Human and Nature – Working Together for Sustainable Development of Drylands

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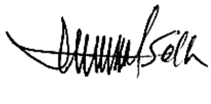
Foreword

Land degradation and desertification constitute one of the severest threats to sustainable livelihoods of the people inhabiting the arid and semi-arid areas of the world. Because of harsh climatic conditions, the natural resource base in these areas is very fragile. Yet, some of these areas have been home for the domestication and evolution of some of the most important crop and animal species that provide sustenance and nourishment to billions of people the world over. The wild relatives and landraces of these species are still found there, and they continue to evolve and adapt to the harsh climatic conditions in their natural habitat. They are, thus, a valuable resource not only for increased agricultural productivity but also to cope with the challenges of global climatic change. However, these precious resources are being eroded due to demographic pressures, urbanization, overexploitation of land and water resources, and other human activities. Sustainable management of the fragile ecosystems of the dry areas, particularly to prevent land degradation and desertification, is therefore becoming an issue of increasingly global concern. This concern has been emphasized in the recent global evaluation report on desertification developed by the Millennium Ecosystems Assessment. Declaration of 2006 as the International Year of Deserts and Desertification (IYDD) by the United Nations was also aimed at enhancing global awareness of the problems of land degradation and desertification and promoting integrated international efforts to find solutions.

The International Dryland Development Commission and the International Center for Agricultural Research in the Dry Areas (ICARDA) took the initiative, in collaboration with the Arid Land Research Center (ALRC) of Tottori University, Japan; the Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI) of the Chinese Academy of Sciences, China; National Natural Science Foundation of China (NSFC); the Desert Research Institute, Nevada, USA; and the United Nations University (UNU), Japan, to mark the start of the IYDD and contribute to its objectives by organizing the Eighth International Conference on Dryland Development, 25-28 February 2006, in Beijing, China, under the theme 'Human and Nature – Working Together for Sustainable Development of Dry Areas.' Some 200 scientists and administrators from 22 countries and five international organizations participated in the Conference. Multidisciplinary oral and poster presentations were made on Soil and Water Conservation and Degradation, Dust-storm Process, Range Management, Forage and Livestock Production, Biodiversity and Ethnobotany, Stress Physiology, Renewable Energy, Indigenous Knowledge and Heritage, Sustainable Development of Oases and Desert Communities, and New Technologies and Crop Improvement in the Dry Areas. A panel of experts held discussions on the Implementation of the United Nations Convention to Combat Desertification (UNCCD). The Conference served as an extraordinary forum for dialogue, discussions and exchange of knowledge on the diagnosis and assessment of the problems of desertification and development of solutions that could help in sustainable development. During the closing session a 'Central and West Asia and North Africa Plus Partnership' (CWANA Plus) between UNU and ICARDA was launched to develop human capacity for research on developing drylands.

This volume contains the presentations made at the Eighth International Conference on Dryland Development. It is hoped that it will serve as a repository of information on the problems and prospects of sustainable management of dry areas and preventing desertification, and will thus be of interest to those involved in research, extension, development and policy formulation for the benefit of the people of the dry areas. It is our belief it would serve as an important contribution to the objectives of the IYDD.



Mahmoud Solh
Director General
ICARDA

Note from the Editors

The decision to hold the 8th International Conference on Dryland Development (ICDD) in Beijing, China was taken during the meeting of the full assembly of the 7th ICDD, held in Tehran, Iran, 20-23 September 2003, when the Chinese Academy of Sciences (CAS) proposed to host it. Subsequently, the International Scientific Committee of the International Dryland Development Commission and the Local Scientific Committee of CAS together developed a comprehensive program for the 8th IDDC Conference to address a theme focused on how humankind can work with nature to sustainably develop the drylands. The program was posted on the web sites of ICARDA and CAS, and the call for participation received enthusiastic global response. More than 500 potential participants submitted letters of intent to participate and make oral or poster presentations. After a careful scrutiny, 175 papers were accepted for oral and 159 for poster presentation, covering the 10 sub-themes included in the program. In addition, 12 leading authorities in the field of research and development in the dry areas were invited to make plenary presentations.

This volume contains the text of most of the presentations made in the three plenary and 30 concurrent sessions of the Conference; only a few presentations are missing because the manuscripts were not received in spite of extending the submission deadline. We would like to thank Dr Xue Xian, Associate Research Professor, Key Laboratory of Desert and Desertification, CAREERI, CAS and Vice-Secretary General of the Local Organizing Committee of the 8th ICDD, for keeping track of the manuscripts and making them available to the editors. Although several manuscripts exceeded the page limit, we have tried to retain as much of the material as possible and only in a few cases some avoidable text, figures or tables had to be deleted. Substantial editing had to be done on some manuscripts that did not conform to the expected presentation level. We seek the understanding of the authors in this regard. We sincerely hope that in this process the messages intended to be given by the authors did not get altered and the readability of their contributions has improved.

We would like to thank ICARDA for helping the International Dryland Development Commission in the publication of these proceedings. Several members of the Communication, Documentation and Information Services Unit (CODIS) of ICARDA contributed to the painstaking task of designing and typesetting of this volume and seeing it through the printing process. We are greatly indebted to Dr Surendra Varma, Head of CODIS, and his entire team for these efforts.

Adel El-Beltagy
Mohan C. Saxena
Tao Wang
Editors

Welcome address by Prof. Dr Adel El-Beltagy, President, International Dryland Development Commission

Prof. Dr Li Jiayang, Academician and Vice President of Chinese Academy of Sciences
Prof. Dr Iwao Kobori, Senior Program Advisor, United Nations University
Dr Noureddin Mona, FAO Res Rep. for China, DRK and Mongolia
Dr Stephen G. Wells, President of Desert Research Institute, Nevada, USA
Prof. Dr Tao Wang, Director General of CAREERI, CAS
Prof. Dr Shinobu Inanaga, President of JIRCAS, Japan
Prof. Dr Mohan C. Saxena, Executive Secretary, IDDC
Fellow Participants
Ladies and Gentlemen:

On behalf of the International Dryland Development Commission (IDDC) and on my personal behalf it gives me great pleasure to extend a hearty welcome to you all to this 8th International Conference on Dryland Development in the ancient and beautiful city of Beijing. A particularly warm welcome is extended to Academician Prof. Dr. Li Jiayang, Vice President of the Chinese Academy of Sciences, who has agreed to our request to inaugurate the Conference.

The International Dryland Development Commission, which is a non-governmental organization established in 1987 by individuals and institutions interested in sustainable development of dryland areas, is promoting all aspects of dryland studies by fostering cooperation and networking between various international, regional and national organizations. One of the important *modus operandi* of networking has been the holding of a major scientific conference every three to four years to provide opportunity to participants from around the world to exchange research results and experiences in dryland development and combating desertification. In pursuance of this approach of networking, the IDDC has organized in the past seven international conferences. The Proceedings have been published.

The idea to establish the International Dryland Development Commission originated several years back when like minded people came together to analyze the problems being faced by the dwellers of dry areas and deserts in sustainable management of the natural resources to earn their living. We are delighted that one of the founding fathers of the IDDC, Prof. Dr Adley Bishay, is gracing this occasion by his presence. As a token of our appreciation, I have the privilege of presenting Prof. Bishay the first copy of the Proceedings of the 7th International Conference on Dryland Development that was held in Tehran, Iran in September 2003.

I am delighted that China is hosting the International Conference for the second time; the first time that the ICDD was held in these premises of the Friendship Hotel was in 1990. This is a reflection of the importance that this country attaches to the sustainable development of dry areas. As you know, the United Nations Organization has declared 2006 as the International Year of Deserts and Desertification to attract global attention to the subject. The 8th International Conference on Dryland Development is the first major activity heralding the start of the year of desert. It is very befitting that China, with a strong track record of combating desertification, is the venue for starting the activities commemorating the international year of desert. We will like to thank the Chinese Academy of Sciences for hosting this Conference.

The Conference is being cosponsored by the Arid Land Research Center (ALRC) of the Tottori University, Japan, the Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI) of the Chinese Academy of Sciences (CAS), Desert Research Institute (DRI) of the University and Community College System of Nevada, USA, International Center for Agricultural Research in the Dry Areas (ICARDA), National Natural Science Foundation of China (NSFC), and the United Nations University (UNU). The Commission will like to thank these partner institutions and organizations for co-sponsoring the Conference. We will also like to acknowledge the support provided by AAAID, CGIAR, COMSTECH, FAO and

ICARDA that enabled several participants from the developing countries to attend this Conference and contribute to scientific deliberations through oral and poster presentations.

The International Scientific Committee and the Local Scientific committees have done an outstanding job in developing a very comprehensive program of scientific presentations and discussions. The Local Organizing Committee, under the Chairmanship of Prof. Tao Wang and the overall leadership of Academician Prof. Li Jiayang, has made excellent arrangements for scientific deliberations and networking. They have made immaculate logistic arrangements for comfortable stay of the participants. The Commission is therefore grateful to them.

Finally, I will like to thank all the participants for their attendance. I wish them all a very rewarding Conference and a comfortable stay here in Beijing.

Statement by Prof. Dr. Iwao Kobori, Senior Program Advisor, United Nations University

Prof. Dr. Li Jiayang , Academician and Vice President of Chinese Academy of Sciences
Prof. Dr. Adel El-Beltagy, President, International Dryland Development Commission
Dr. Noureddin Mona, FAO Res Rep. for China, DRK and Mongolia
Dr. Stephen G. Wells, President of Desert Research Institute, Nevada, USA
Prof. Dr. Tao Wang, Director General of CAREERI, CAS
Prof. Dr. Shinobu Inanaga, President of JIRCAS, Japan
Prof. Dr. Mohan C. Saxena, Executive Secretary, IDDC
Ladies and Gentlemen:

On behalf of Prof. Dr. Hans van Ginkel, Rector, United Nations University, it gives me great pleasure to welcome you to the 8th International Dryland Development Conference. Dr. van Ginkel had to attend to some urgent meeting in New York; hence he has asked me to welcome you and to convey to you his greetings. He will be soon joining you in your deliberations. I am greatly privileged to get this opportunity to welcome you as I have been associated with the International Dryland Development Commission since 1996 as a member of its Executive Board.

The United Nations University has a challenging mission: to contribute through research and capacity-building, to find original, forward-looking solutions to the most pressing problems which concern the United Nations, its Peoples and Member States. The value of the UNU - as a University, yet within the UN System - is that it not only seeks responses at a theoretical level, but also concerns itself with the down-to-earth need for practical action. The University focuses its work within two thematic areas - Environment and Sustainable Development and Peace and Governance. Within these areas UNU undertakes research and training on a broad range of issues: from food and nutrition to information technology; from land use and climate change to the freshwater crisis; from managing international financial flows to the challenges of urbanization; and from the legitimacy of international organizations to the causes of complex humanitarian emergencies. Within the theme of Environment and Sustainable Development, the University devotes considerable attention to the drylands and participates in research and capacity building for sustainable development of dry areas through collaboration with ICARDA, the national research institutions in the countries in the dry areas, and other organizations within the United Nations system.

The UNU is very happy to be associated with the International Dryland Development Commission in organizing this International Conference, which marks the start of a series of activities to celebrate the United Nations' Year of Deserts and Desertification. UNU is going to participate with other UN agencies in various other activities scheduled including the upcoming meeting in Tunisia where the policy on desertification control would be reviewed.

