse radiation have been used. The data obtained from these stations were interpolated to cover our area of the study. The induced empirical formulae were used to estimate diffuse radiation as a function of global solar radiation. We found that these formulae are available for regular observation for a long time at sufficient number of stations located in different climatic regions.

INTRODUCTION

The intensity of diffuse radiation in the atmosphere depends to a great extent on a large number of *astrophysical*, *physical*, and *geographic* factors. Among these may be included the value of solar constant, the sun declination and the hour angle of the sun, the latitude of the location and altitude above sea level, the amount of scattering and absorbing substances in the atmosphere, cloudiness and the albedo of the underlying surface.

In a project for making an atlas for the Arab Region (Eastern Region) for solar radiation, sponsored by the Arab League Educational, Cultural and Scientific Organization (ALECSO), 25 stations were used for measurements, these are not enough for making such maps since with global radiation measurements are made at 125 stations, which are sufficient for drawing the field of the global radiation.

The empirical relations between diffuse radiation and global radiation has been investigated in many places in many ways. The linear relationship predominated, on the reasonable assumption that variation of diffuse radiation between overcast is linear in global radiation, but the relationship is reverse in clear sky. On an empirical formula depend on global radiation and the theoretical global solar radiation outside the earth's atmosphere by use of different functional relations such as second- and third- order equations in their various forms at different climate regions.

METHODOLOGY

Due to the shortage of diffuse radiation data, the following general empirical formula has been used to calculate the diffuse from global radiation, as in the form:

$$D/G = A + BK + CK^2 + EK^3.....(1)$$

Where:

$$K = G/G_o;$$

D is the estimated of monthly mean of daily value of diffuse solar radiation on a horizontal surface, kwh/m²/day;

G and G_o are the monthly means of the daily global radiation on a horizontal surface for a given site, respectively, at the ground and outside the atmosphere (extraterrestrial irradiation), in kwh/m²/day; A, B, C, E are constants empirically determined from different values of K by using multiple correlation and the LSM for obtaining the best-fitting curve;

For the Sudanese stations north of latitude 10°, the diffuse solar radiation was calculated from the above formula after using Aswan measurements data from 1981 to 1996 to determine the statistical parameters (A, B, C, E) of this empirical formula.

$$D = G (-4.3366K - 32.5925K^2 + 15.8257K^3).....(2)$$

For those Sudanese stations south of latitude 10°, and for Addis Ababa station, diffuse radiation was estimated by the empirical formula calculated from measurement data of Bahrain.

$$D = G (.999 - 1.28 K).....(3)$$

For the Kingdom of Saudi Arabia, based on the city of Riyadh measurements, the empirical formula used to calculate diffuse solar radiation is as in the form:

$$D = G (-16.3814 + 87.78127K - 147.446K^2 + 79.9576K^3).....(4)$$

The empirical formula for Iraq and State of Palestine was based on actual measurements in the Jordanian city of Irbid. It took the form:

$$D = G (1.0278 - 1.9039K + 2.362K^2 - 2.362K^3).....(5)$$

For the state of Qatar, Bahrain, Sultanate of Oman, and the United Arab Emirates, the empirical formula for estimating the diffuse solar radiation, on the basis of Abu Dhabi measurements, had the following form:

$$D = G (-1.897 + 14.536K - 26.828K^2 + 14.97K^3)....(6)$$

The above relations between diffuse and global solar radiation are utilized principally to obtain estimates of diffuse radiation either for the past before installation of pyranometer to measure diffuse at the

same place, or for places in the same region (geographic or climatological) where the relationship has been established.

RESULTS

The above formulae, which were derived from data observed over five stations in different regions, are suitable for estimating the diffuse radiation in the Eastern Arab Region. For testing these formulae, we use the formula which is calculated from Aswan data for estimate the diffuse radiation measured and calculated over Cairo, Kharabo (calculated from Irbid, Jordan), Amman, and over Abu Dhabi (Fig. 1). These comparisons establish that these formulae are refined for estimating this parameter.

There are another two methods for verification. The first is, Mean Bias Error (MBE), defined as:

$$MBE = \frac{\sum_{i=1}^N (D_i' - D_i)}{N} \dots\dots\dots (7)$$

Where:

D_i' and D_i denote the i^{th} estimated and measured values of diffuse radiation. (Positive and negative indicate over-estimation and under-estimation by the formula).