I am personally very impressed with the progress China has made in the field of rehabilitating desertified lands. This Conference will provide an opportunity to all of us to become familiar with the latest developments in this regard. On behalf of Prof. van Ginkel, I will like to thank the Chinese Academy of Sciences for hosting this Conference.

Statement by Dr. Noureddin Mona, FAO Resident Representative for China, Democratic Republic of Korea and Mongolia

Once again, I extend warm welcome to all of you and wish you a very successful Conference.
Prof. Dr. Li Jiayang, Academician and Vice President of Chinese Academy of Sciences
Prof. Dr. Adel El-Beltagy, President, International Dryland Development Commission
Prof. Dr. Iwao Kobori, United Nations University
Dr. Stephen G. Wells, President of Desert Research Institute, Nevada, USA
Prof. Dr. Tao Wang, Director General of CAREERI, CAS
Prof. Dr. Shinobu Inanaga, President of JIRCAS, Japan
Prof. Dr. Mohan C. Saxena, Executive Secretary, IDDC
Distinguished Delegates
Ladies and Gentlemen:

I am greatly honored to be with you at the inaugural ceremony of the 8th International Conference on Dryland Development. On behalf of the Food and Agriculture Organization (FAO) of the United Nations, I will like to thank the Chinese Academy of Sciences and the International Dryland Development Commission for organizing this 8th International Dryland Development Conference and would like to congratulate them at the opening of this Conference in Beijing, China.

As you know, in the world more than 900 million people live in dry land areas. Dryland ecosystems have provided many of the plants and animal species that have shaped the development of many cultures and civilizations. However, poor management of natural resources in these areas over the years has resulted in severe land degradation. In turn, this has diminished the land's inherent low carrying capacity for human and animal populations. It is estimated that of the world's some 630 million poor live on marginal agricultural lands while about 325 million live on well endowed lands. Increasing populations on marginal lands result in their increasing impoverishment and pose severe threat to food security. A lot of efforts remain to be made to halt this process. I am sure this Conference provides a good opportunity for the participants to address this important issue.

China is one of those countries in the world that are witnessing most severe land degradation and desertification problems. Drylands account for nearly 30% of the total Chinese territory where the ecosystem is harsh and mostly the poor live. China is paying much attention to this problem and has undertaken three national surveys, in 1994, 1999 and 2004, to assess the magnitude of the population. The country has also passed a national law on desertification in 2001. More importantly, a series of degraded lands rehabilitation and desert control programs have been successfully implemented in the past ten years, including the famous "Great Green Wall" in northern China. With these efforts the desertification has slowed down. The latest check conducted in 2005 showed that deserted land decreased by 1,283 km^2 in a year, which is the first time that absolute decrease in desertified area has occurred since the founding of the Republic in 1949.

FAO's strategic priority is food security. According to World Food Declaration on World Food Security, poverty was the major cause of food insecurity and there was a need to increase food production within the framework of sustainable management of natural resources. FAO has been active for decades in the fight against desertification by regular monitoring and normative programs as well as field projects. With UNEP, FAO has launched the Land Degradation Assessment in Drylands (LADA) and has successfully conducted pilot studies in Argentina, China and Senegal. Supported by GEF, LADA will be implemented globally and will assess the causes, status and impact of land degradation in drylands in order to improve decision making for sustainable development in the drylands at all levels and to meet the needs of those involved in the implementation of the action programs of the UNCCD. In China, FAO introduced management techniques for improvement of salt affected soils in Heiongjiang province. Other FAO projects in China address preservation of dryland resources and its ecosystems.
I am happy to note that recently the Chinese government has confirmed its generosity to share with other developing countries its vast experience

gained in recent decades in the field of degraded land reclamation, sand dune fixation and desertification control. FAO is determined to work with all to achieve the objectives of UNCDD.

Finally, I wish the Conference a great success and wish the participants coming from abroad a pleasant stay in China.

Thank you.

Statement by Dr. Stephen G. Wells, President, Desert Research Institute, Nevada, USA

Prof. Dr. Li Jiayang, Academician and Vice President of Chinese Academy of Sciences
Prof. Dr. Adel El-Beltagy, President, International Dryland Development Commission
Prof. Dr. Iwao Kobori, United Nations University
Dr. Noureddin Mona, FAO Res. Rep. in China
Prof. Dr. Wang Tao, Director General of CAREERI, CAS
Prof. Dr Shinobu Inanaga, President of JIRCAS, Japan
Prof. Dr. Mohan C. Saxena, Executive Secretary, IDDC
Distinguished Participants

It is an honor to join my colleagues Prof El-Beltagy, Prof. Kobori, Dr Mona and Prof. Tao in welcoming all of you to the 8th International Conference on Dryland Development, and to be here with so many distinguished people involved with issues of deserts, desertification, and sustainable development. It is also my privilege to represent the Desert Research Institute of the Nevada System of Higher Education in supporting this important international conference that focuses upon the interactions of Human and Nature to forge a sustainable environment.

Of all environments on planet Earth, drylands present one of the greatest challenges for sustainability. It is a "landscape" that can tax the earth systems that service our planet because of widely variable productivity, spatially and temporally restricted resources, and rapidly growing populations. The earth systems servicing our planet are composed of complex sets of geologic, hydrologic and biologic conditions and their interactions that act collectively to sustain productive terrestrial landscapes and to support the livelihood of humanity – support the biosphere. Thus, to ensure the appropriate function of the earth system services, an integrated approach is required, combining an understanding of the problem from many aspects: from biophysical to understanding the climate, the soil, vegetation and human use systems. The multidisciplinary range of the participants at this conference is important to the success of our efforts.

In addition to an approach that integrates diverse disciplines, all of us recognize that dryland environments have and will continue to experience rapid changes in the magnitude, frequency, and the extent of landscape processes. These changes can threaten sustainability of an area through degradation and can result from increasing human interactions, normal changes in landscape dynamics related to external forces such as climate changes, and from a combination of these actions. Almost 70 years ago, the implications of such complexities and landscape changes in drylands were recognized by the President of the United States.

Desertification, or landscape degradation, results in reduced biodiversity and productivity within human systems, threatening the livelihoods of one billion people. This was so dramatically illustrated by the plight of West Africa countries like Niger who suffered devastating droughts in 2005. While the UN has designated this year to be the International Year of Deserts and Desertification, we in the scientific community should think of this year as the year to make a difference – to the people who are faced with the day-to-day struggle against desertification.

Through international collaboration with research institutions such as CAREERI and philanthropic organizations such as Hilton Foundation, the Desert Research Institute has enthusiastically embraced the call to develop the appropriate research and techniques to live sustainably within dryland environments and to assist in the mitigation of lands that are faced with the ongoing threat of desertification.

Thank you.

Statement by Prof. Dr. Tao Wang, Director General of Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences

Prof. Dr. Li Jiayang, Academician and Vice President of Chinese Academy of Sciences
Prof. Dr. Adel El-Beltagy, President, International Dryland Development Commission
Prof. Dr. Iwao Kobori, United Nations University
Dr. Noureddin Mona, FAO Res. Rep. in China
Dr. Stephen G. Wells, President of Desert Research Institute, Nevada, USA
Prof. Dr. Shinobu Inanaga, President of JIRCAS, Japan
Prof. Dr. Mohan C. Saxena, Executive Secretary, IDDC
Dear Participants

Hearty welcome to all the participants in Beijing for the 8th International Conference on Dryland Development. The long efforts that had gone in the planning of this conference have now come to fruition.

In the drylands of the world, the most serious environmental and socio-economical problem being faced by the humanity is the desertification /land degradation. Over 250 million people are directly affected by land degradation and nearly one billion in some 100 countries are at a risk. China is one of the countries that have suffered seriously from land degradation in the drylands.

This Conference brings together all of you from all around the world for sharing researches into the process of desertification in the drylands and methods for reclamation. It will engage you in a discussion on the prospects for international collaboration in this field. The program has been designed to challenge us as scientists, engineers, educators and students to frame scientific and societal problems in ways that create opportunities to apply the best science and technology for common good. Combating desertification requires organized, multidisciplinary research across many fields of natural and social sciences as well as active international cooperation.

The scientists in China have made lots of efforts on researching and combating desertification during last five decades. We hope you would be able to see how the Chinese scientists have expanded their work in this field.

My colleagues in the Academy and other Chinese institutions have made their best efforts in making your stay as comfortable as possible. However, there might have been some lapses on our part, for which I would seek your forgiveness. We sincerely hope that you will enjoy your stay in Beijing and also take time out to visit the cultural land marks of the Capital City.

I wish you a successful Conference and a most pleasant stay in Beijing.

Message from Dr. Ian Johnson, Chair, Consultative Group on International Agricultural Research (CGIAR) to the participants of the 8th International Dryland Development Conference

Colleagues:

I regret my inability to be with you, due to a previously scheduled commitment. My absence does not in any way diminish the importance that the CGIAR places on the need for the best in agricultural science to be directed at the attainment of sustainable development in the drylands of the developing world.

The CGIAR welcomes the decision of the United Nations to declare 2006 the International Year of Deserts and Desertification as a means of creating increased attention to the problems caused by desertification. We are particularly supportive of your conference which inaugurates the International Year of the Deserts and Desertification, and will be engaged in many other related activities throughout the year. For instance, two CGIAR Centers, ICARDA and ICRISAT, jointly convene the Desertification, Drought, Poverty and Agriculture Consortium which will sponsor and participate in the UNESCO Science Conference on “The Future of Drylands” to be held in June.

Human activities and climate change both contribute to desertification which, essentially, is about land degradation. Desertification reduces biodiversity, harms ecosystems and, overall, degrades the natural resources on which agricultural productivity depends. The poor are worst hit by the consequences of desertification. Over 2 billion people who live in drylands that cover some 40 percent of the earth’s surface are affected. This makes desertification very much a direct concern of the CGIAR System. The efforts of the CGIAR to combat desertification are consonant with and supportive of international programs as provided for in the UN Convention to Combat Desertification, the Convention on Biological Diversity, and the UN Framework Convention on Climate Change.

For some 35 years several CGIAR Centers and their partners have been conducting research whose results help to combat desertification and its negative results. The CGIAR has concentrated its efforts in three specific areas:

- Increasing food productivity by developing crop varieties that are able to thrive in desertification-prone areas;

- Developing farming techniques that protect natural resources in ecologically fragile areas; and

- Fostering policies that utilize local knowledge and enable the poor to confront the challenges of drought and desertification.

We will continue on this course. We will pay close attention to the exchange of ideas at your conference, and the conclusions you reach, to enhance our research. I wish you a productive conference, with frank discussions and clear-cut decisions.

Inaugural Address by Prof. Dr. Li Jiayang, Academician and Vice President of Chinese Academy of Sciences

Dear Mr. Chairman,
Ladies and gentlemen:

It gives me great pleasure to welcome you to Beijing and the 8th International Conference on Dryland Development, which is being held under the auspices of The Chinese Academy of Sciences and the International Dryland Development Commission.

In the drylands of the world, the most serious environmental and social-economic problem is the desertification/land degradation. It is caused primarily by human activities and climatic variations, and occurs because dryland ecosystems, which cover one-third of the world's land area, are extremely vulnerable to overexploitation and inappropriate land use. Poverty, political instability, deforestation, over-cultivation, over-grazing, and bad irrigation practices help undermine the land's productivity. Over 250 million people are directly affected by the land degradation, and more than 1 billion people in 100 countries are at risk. China is one of countries that had suffered seriously from the land degradation in dryland. Large areas have been degraded over thousands of years, and especially during the last 100 years. A recent estimate indicates that the economic loss because of desertification and land degradation can be around 45 billion Chinese Yuan (5.6 billion US Dollar).

This conference brings scientists from around the globe who are engaged in research into the process of desertification in the dryland and have been developing methods for reclamation. The program is designed to challenge us as scientists, engineers, teachers and students to face the scientific and societal problems in ways that create opportunities to apply the best science and technology for the benefit of all. Combating desertification in dryland is essential to ensuring the long-term productivity of inhabited drylands. Addressing these problems requires organized, multidisciplinary research across many fields of the natural and social sciences, as well as active international cooperation. It is one of the very true reasons why we are here. This Conference would provide an excellent opportunity to the participants for discussing prospects for international collaboration in this field.

Chinese scientists have made lot of efforts on researching and combating desertification during last 5 decades. It is particularly gratifying to see that Chinese scientists have expanded their scientific endeavour to the global activities in this field. We will continue to do so in the coming decades.

Finally, I wish you a successful conference and a pleasant stay in Beijing.

Thank you!

A. Plenary Sessions

Future challenges to the sustainable use of natural resources in the dry areas

Adel El-Beltagy

Director General, International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria
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Abstract

The dry areas of the world are particularly prone to desertification. An estimated 80 million people are affected annually. The deterioration of vegetative cover, wind and water erosion, salinization, and the degradation of soil fertility and structure are all manifestations of desertification. Nearly 50% of the arid regions globally, including one-quarter of the irrigated land, one-half of the rainfed cropland and three-quarters of the rangeland, are estimated to be degraded. Unless this trend is checked, the food security of the people in the dry areas will continue to be under threat. In attempting to develop options for the development of drylands there is an urgent need to improve the livelihoods of the poor, while at the same time protect natural resources of land, water and biodiversity. Experience has shown that simple recipe solutions that tend to be sectoral do not function efficiently and that there is a need for customizable toolkits and options that can be tailored by communities to meet their priorities. Such toolkits and methods are knowledge intensive, requiring greater attention to knowledge management and exchange including new institutional arrangements and greater attention to informal and community social structures. Through consultations at a broad level, ICARDA has developed an integrated multisectoral approach that distilled the main question: how can poverty in desertification-prone areas be reduced and the poor achieve stable, secure livelihoods without undermining the ecosystem goods and services that they vitally depend on? Under a new consortium called the 'Desertification, Drought, Poverty and Agriculture' a set of six inter-related research themes were proposed: Understanding and coping with land degradation and drought risk; Managing and restoring ecosystem functions; Policy and institutional options; Harnessing genetic resources; Diversifying systems and livelihoods; and Knowledge and technology sharing. Examples of how ICARDA is contributing to these themes are presented.

Introduction

The world is going through an unprecedented phase of ecological transition, in which social, political and economic realities are changing. Human activities, climate change and natural disasters are placing earth's ecosystems under severe stress. The dry areas, where the climate is harsh, face a multitude of challenges. Desertification is one of the main challenges of this ecological transition.

Desertification, as defined by the UNCCD, is "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variation and human activities." But land degradation has several dimensions including biodiversity, soil health, water resources, landscape and agro-productivity.

This is what makes it difficult to precisely define desertification and measure it. However, the human suffering it causes is well known. Reports in literature indicate that, globally, desertification threatens over 41% of the earth's terrestrial surface. But it is in these dryland areas that about 2.1 billion people live. Much of desertification is human-induced. The annual losses caused by desertification are estimated to be in the range of 42 billion US dollars.

The dry areas in the developing countries constitute the global geographic mandate of ICARDA—the International Center for Agricultural Research in the Dry Areas. Of these, the Central and West

Asia and North Africa—CWANA—region, which includes 35 countries, accounts for the major proportion of about 1.7 billion hectares. Of this area, about 45% is estimated to be affected by some form of desertification.

ICARDA’s mission and geographical mandate

ICARDA is one of 15 international agricultural research centers under the umbrella of the Consultative Group on International Agricultural Research, or the CGIAR. The CGIAR is a strategic alliance of donor-members, from both North and South. The World Bank, FAO, UNDP and the International Fund for Agricultural Development (IFAD) are cosponsors of the CGIAR. The mission of the CGIAR is to promote sustainable agriculture to alleviate poverty and hunger and achieve food security in developing countries. The 15 CGIAR Centers work in more than 100 countries.

ICARDA's mission is to improve the welfare of poor people in the dry areas of the developing world. The work involves research and training designed to increase the production, productivity and nutritional quality of food to higher sustainable levels, while preventing degradation of the natural resource base and protecting the environment. ICARDA’s strength lies in its research expertise drawn from all over the world. The current senior researchers at ICARDA represent over 50 nationalities.

Challenges in CWANA

The foremost challenge of CWANA is the rapid population growth, which is among the highest in the world. The population in the region is projected to increase from 750 million in 2002 to 1.15 billion by 2020.

Poverty in the region is high. According to the UNDP human development indicators report (UNDP, 2005) CWANA is the poorest region after Sub-Saharan Africa. About 132 million people in this region live on less than one dollar a day, and 382 million live below the national poverty lines. Women and children are affected most by poverty. On average, nearly 41% of the population in CWANA depends on agriculture as a major source for its livelihood, but this figure is as high as 81% for Ethiopia, 77% for Eritrea, 70% for Somalia, and 66% for Afghanistan. But CWANA is the most water-scarce region, in addition to being most vulnerable to desertification and drought. The average annual per capita water currently available from renewable supplies in the West Asia and North Africa countries is less than 1500 cubic meters, much below the world average of about 7000 cubic meters. This is expected to fall to less than 700 cubic meters by the year 2025 when at least 19 CWANA countries will be in the grip of severe water poverty.

The CWANA region contains 3 of the 8 centers of agrobiodiversity described by N.I. Vavilov. But when land degrades, plant species also disappear with the result that there is an ever-increasing threat to the rich sources of biodiversity in the region of both plant and animal species.

Climate change is another major threat that has long-term effects on agriculture. The 1990 was the warmest decade since 1860 when record keeping of temperature began. Global average temperatures are projected to rise by about 1ºC to 6 º C by 2100. The effect of changing climate on hydrological cycles will perhaps be the greatest threat to agricultural productivity. The dry areas will become drier and hotter.

War, civil conflicts and natural disasters are further compounding human misery and destroying the natural resources in the CWANA region.

With these multiple challenges the question arises: will the world survive? The answer is: yes, it will. The use of cutting-edge science and of the knowledge generated through research can help us develop packages of technologies and policies that will enable us not only to sustain the future of this planet but also make it a better place for all.

Development pathways in drylands

To reflect on the title of this conference—“Man and Nature: Working Together,” let me present to you a schematic description of development pathways in drylands from the report published by Millennium Ecosystem Assessment (2005).

The graphic in Figure 1 shows how drylands can be developed in response to changes in key human

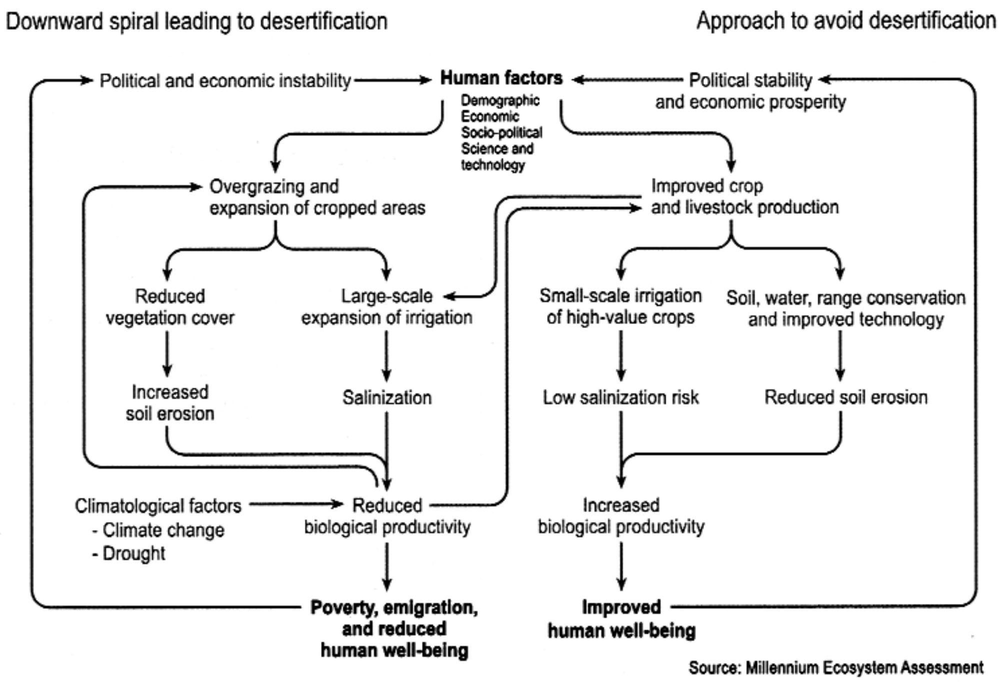

Fig. 1. Pathways to development in the dry areas (source: Millennium Ecosystems Assessment, 2005).

factors. The left side shows developments that lead to a downward spiral of desertification. The right side shows developments that can help avoid or reduce desertification. In the latter case, land users respond to stresses by improving their agricultural practices on currently used land. This leads to increased livestock and crop productivity, improved human well-being, and political and economic stability. And, in Figure 2, which is also from the same report (Millennium Ecosystem Assessment, 2005), we see how the major components of biodiversity loss directly affect major dryland services.

The inner loops connect desertification to biodiversity loss and climate change through soil erosion. The outer loop interrelates biodiversity loss and climate change. On top of the outer loop, we note that reduced primary production and microbial activity reduce carbon sequestration and contribute to global warming. On the bottom of the outer loop we note that global warming increases evapotranspiration, thus adversely affecting biodiversity. Changes in community structure and diversity are also expected because different species will react differently to the elevated levels of CO_2 concentrations.

New tools of science

Fortunately, we now have cutting-edge science to increase the pace and efficiency of research to improve and stabilize agricultural productivity. I will present some examples of the use of these tools at ICARDA.

Remote sensing

Mapping hot spots of drought vulnerability is very useful for drought planning. It is now feasible to analyze through remote sensing the response of vegetation to weather fluctuations, from year to year, over large areas at a reasonable spatial resolution. This makes it possible to identify areas most sensitive to drought. Figure 3 shows the results of ICARDA’s study of spatial distribution of drought vulnerability in West Asia.

Integrated research sites

ICARDA is using the concept of integrated research sites to conduct its research on crop improvement and natural resource management. The Khanasser Valley in northern Syria is one of ICARDA’s integrated research sites, representative of the range of problems of the widespread crop-livestock systems found in CWANA. The major objective is adaptation of known principles and techniques to site- and situation-specific conditions (biophysical constraints and potentials), considering the specific needs and capacities of the people of the Valley. The strength of the project lies in its holistic philosophy, its inter-disciplinarity, and its participatory approach involving all stakeholders.