The second is Root Mean Square Error (RMSE), which is a measure of the variation of values around the measured, and it is given by:

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (D_i' - D_i)^2}{N}} \dots\dots\dots (8)$$

When applied the above two method over the five stations, it was found that the formulae for estimating diffuse radiation are highly suitable (Table 1).

Table 1. Formulae for calculating diffuse radiation stations.

Station	RMS ¹ Error	Mean Bias Error
Cairo	0.176	-0.13
Kharabo	0.166	-0.08
Amman	0.414	-0.21
Abu Dhabi	0.225	-0.076
El-Kaseem	0.439	-0.336

¹RMS=Root Mean Square.

CONCLUSION

The five formulae which were presented in this work permit highly accurate estimation of the monthly mean daily value of diffuse radiation on a horizontal surface at the earth's surface by kwh/m²/day. These formulae are functions of G (monthly means of the daily global radiation) and G_o (extraterrestrial radiation). Such a tool is useful in estimating the diffuse radiation at any location where global radiation (G) is available, also in completing the missing data of diffuse radiation at the stations which measure it and in checking uncertain data.

REFERENCES

Alanser, W. 1992. The calculate of diffuse and direct radiation over Bahrain *Applied Energy*, 42: 237-252.
Solar radiation ATLAS for the Arab World. 1997.

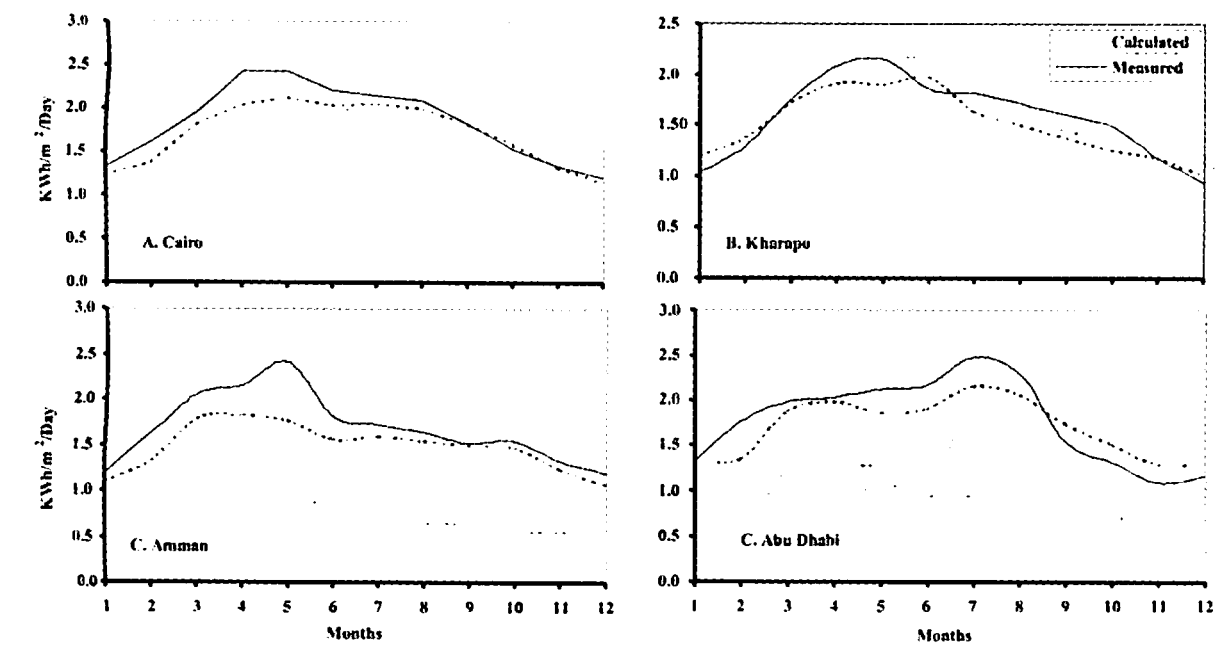


Fig. 1. Measured and calculated diffuse radiation at a four locations.

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