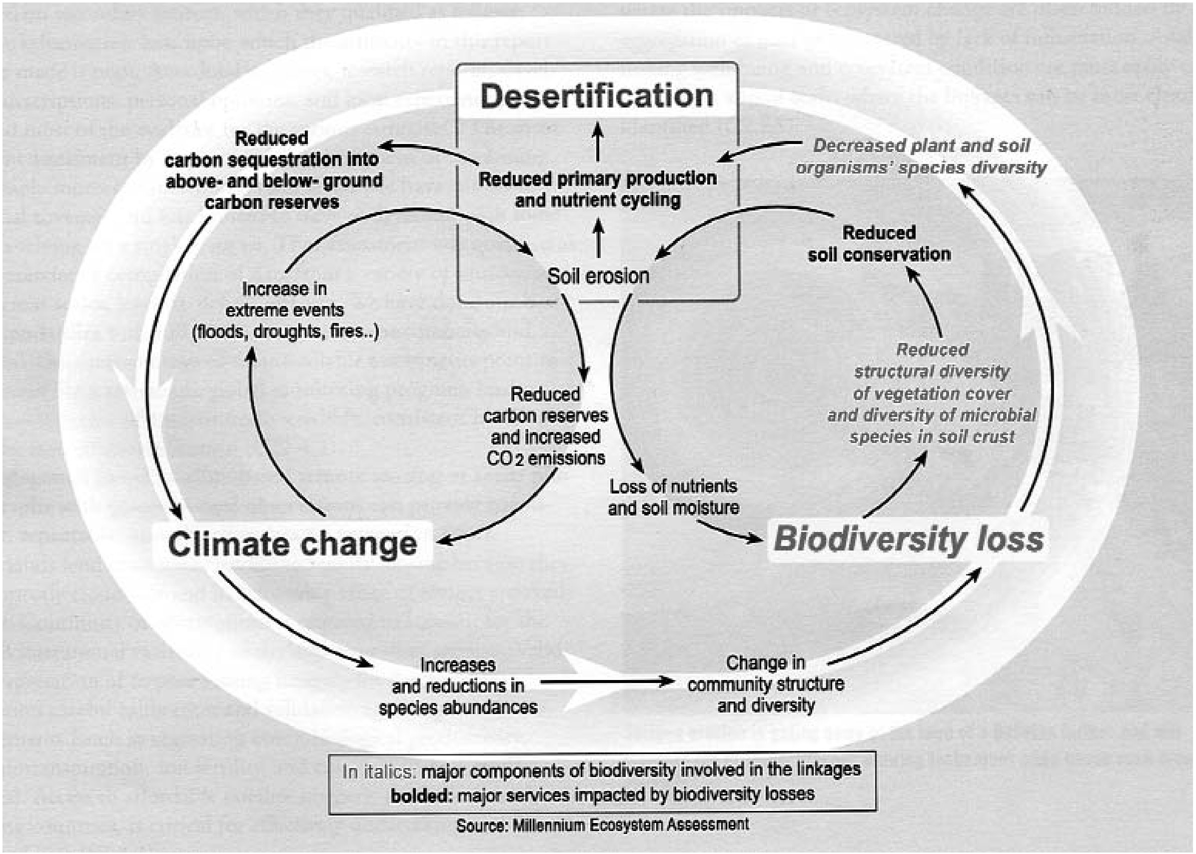

Fig. 2. Linkages and feedback loops among desertification, global climate change, and biodiversity loss (source: Millennium Ecosystems Assessment, 2005).

A toolbox approach is being developed and tested that is based on the cornerstones of the operational framework for integrated natural resource management. These tools are helping to determine the main driving variables and plausible technological, institutional and policy options for an integrated barley-livestock production system.

Up-scaling (or extrapolation) and down-scaling effectively take place within similar agro-ecological environments. However, scaling-out, or transfer and adaptation, may be conceived as the movement of a technology or management option from one environment to a different environment to address a problem across environments and systems. For this, additional tools are needed. If up-scaling mainly utilizes GIS techniques, then transfer and adaptation need to combine GIS much closer with other modeling techniques, combining data from numerous disciplines and sources to arrive at estimations of the differing environmental effects on the utility and performance of alternative options.

Water harvesting

Water is the most critical resource in dry areas. In spite of its scarcity, billions of cubic meters of rainwater in these areas are lost to evaporation and runoff. ICARDA and its partners have demonstrated that over 50% of this water can be captured and utilized for agricultural production, if appropriate water harvesting systems are used.

These could be macro- or micro-catchment systems. Several micro-catchment techniques have been developed at ICARDA that help to capture rainwater for use in agriculture. Remote sensing and GIS tools help in designing ideal water harvesting systems under different terrains and rainfall regimes.

There is also potential to exploit indigenous knowledge for water harvesting. In the ICARDA region, Byzantine cisterns for water harvesting exist to this day. In our Matrouh project in Egypt, the communities are renovating as well as constructing new water cisterns and reservoirs to store

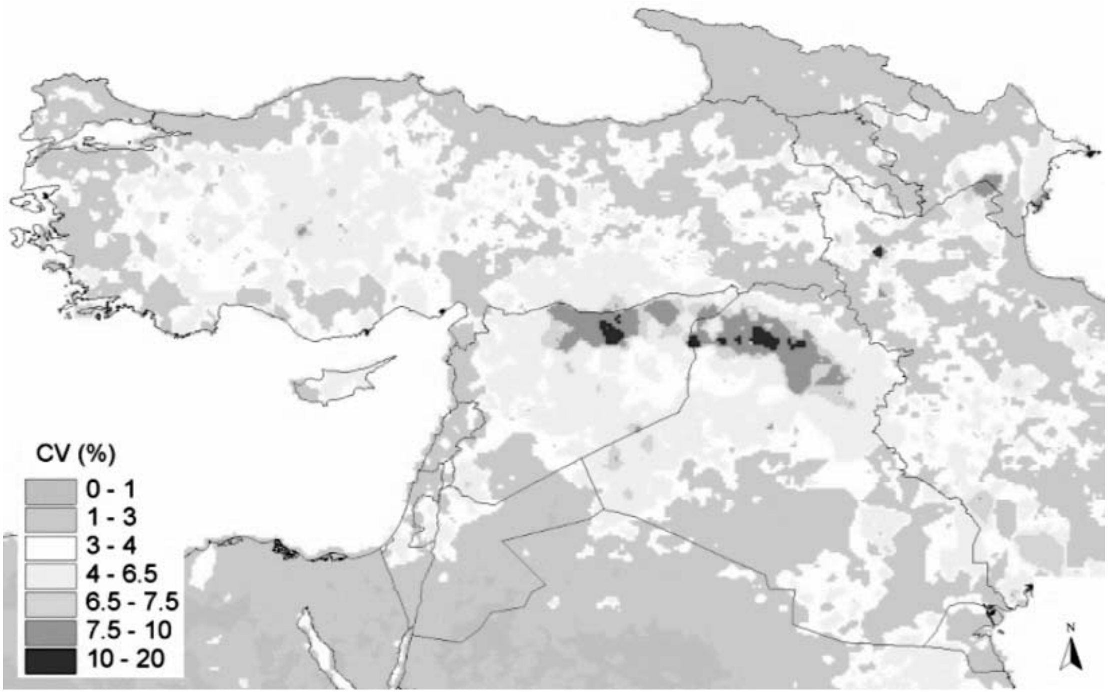

Fig. 3. Spatial distribution of drought vulnerability in West Asia.

rainwater, and stone dykes to retard or slow down water flowing out of the plantation areas to the Mediterranean Sea (Salkini et al., 2005). The stored water is used to grow fruits and vegetables.

Improved water productivity

Research at ICARDA has also shown that a cubic meter of water can produce several times the current levels by adopting efficient water-management techniques such as deficit and supplemental irrigation (Oweis, 1997; Oweis et al., 1999). In supplemental irrigation, limited amount of water applied to rainfed crops during critical stages results in substantial improvement in yield and water-use efficiency. Adoption of deficit irrigation increases water productivity and saves water to irrigate additional land.

Diversification and intensification of production systems can also help in soil and water conservation. For example, protected agriculture, particularly under low-cost plastic structures, provides one of the most efficient uses of limited land and water. It can significantly reduce the use of water, fertilizer and other chemicals. It can provide a good supply of fresh, healthy fruits and vegetables. Farmers in Yemen are increasingly adopting this system.

Land management and conservation

After water, the second most critical resource for agriculture in dry areas is land. Both cropland and rangeland continue to be degraded, so land management is another major challenge. ICARDA is using several approaches to both conserve and rehabilitate degraded land.

Conservation tillage (minimum tillage as well as no-till systems) is one of the mechanisms that ICARDA is using to mitigate the effects of drought and climate change. It helps to improve soil quality, increases carbon sequestration and moisture conservation, reduces soil erosion and improves water-use and energy-use efficiency.

To improve the existing farming systems in the dry areas, ICARDA initiated long-term rotation trials 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 (*Medicago sativa*) and vetch (*Vicia sativa*) 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 mono-cropping 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 mono-cropping.

The results of these experiments were taken to farmers' fields. Barley/vetch rotation gave the highest yield of total feed, crude protein, and metabolizable energy. 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.

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.

Fodder shrubs are another option. ICARDA has found that native forage-shrub species are more promising than exotic species. In a collaborative project with Syrian national program, 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.

Genetic resource conservation and utilization

Genetic resources are the building blocks of crop improvement. ICARDA holds over 132,000 accessions in its gene bank, including the landraces and wild relatives that have evolved under harsh conditions over millennia. About 70% of our collections are now geo-referenced. ICARDA has been freely sharing these resources with partners all over the world. On average, the Center distributes 35,000 samples each year.

In the barley improvement research at ICARDA, the major focus is on exploiting variability in adapted landraces and on the use of the wild relative *Hordeum spontaneum.* In a cross of 'Arta' barley line with *H. spontaneum* the objective was to combine the high yielding ability of Arta with drought tolerance of *H. spontaneum.* In the recombinant inbred population of this cross, QTLs for grain yield, biological yield, plant height, and days-to-heading were located on chromosome 3H. The plant height alleles of *H. spontaneum* at this location directly influence traits such as the biological yield and grain yield (Baum et al., 2003).

Application of biotechnology

ICARDA is also addressing the problems of drought and salinity tolerance in crops by blending biotechnology with farmer-participatory breeding (Ceccarelli et al., 2000). Farmers identify which lines perform best in their fields, including their own landrace selections. ICARDA scientists characterize those selections using molecular marker 'stress microarrays' that help find the genes responsible. Then crosses are made and selection in the segregating populations is made for those genes. The selected improved germplasm goes back to farmers to start another cycle of testing and breeding.

In our collaborative work with Japan, ICARDA's crop improvement programs are using the DREB gene that can increase tolerance to abiotic stresses. The gene is being incorporated into lentils and chickpeas.

Transgenics hold great promise in dryland development. Pest and disease resistance has been the major objective of transformation work so far. This will help reduce the reliance of agriculture on chemical sprays. Molecular studies have shown the possibility of single gene-controlled salt transport mechanisms (Kasuga et al., 1999). Drought tolerance and salinity tolerance is likely to continue to be the focus of many biotechnology efforts in research and development in dry areas.

Bridging the digital divide

Since natural resource management innovations are knowledge-intensive, communication and knowledge-sharing deserves strong emphasis in drylands development. We need to build on ICT experience of developing countries, such as India. New satellite systems offer practical internet connections that can be paid by private-sector sponsors who also need them to deliver services to villagers, such as credit and inputs. Skilled village moderators are the key element. They act as intermediaries, working with communities to find out their information priorities. ICARDA is forging a unique partnership with the United Nations e-Volunteer Service created by UN Secretary General Kofi Annan, called UNITeS, to find these skilled moderators (United Nations Information Technology Service, 2005). It will be a "win-win" partnership.

As women play a major role in rural livelihoods, their role as agents of change needs careful attention. Our rapid rural appraisals and formal surveys have covered female household heads and other women in the targeted communities. This has led to the identification of relevant income-generating activities, as well as contributed useful information to refine our research strategy.

DDPA initiative

Recognizing that the complex problems of drylands development can only be addressed through global partnerships, and in line with the action plans of UNCCD, ICARDA, in collaboration with its sister center ICRISAT, has launched the development of a Consortium entitled 'Desertification, Drought, Poverty and Agriculture'. Under this consortium a set of six inter-related research themes have been proposed: Understanding and coping with land degradation and drought risk; Managing and restoring ecosystem functions; Policy and institutional options; Harnessing genetic resources; Diversifying systems and livelihoods; and Knowledge and technology sharing (Thomas et al., 2005). It is a multi-partner initiative involving donors, international centers and national programs. The initiative will create a powerful mechanism to catalyze world action to combat drought and desertification. In addition, ICARDA is contributing to UNCCD-related activities through national and regional action programs and country pilot programs.

New opportunities

There are other domains of science that hold great potential for the development of drylands. For example, to create new resources of water, removing salt from seawater is being done in several parts of the world. But it is too expensive and energy demanding. Research in developing economically viable technologies deserves additional support, because a breakthrough in desalination could provide major relief from water scarcity.

Agriculture, by providing biofuel and bioelectricity, can help make desalination economically viable. The oils used in biodiesel production are often a by-product or residue from feedstocks used for other purposes. Soybeans currently provide about 60% of the feedstock for biodiesel. The other potential crops are corn, walnut trees, sunflower, wheat, barley, sorghum, rapeseed, peanut, rice and canola, *Jatropha curcas*, to name a few. Biodiesel is environment friendly. It is biodegradable, and not toxic to water, soil or animals.

Nanotechnology, though still in its infancy, also has great potential to revolutionize agriculture and food systems. It is beginning to receive serious attention in industrialized countries, but not yet in developing countries. The basic areas include microfluids, BioMEMs, nucleic acid bioengineering, smart delivery systems, nanobioprocessing, bioanalytical nanosensors, nanomaterials and bioselective surfaces. The technology will provide the capability for pathogen and contaminant detection, preservation and historical tracking of agricultural commodities, improved digestibility and flavor of foods and to combat disease long before symptoms are evident, real-time monitoring and control of plants and their local environment, and tools for the study of enzymatic processes, microbial ecology and kinetics in biological communities.

Epilogue

We are witnessing a period in the history of mankind when the basic code of ethics for humanity and the respect for human diversity are under serious threat. The increasing socio-political upheavals are taking the lives of thousands of innocent civilians, and destroying the natural wealth of our planet. We must not allow this to continue. In today's world the scientific community, more than ever before, has a great responsibility to work in a unified way so that the physical, biological, behavioral, and social sciences can address these profound and pervasive problems.

The scientific community can generate new knowledge and apply it to understand the problems of food security as well as human conflict, and develop appropriate solutions. Our challenge today is to use science and technology for peace and food security throughout the world.

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Sustainable water supply in the 21st century

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Abstract

The world is mostly made of water. But, only 2.5% of world's water is fresh water, with less than 1% available for use. We draw down about fully 56% of that 1% of water that is actually *accessible* to us. Drylands, by definition, enjoy a much less proportion of this resource than more privileged areas. Water resources are central to food security, to the health of the environment, to our enjoyment of nature, to energy production, to transport, and often to our national conceptions of ourselves. Because of a combination of population growth, pollution, and increasing per person use, there are about 450 million people in 29 countries facing water shortage, and by 2025 about 2.7 billion, or 1/3 of the expected world population, will live in regions facing severe water scarcity. Agriculture is the biggest water using activity and is responsible for 70 to 80 % of a country's water consumption. It warrants careful attention. Billions of dollars are spent in subsidies to farmers throughout the world but they are allocated without any consideration to water problems, thus artificially inflating a real water crisis, which will manifest itself as a food security crisis. The water problem is as much a financial problem as a water problem. There is no solution to the water problem without some overhaul of the way agriculture is subsidized, water as an industrial or agricultural input is priced, local authorities are vested with the responsibility to provide water to their inhabitants and good managers, and sustainable financial resources are allocated to them.

Introduction

The UN Secretary General asks, in a year end broadcast, if the next wars will be water wars. "Water is the 21st Century Gold" avers a Middle Eastern research group. We see TV images of draught where rains fail, water tables drop and then crops wither, roots die, lands erode and soil blows away. Many countries experience unprecedented flooding. We know that more and more rivers – major rivers -- dry up before they reach the sea, and fertile lands are ruined by salt. And we know that somehow connected to this is the daily reality of 6 thousand water-related deaths, and of 2 ½ billion people suffering the indignities of being without sanitation facilities, and fully half that number suffering the health and livelihood effects of not having access to clean water. What is going on? Doesn't it still rain? How do these issues fit together?

The world of water

Here is the world of water in brief. The world is mostly made of water. But within this watery world, only 2.5% of world's water is fresh water, with less than 1% available for use. We draw down about fully 56% of that 1% of water that is actually *accessible* to us. Water use sextupled when population doubled since the 1960's (i.e. added 3 billion); what will be the situation in 2050 when we add the next 2-3 billion? Sextupling isn't possible – we're already over the half way mark (Shiklomanov, 1997).

Water resources comprise the totality of rainfall, rivers, lakes, aquifers, and groundwater. Drylands, by definition, enjoy a great less of this resource than more privileged areas. This Conference is all about how to apply science and knowledge to alleviating the difficulties and hardship of life with less water. Water resources are central to food security, to the health of the environment, to our enjoyment of nature, to energy production, to transport – (especially in this country) and often to our national conceptions of ourselves. Water resources are managed – or should be – by public policy: by finance and trade ministers through tariff policies, by natural resource ministries and agricultural ministries, by environmental regulations such as the European Framework Directive, by resource inventories and surveys, monitoring, trying to integrate the various uses made of water by various parts of society. Determinants of who gets what relate to the relative political power of the agricultural sector, the mining sector, the energy producers, the environmentalists.

Most of the Millennium Development Goals - reduced malnutrition, decreasing the number of those in poverty, improving the environment - will not be reached without improved water *resource* management. The Johannesburg Earth Summit (2002) passed a specific directive calling for all countries rich and poor, water scarce and water plentiful to develop integrated water resources management (IWRM) and water efficiency plans by 2005. IWRM is an approach "which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without comprising sustainability of vital ecosystems" (Global Water Partnership, 2000).

The aspect of water that is most immediate to everyone, dryland or other, is *water supply* – or *drinking water supply* – that takes but a small part of water use, generally about 7 or 8%. Water supply, often with sanitation and water treatment, is managed by municipal managers, water engineers, sanitation specialists. The decisions about who gets water supply or who gets sanitation are primarily about financial and policy priority decisions.

The two are related: bad water treatment pollutes drinking water supplies. But, for example, whether the citizens of a country have adequate drinking water is much more closely related to the income level of that society than simple water availability. This is logical. In an increasingly urban world, water supply is related to costly urban infrastructure which must be financed. Poorest countries have the greatest challenge, even those with ample water supplies.

Both of these have changed a great deal in the last decades because of the following:

1. Huge population increase has reduced the absolute amount available *per person* for these purposes.
2. Humankind has invented about 100,000 chemicals to help us with food and industry and daily life; we also use the streams and rivers around us to dispose of these and agricultural and human waste products. Ninety percent of the South's waste water goes untreated into the streams and oceans with consequences for the downstream and the reefs and coastal regions. Ergo, there is less water available for each of us, and often it is polluted - occasionally to the point where it cannot be used, often to the point where it causes illness.
3. The impact is not just on humans - About one quarter of the fresh water fish species are endangered. Fully 50% of the global wetlands disappeared in the 20th century (Schuyt and Brander, 2004). Mangrove swamps are being pulled out. Aquifer levels are falling, not everywhere, but in far too many places.

So, this combination of population growth, pollution, and increasing per person use means that there are about 450 million people in 29 countries facing water shortage, and by 2025 about 2.7 billion or 1/3 of the expected world population will live in regions facing severe water scarcity (Rosegrant et al., 2002).

Because of the enormous temporal and special variability in water, this hits some areas much harder than others. This means that some parts of India receive 90% of their water in five days of rain, perhaps spread over two intervals a year. If they cannot store this water they will lose it – and have no more for months to come. To add even more complexity, 263 of the world's river basins are shared by two or more nations, and about 40% of the global population lives in these shared basins.

The impact on people's lives and livelihoods depends on who they are and where they are. Poor people suffer most when water is unavailable, they suffer in particular from the absence or poor working of municipal services and poor people suffer disproportionately from the health impacts of dangerous or low water quality and quantity.

It would in fact be difficult to exaggerate the impact that the lack of clean drinking water has on the lives of the poor. Close to half the population of the developing world suffering at any one time suffer from diarrhea, ascarids, guinea worm, hookworm, and shistosomiasis. A well designed water system reduces the incidence of shistosomiasis by close to 80% (UN Millennium Project, 2005). There are 4 billion cases of diarrhea yearly which cause 2.2 million deaths. Fully 6 million are blind from trachoma – a disease which could be largely prevented if there was enough water to wash the face, and if the habit of doing so could be taught and learned. The naturally occurring arsenic in Asian groundwater has diminished quality of life for hundreds of thousands of the millions who lived because they no longer faced cholera (UN Millennium Project, 2005).

Cholera means both loss of life but also loss of livelihood. Chile took years to recover from the losses suffered in the fruit and vegetable export earnings after their 1990s cholera scare, and it actually cost infinitely more than would have improved water systems. Poor water impoverishes the poor in other ways. About 73 million working days are lost in India to problems associated with poor water quality and the health impact, with $600m lost in paying treatment costs and in the cost of lost production. A staggering 40 billion working hours in Africa are lost to carrying water. This is women's work and if women cannot do it their daughters will come out of school and fetch water (UN Millennium Project, 2005).

The per person count is what counts. If we look at one of the most unstable areas of the world, we see a truly disquieting water picture. In the Middle East and North Africa region the population doubled from 1970 to 2001. In 1960 there were 3,500 cubic meters of water per capita available to be used for all purposes – food, industry, personal use – for all residents; by 2025 that will be down to 600 cubic meters per person, or a *six* fold decrease. Irrigated agriculture uses a hefty 85% of the water in the region. This part of the world is now 60% urban. The scarcity will intensify for agriculturalists and urban alike. The Arabian Peninsula, Jordan, Palestine, Israel and Libya consume more water than annual renewable supply, with Egypt, Sudan, Morocco, Tunisia and Syria – close behind. Jordanians have but 163 cubic meters per person per year, Yemen 133. How will prosperity – or peace - come in these circumstances?
By common consent, the problems of water are problems of water management.
First, some water resource issues:

- According to the World Bank estimates, Australia and Ethiopia and Western USA all have about the same rainfall and climate but where the USA and Australia have around 5000 m^3 per head of water storage capacity, Ethiopia has only 50 m^3, and Africa and the Middle East as a whole only 1000 m^3. Each USA citizen has fully 100 times as much stored for him or her vis a vis each Ethiopian. So how can Ethiopia grow more food, offer conditions under which industry might be established and meet people's needs for water.
- China has about 50% of its agriculture under irrigation – with as much as 70% of that water lost to wasteful methods.
- In China it takes 25-50 tons of water to produce a ton of steel as against 5 tons of water taken by Germany, Japan and US to make 1 ton of steel.
- The Aswan high dam is built in where summer temperatures reach 44 degrees C. Were it further upstream, the evaporation losses would be cut substantially.
- Saudi Arabia uses fossil water (i.e. laid down eons ago, not replenishable) for agriculture; the practice has been cut back.
- India and China between them probably pump about twice the Nile River's worth of water *more than rainfall will replenish* from underground sources for irrigated agriculture – often the electricity and the water are both free.
- Household consumption: In North American we dam rivers to store water, pipe it, filter it, add chemicals to it, preserve its purity and then flush more than a third of it down the toilet (about 8% worldwide).

- **Food security**. Water scarcity is a threat to food security. Although only 17% of agriculture is irrigated, this irrigated land accounts for more than 40% of all agricultural production, and it accounts for about 80% of all the water we humans use. With both upsides and downsides, we have fed an additional 3 billion people since the mid point of the last century through *intensifying* agricultural production, primarily through Green Revolution techniques and substantially but not uniquely through irrigation. Had this not been done, the burgeoning world would have fed itself by *extensive* means, i.e. clearing more forests, more tropical lands, denuding more hillsides. And much of the world's water supply to agriculture is under threat.
- **Irrigation investments** declined continuously since 1980 and have in any case virtually not touched Africa. There is a combination of

relevant factors: agricultural water storage involves dams, now rarely financed by concessional funding sources; past projects are perceived to have performed poorly (there are hardly ever water charges or budget appropriations to keep the systems in good working order); irrigation projects are more costly than education or social projects; irrigation investments were crowded out by lending in structural adjustment in 1980s and later focus on environment (Seckler et al., 1997). These declines help the urban poor, but not the rural poor who have to make money to buy anything, including food. Some 70% of the poor are still rural.

- **Floods and disasters.** Hotter air holds more water than cold air. As temperatures rise, more water accumulates. Rain becomes torrential, in more places, more often. It is not imaginary that there are more named Hurricanes – there are. Climate variability is having an enormous impact on water management and will do so even more in the future. According to the International Climate Change Partnership (ICCP) reports the flood damage claims since 1950 have risen from $39.6 to $607 US billion with the curve still climbing sharply. Loss of lives in flooding has dramatically *decreased* in the industrialized world as early warning measures and long term disaster prevention measures take hold – helped by skyrocketing insurance premiums. Loss of lives has however *increased* dramatically in many places in the developing world as burgeoning populations build in floodplains, and less than well organized societies try to cope with a stream of weather events increasing in frequency and violence in the tropical regions. There are welcome exceptions – Bangladesh has reduced the lives lost to flooding as they have applied the experience of past inundations.

- **Population increase** is the biggest threat to water security. Although population growth rates have decreased dramatically, the human race will increase by another 2 to 2.5 billion before population levels stabilize. With higher levels of development come higher demands on water – for energy, for food, for personal use. Water use increased by a factor of 6 when the world's population doubled, by adding 3 billion since the mid point of the last century.

Not-yet threats

Water wars. It is absolutely the case that two Middle Eastern cities armed themselves and went to war directly over water (Wolf, 2002). But it was 4500 years ago and in the years since, the participants have often been edgy, but actual violence only ensues on the local level. In 1980, armies were mobilized. Shots have been fired: Egypt, Ethiopia, Sudan, Jordan in 60s. Landmines have been put down in Uzbekistan, and a dam blown up in Oregon. But generally and amazingly, nations have found more to cooperate about with water than to fight over. The reality is a fairly rich tradition of Transboundary Cooperation with India continuing to pay Pakistan for the costs of building and operating dams which Pakistan continued to build and operate – right through several periods of Indo-Pakistan hostilities. The Mekong River treaty held, with some difficulties, right through the Vietnam War. The Jordan River treaty is more observed than it is violated, though it is violated.

A study of the last 50 years shows that 2/3 of all events involving water issues between two or more states have in fact been cooperative, with acute violence being rare. Where there is violence, the water issue is usually as subset of other difficult issues. USA intelligence reports suggest that shortages have often stimulated cooperative arrangements for sharing scarcity (US National Intelligence Council, 2000). As countries come up against tighter and tighter limits, conflict may increase. Wolf's Axiom says that "the likelihood of conflict rises as the rate of change within the basin exceeds the institutional capacity to change" (Wolf et al., 2003). In other words, the strong linkages, history, technical capacity and managerial competence of the Canada/USA International Joint Commission suggest that it will help our two countries to find solutions to new challenges such as deformed fish, zebra mussels, declining Great Lakes Water levels. In the Aral Sea, given the weak linkages between the regional countries, it is much less likely that solutions will emerge easily. Water-related violence very much exists in the world of today but the most intense conflicts are intrastate, intercommunity, and intervillage. Pastoralists and planters do come to blows. The poor are at the bottom – and when we wonder about water and violence, we should think of the women at the well who resort to blows to maintain their position in the line up – day after day after day. But it is unlikely that we will be as drawn to their bitter daily conflict as we will to those where armies line up and command camera attention.

The international community tried to forestall tensions over shared waters. The Nile River Treaty tries to create a win-win situation through finding agreement on and financing for an impressive range of development projects for all of the countries in the region. The price tag is very steep but wars would undoubtedly cost more on all measurement scales.

The new transboundary issues will be complex. They are unlikely to be about water availability alone. There are rich mixes of issues that will plague the 260 shared river basin countries: water dumping in times of flood risk; existence of toxic dumps near water sources; inadequate industrial protection; salinity and agricultural wastes in the stream; building dams and infrastructure without consultation. Climate variability will add to the complexity of this mix.

Promises

Desalinization

Desalinization becomes a more and more interesting option for some, given that sea water comprises 97% of the earth's water. Some 12,500 desalinization plants now dot the planet, with 2/3 of these in the Middle East, and fully one quarter in Saudi Arabia. New plants are being built in Florida, California, and the Caribbean. Only 1% of water use is accounted for by desalinated water, but the number is growing (GWI, 2004).

Membranes

Membranes offer promises for water remediation. Why not re-circulate all of the gray water in an apartment building – indeed if the membrane is good enough – why not re-circulate all of the water? Why not build whole neighborhoods on this principle – why have huge water mains and sewer mains if the processing can be done locally by membrane?

Demand management

Anywhere there is metering, demand drops. In California – Pacific Institute "Waste Not, Want Not" estimates that up to one-third of California's current urban water use – more than 2.3 million acre-feet – can be saved using existing technology. And at least 85% of this savings (over 2 million acre-feet) can be saved at costs below what it will cost to tap into new sources of supply and without the social, environmental, and economic impacts that any major water project will bring (Gleik et al., 2003). Composting toilets reduce the demand for water, as do innovative pit latrines for communities of modest means as has been shown by Sulabh Institute in India. Separating feces and urine allows these to be treated as resources.

More water

The time honored solution to water problems has been to increase supply, i.e. build dams, extend the pipelines, and pump more out of the aquifer. China is busy moving part of the Yangtze River to the North, and India is talking very seriously about joining its rivers in a national grid. The Red-Dead Sea Connector talks go on throughout the Middle East atrocities.

So the supply side process continues, with its serious consequences for rivers, aquifers, and displaced populations. Many unnecessary dams have been built, with benefits to be sure but a great deal of ancillary damage for the simple reason that it is a lot more politically rewarding (and in many countries a major source of corruption income) for Governments to supply more water than to attempt to reduce the demand of their populations.

As of two years ago, there were 47,655 large dams in the world and about 800,000 small dams (WCD 2002). Interestingly, they are almost all in the medium to rich countries. Anti dam protesters in the industrialized world, through their pressure on industrialized state governments and international financial intuitions, have ensured that international financing institution (IFIs) no longer fund dams. As a result even needed water storage capacity has not increased in the poorest countries as shown in the reports presented during the World Bank Water Week 2004. Middle class countries such as Turkey, Iran, China and many others have gone on building dams using other resources. The poorest cannot finance with their own resources, and therefore do not have the storage they need. No countries with variable rainfall have become prosperous without being able to store water. There is almost no storage capacity in the poorest countries, almost all of which have highly variable rainfall patterns. Unless this changes, they will stay poor.

Nanotechnology

If engineered microbes can eat oil in oil spills, and might be designed to transform arsenic to less harmful compounds, why not engineer them through nanotechnology to take on the heavy metals in our waste water (and then use bulrushes to purify the organic wastes, a delightful mixture of high tech and low tech!)

Better science for water for food

For the first time in world history, water demand for nonagricultural uses is growing more rapidly in absolute terms than water demand for agriculture (Rosegrant et al., 2002). The task is to 'reinvent irrigation for the 21st century'. There is, for example, a wide technology gap between *required* irrigation practices for wheat, barley, corn, cotton, sugar beet, potatoes and tomatoes and *actual* water application in most areas. Improved water use efficiency means high potential water savings. The 'free ride' we have had while we have depleted groundwater resources is coming to its inevitable end.

The objective must be that each cubic meter of water should be applied at right time – efficiency comes by applying even small amount of water to alleviate severe moisture stress during most sensitive stages of crop growth and seed filling – applying before stress reduces plants yield potential.

New technology can and will help in this process. There are many new and exciting techniques we can use to help us make water go further.

- Watershed modeling
- Integrating simulation techniques with GIS projections
- Maps graphs for natural resource impact
- Daily temperature data, soil and land management data collected from meteorological data
- Satellite imagery
- Surface flow processes, erosion, nutrient transport, grazing effects, yields

The evidence that these techniques can work is provided in compelling figures. ICARDA's special expertise in the area most likely to be most affected by climate change suggests that:

- a 50% decrease in irrigation water use in wheat irrigation in the ICARDA area gives only 10 – 20% loss in cereal production
- winter sowing of cereals reduces water needs - lentil and chickpea yields are doubled if they are planted earlier to catch the Mediterranean rain
- water harvesting yields small and big miracles around the world
- New drought-tolerant cultivars offer huge potential for improved yield in dry conditions
- improved forage crops – it is estimated that if 70% of the 30 m hectares of land left fallow in West Asia and North Africa every year could be sown to forage legumes, this would produce enough feed for 80 million sheep, and could result in 1.4 m tones of nitrogen fixed in the soil (ICARDA, 2005).

Saltwater and wastewater agriculture

We can also find "new" water for food if we redirect research priorities and put in place effective regulatory frameworks.

- Water harvesting
- Brackish water
- Treated effluent – the issue here is how much treatment? This has to be one of the most exciting potential areas for "finding" water; the hazard is that industrial and biological wastes are often mixed, resulting in toxins and heavy metals in the admixture.

Rainwater harvesting

The old techniques are being rediscovered and reapplied to yield more water for topical use. Eaves-troughs are collecting water from schools and public buildings to provide water for community use. Families are collecting rainwater – all over India, but also in Germany. Tanks are being rebuilt and watersheds refurbished in the process; rivulets are flowing in formerly denuded landscapes (GRWHC, 2005). Communities are putting water back into the subsoil and aquifer by conscious channeling of rainwater. Global satellites may help us to do this on a global basis.

Re-allocation

Some of the real answers will have to come through allocation decisions. Pragmatic but sometimes difficult steps can lead to dramatic consequences

- Jordan –a 5% transfer from agricultural use would increase domestic supplies by 15%
- Morocco – where 92% of water is used for agriculture, a 5% diversion would effectively double the supplies in domestic sector
- The San Diego and Imperial Valley accord sees the municipality pay for water that allows

investment in improved irrigation facilities. The water used in Imperial Valley agricultural use would provide for domestic use for 12 million people.
- Costa de Hermosilla in Mexico – proposals to improve agricultural use pattern could avoid need for desalination plant (100 km from coastline).

Can the world manage better?

Water cannot be created; it can only be managed. And water is local, quintessentially so, unlike energy or food commodities which travel through trade. If by common consent, there is enough water – *just* enough in many areas, but probably enough, can't we just improve management? A brief glimpse at traditional water management precepts will signal some of the issues. How do we manage water now, or, how did we get into these difficulties?

- There is usually no Ministry of Water, and there is no single UN water organization to set global standards for water management. There are sectoral standards, of course.
- Governments see their principal role as delivering water to their citizens
- Far too many people insist that "Water should be no cost/low cost". Many who advocate that water is a Human Right insist that it must be free. The relevant UN resolution says it should be 'affordable' (ECOSOC, 2002). While subsidy is essential to protect the poor, paying enough to keep the pipes and reservoirs of the system going is essential in countries with no tax base, few government revenues and other priorities for aid Euros.
- Water governance/expertise is organized sectorally.
- Jurisdiction: rivers, lakes, groundwater do not respect national boundaries.

Things are changing and there are new ways of looking at water governance. More rather than less governance is needed for this ultimate public good. The following water management functions must therefore stay in public hands:

- Allocating water
- Deciding on protecting the environmental share
- Establishing water law
- Setting regulatory framework
- Managing inspection functions
- Ensuring data collection, retention and distribution
- Managing public debate on issues
- Managing communication on water issues
- Getting some of the corruption out of the water sector (Transparency International, 2004)
- Ensuring subsidy for poorest population

Agriculture is the biggest water using activity and is responsible for 70 to 80 % of a country's water consumption. It warrants careful attention. Billions are spent in subsidies to farmers throughout the world but they are allocated without any consideration to water problems, thus creating artificially a water crisis, which will manifest itself as a food security crisis

The water problem is as much a financial problem as a water problem. There is no solution to the water problem without some overhaul of the way agriculture is subsidized, water as an industrial or agricultural input is priced, local authorities are vested with the responsibility to provide water to their inhabitants and good managers and sustainable financial resources are allocated to them.
It is not simple. Moving to a conscious, transparent, publicly announced allocation of available water is a fraught process almost guaranteed to generate more enemies than friends for the party doing the allocating. The move toward charging for water services offers opposition parties an instant election issue. Managing across boundaries and agreeing to share the benefits of water, often between neighbors with centuries old traditions of mistrust is not easy. Current arrangements favor the powerful; who will speak for the weak? Who speaks for the environment? Irrigated-land agriculturalists in many countries have much more power than either the rural or urban poor. There are taboos against waste water re-use.

All of this changes every day. Every day, the population grows and the amount of water available per person decreases. Every week, somewhere in the world there are manifestations of climate variability which will have marked impact on water resources. Every month, pollution increases. Meetings are held to assess how best to intervene. We must rethink our use of water – there is no other option. The path ahead is full of challenge, nowhere more than in the dryland areas.

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Sustainable development for fragile ecosystems

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Abstract

The mission of Friends of Environment and Development Association (FEDA) is to implement strategies for sustainable development in Egypt, as put forward by a special UNDP Task Force coordinated by the author. The sustainable development framework was based on a dynamic balance between resource management, environmental protection, and human and economic development. Public participation, adequate infrastructure and efficient support services are of utmost importance in implementing strategies for sustainable development. The FEDA's Board realized that it would be more effective to limit its implementation activities to fragile ecosystems, namely the coastal, desert and historic areas. Since 1993 work has been undertaken in Rosetta (coastal area), Wadi Natroun (desert area) and Gamalia district (a historic part of Cairo). These three fragile ecosystems, though different in location, climate and natural resources, are well known for their cultural heritage. Both Gamalia and Rosetta have some of the most important Islamic monuments, while Wadi Natroun is known for its famous Coptic Christian monasteries. FEDA is implementing projects leading to upgrading of these fragile ecosystems with the goal of improving the quality of life of its residents and encouraging tourism. Both human and environmental aspects are considered.

The paper reviews some of the steps taken towards achieving sustainable development in these fragile ecosystems through upgrading physical conditions and improving infrastructure of demonstration areas, developing democratic community structure through information management, monitoring and public awareness, as well as capacity building and initiation of local organizations, and improving living conditions of the inhabitants through training and technological upgrading.

Introduction

The mission of Friends of Environment and Development Association (FEDA) is to implement strategies for sustainable development in Egypt, as put forward by a special UNDP Task Force coordinated by the author. The Bruntland definition of sustainable development was adopted and its framework was based on a dynamic balance between (a) resource management, (b) environmental protection, and (c) human and economic development. To achieve this balance, we require appropriate management, necessary finances, and research and development (R&D) activities, with emphasis on optimization between the ecological and economic dimensions of development. Public participation, both social and political, adequate infrastructure and efficient support services are also of the utmost importance in implementing strategies for sustainable development (Fig. 1).

The FEDA's Board felt that it would be realistic and more effective if the implementation of its activities were limited to a few selected fragile ecosystems. The choice fell on three deteriorated sites, one each in coastal, urban, and desert areas. Since 1993 work has been done in Rosetta which is in the coastal area, Gamalia district which is a historic part of Cairo, and Wadi Natroun which is in the desert area. These three fragile ecosystems, though different in location, climate and natural resources, are well known for their cultural heritage. Both Rosetta and Gamalia have some of the most important Islamic monuments, while Wadi Natroun is known for its famous Coptic Christian monasteries.

Fig. 1. Framework for sustainable development in Egypt.

Rosetta

Rosetta is located in the farthest north of Egypt. The Mediterranean Sea is its northern boundary and the river Nile is the eastern boundary. The sea shores of Rosetta are impacted by the prevailing eastward wind which moves the heavily industrialized Abou Qir Bay polluted water towards the shores, threatening to ruin them as fish spawning areas and as recreational beaches.

Rosetta is one of the old locations, known from Pharaonic days. The discovery of the famous Rosetta stone, which is now in the British museum and is well known for its role in understanding the hieroglyphic language, has added to its fame. A replica of this stone is now in the citadel erected by Sultan Kaiet Bay (1472 AD), with fences and monitoring towers around it built by Sultan Al Ghoury (1516 AD) to defend Rosetta against the Crusaders.

Rosetta is an open museum, housing 22 historic buildings made out of special El Mangour bricks colored black and red cemented with white cement in an alternating style to decorate the façade. This kind of brick is made only in Rosetta. None of the houses is painted or covered with any other calcareous plaster materials usually used in these localities. The facades of all houses are characterized by Arabesque covered windows made of beautifully interlocked pieces of wood, without the use of any metal nails, and inlaid with ivory, metals and mother of pearl. The Dehliz El- Mulk Street is characterized by a number of these beautiful houses. However, as a result of the deteriorating economy, the surrounding new houses distributed haphazardly and made with no style have diminished the beauty of the historic buildings. A rise of the subsoil water is threatening the foundation of the houses, promoting deterioration of walls, and causing their collapse.

Rosetta has a long beach on the Mediterranean Sea which is suffering from severe erosion, leading to the destruction of the summer resort area previously occupying the beach. The high dam construction has enhanced this erosion due to the disappearance of silt which used to be brought in by the Nile flood every year. It has also changed water flow pattern in the Nile which in the past used to help in blocking the river mouth from the sea through siltation from the annual river flood water. The resulting change in water characteristics of the Rosetta river mouth has also caused a major drop in sardine fish population which used to migrate from Sardinia (Italy) during spawning period. The siltation also prevents the high sea fishing boats from entering the river to dock in Rosetta harbor. All these changes have resulted in unemployment and in major financial losses.

Photo 1. Rosetta: a coastal area.

Photo 2. Rosetta: Citadel of Sultan Kaiet Bay (1472 AD) where a replica of Rosetta stone is exhibited.

Photo 3. Rosetta: Mangour brick building and modern mosque.

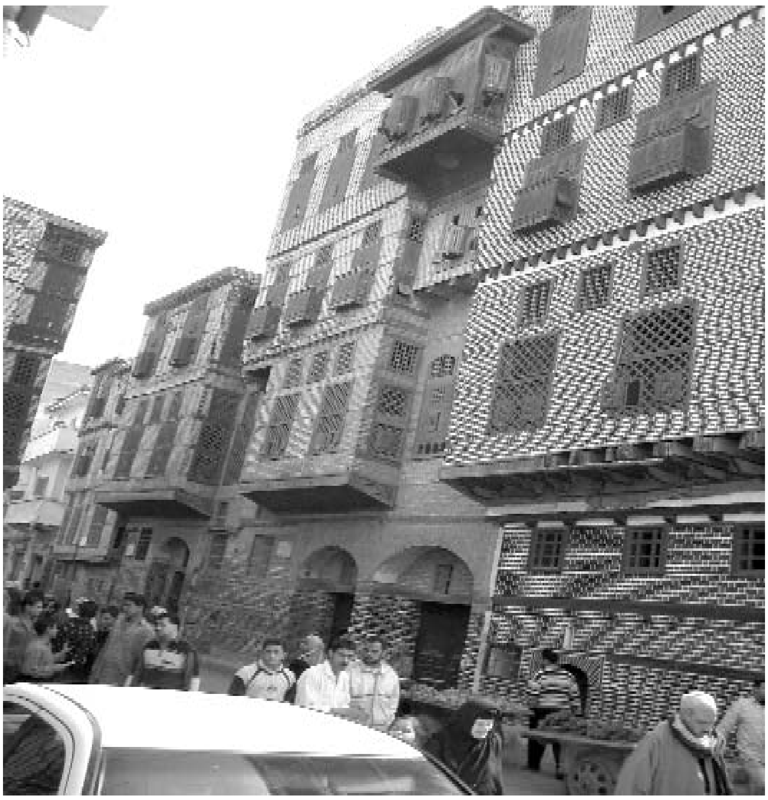

Photo 4. Rosetta: Characteristic Mangour building.

Gamalia

The Gamalia area was built by Fatimids in 969 and surrounded by a wall with Bab al Nasr and Bab al-Foutuh gates in the north, and Bab Ziwaila in the south. This area is remarkably rich in historical buildings and cultural heritage. Examples are: Bayt al Suhaymi, Al Aqmar mosque, Sabil Kuttab of Abdel Rahman Kathuda, Beshtak Palace, Wekalet Bazara, etc.

FEDA in 1994 identified various problems that threatened this heritage, namely poverty, congestion and deterioration of residential buildings, wear and tear of sanitation network, accumulation of garbage, noise pollution, absence of street lights, lack of public concern and utter negligence of historical buildings (e.g. some used as warehouses, workshops and commercial shops), illegal occupancy of roads; and poor social and medical. Field survey showed that almost 50% of buildings suffered serious deterioration. Some workshops in the area had severe impacts on water, air quality, sonic and visual environments, and the physical structure of historical buildings.

Recently, a major effort has been made to improve the Gamalia area through the efforts of several governmental agencies (Cairo Governorate, Department of Antiquity of the Ministry of Culture, Ministry of housing, Ministry of Environment, and the Ministry of Wakf "Endowment") in cooperation with international agencies (specially those interested in Islamic monuments) and NGOs.

FEDA, in cooperation with the Cairo Governorate and the Wakf Authority, has been working in the area since 1994. Swiss Fund for Development, Finnish Embassy, Ford Foundation, UNESCO, American Embassy, GTZ, etc. have supported FEDA in implementing a major project for the sustainable development of Gamalia through renovation of deteriorated buildings (Kahla, Khroub, El Rabae) and initiating " Workshop and Handicraft Training Complex" at Kahla, "Center for Community Development” at Kharoub, and " Center for Training and Technological Upgrading" at El Rabae. In addition, a new local NGO was established and capacity building courses are being offered to ensure sustainability of FEDA's program. A number of activities in health, environment, literacy, school drop-out control, computer literacy, etc. were introduced to improve the living conditions of the community.

Photo 5. Gamalia: Beit Seheimy

Wadi El Natroun

This desert area in Beheira Governorate is known for its historic Coptic monasteries. One of the most popular ones is the Monastery of St. Macaruis, which lies 92 km away from Cairo on the western side of the desert road to Alexandria, and which was founded in 360 AD by St. Macaruis the Egyptian, the spiritual father to more than four thousand monks of different nationalities (Egyptians, Greeks, Ethiopians, Armenians, Nubians, Asians, Palestinians, Italians, Gauls and Spaniards).

In 1969 the monastery entered an era of restoration, both spiritually and architecturally, with the arrival of twelve monks with their spiritual director Fr. Matta El- Meskeen, who had spent the previous ten years living together isolated from the world in caves in Wadi- el Rayyan, about 50 km south of Fayyum. At present, under the Patriarch Shenouda III, who has also restored two other monasteries in Wadi Natroun (St. Bishoy and Baramos), the monastic community of St. Macarius comprises some 100 monks. Most of them are university graduates in such diverse fields as agriculture, medicine, veterinary medicine, education, pharmacology and engineering, and have had job experience before entering the monastery.

Photo 6. Gamalia: Sabil Kuttab Katkhoda.

Photo 7. Gamalia: Kalawoun group of mosques.

Photo 8. Gamalia: Entrance of Kalawoon School.

Photo 9. Gamalia: Islamic architecture.

Photo 10. Gamalia: "FEDA's Center for Community Development" at Kharoub Wekala.

The new monastery buildings were designed and constructed by the monks qualified in these fields. They include more than 150 cells (each comprising a room for prayer and study, a bedroom, bathroom, kitchen and small balcony), a large refectory, a library with space for several thousand volumes, and a spacious guest house. Buildings to house various utilities have also been constructed, including a kitchen, bakery, barns, garages, a repair-shop and a print shop. In addition, the historic buildings in the monastery have been carefully restored under the supervision of prominent archeologists under the auspices of the Egyptian Department of Antiquities.

During the restoration of the big Church of St. Macaruis, the crypt containing the relics of St. John the Baptist and Elisha the prophet was discovered below the northern wall of the church. These relics were then gathered in a special reliquary and placed before the sanctuary of St. John the Baptist in the Church of St. Macaruis.

The monks of St. Macaruis have been reclaiming and cultivating the desert land around the monastery since 1975. First they planted fig and olive trees, number of fodder and other crops, especially water melons. Large farm buildings were constructed north of the monastery to house cows, buffalo, sheep and poultry. The Egyptian government has recognized the importance of their work in these areas in solving the country's food supply problems. Particularly appreciated is the introduction and adaptation to Egyptian conditions of the new strains of livestock, poultry and crops. In appreciation of their pioneering work, President Sadat donated to the monastery in 1978 some 400 ha of desert land and field equipment and arranged drilling of a new well to get groundwater which is the only source for irrigation in Wadi Natroun.

The Desert Development Center (DDC) of the American University in Cairo (AUC) – which was established in 1979, had excellent relations with the St. Macaruis Monastery and Fr. Matta El-Meskeen. An animal husbandry program was established in the DDC on procuring a number of Brown–Swiss cows and a bull from the monastery. A hybrid of Brown-Swiss and local breed is now forming the major animal stock at DDC. Fodder beet was cultivated for the first time in Egypt by the monks of St. Macaruis. This was also adopted by DDC since this crop needs much less water for irrigation compared to alfalfa and clover.

Photo 11. Wadi El Natroun: St. Macarius monastery.

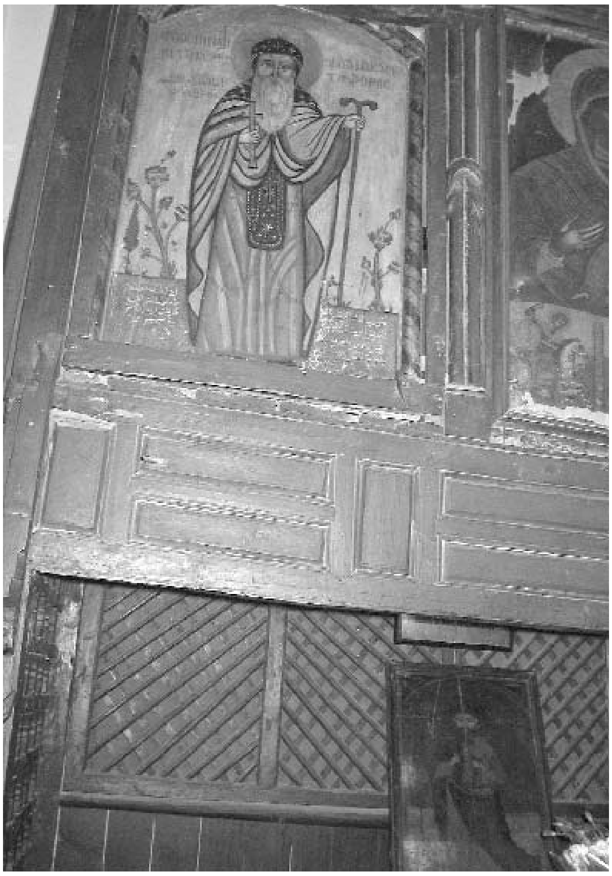

Photo 12. Wadi El Natroun: St. Macarius Church.

Photo 13. Wadi El Natroun: St. Macarius Church.

Photo 14. Wadi El Natroun: Desert Agricultural activities by St. Macaruis Monastery.

Sustainable desert development

FEDA's desert development program was based on the philosophy of the DDC, which the author founded in 1979 and directed from 1979 to 1993. It adopts a systems approach integrating biological, technological, and community aspects of desert development. The DDC integrated approach advocates that a desert should be treated as a desert (no outside manure or silt added to the land), and that desert development should be based on a balance of appropriate indigenous methods with modern technology. Any trials for improving productivity should be environmentally compatible with desert conditions and economically replicable under the prevailing social and technical constraints.
FEDA implemented a Pilot Demonstration Project for Sustainable Development at Wadi El Natroun. The objective was to achieve sustainable desert development, with emphasis on reducing greenhouse gas emission and protecting biodiversity. More specifically the primary objectives were to:

1. Reduce greenhouse gas emission through replacing use of fossil fuels by solar water heaters, biogas and passive solar architecture, and through planting different kinds of trees and crops.
2. Protect biodiversity through conservation of indigenous medicinal plants and micro-organisms available in Wadi El Natroun and through biological agriculture of fodder crops for grazing animals.

Photo 15. Wadi El Natroun: Brown Swiss bull offered to Desert Development Center (DDC) for initiating DDC's animal husbandry activities.

3. Use sprinkler and drip irrigation techniques to ensure rationalization of use of good quality irrigation water and enhance use efficiency.
4. Promote awareness amongst the Wadi El Natroun community and the members of FEDA about importance of a clean environment, reducing greenhouse gases and protecting biodiversity.

FEDA also adopted a scenario to solve problems caused by water scarcity, energy limitations and population increase as well as the problems facing graduates and small farmers allocated reclaimed land in the desert. The scenario aimed at creating viable multipurpose communities involving agriculturally reclaimed land as well as industrial, agro-industrial, and urban activities. Since the present horizontal expansion has not succeeded in attracting a sizable part of the population, the proposed multipurpose communities should be structured in such a way to provide its residents with technical, financial, social, economic, and cultural services (Bishay, 1999).

It was also proposed that mechanisms should be established to create holding companies based on the partnership of graduates and small farm own-

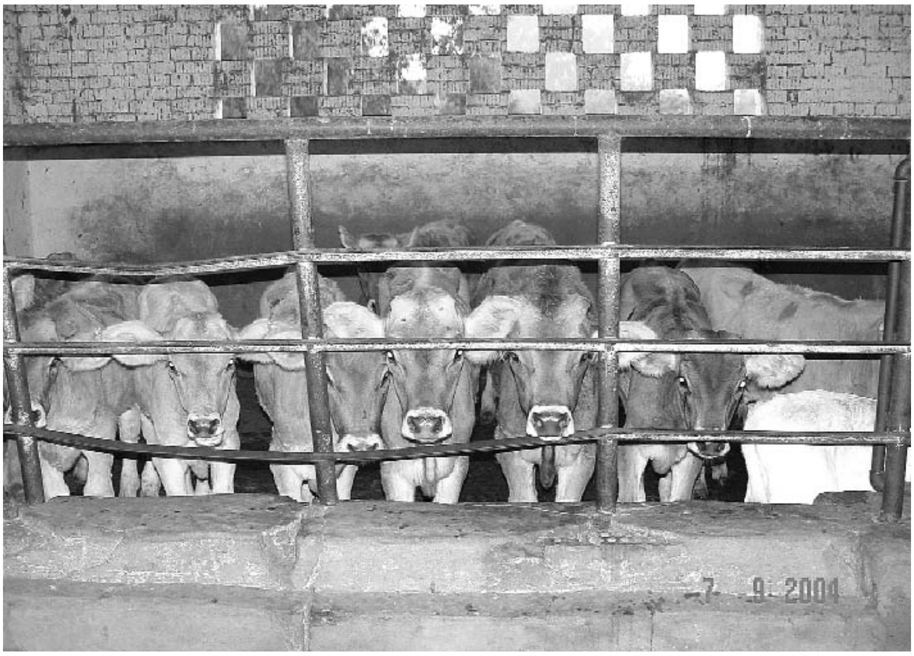

Photo 16. DDC: Brown Swiss / local hybrid at AUC Desert Development Center (DDC).

Photo 17. DDC: Brown Swiss / local hybrid grazing on alfalfa.

ers, as well as small business owners and other investors in the area. This will minimize the cost of procurement of their inputs and maximize quality and quantity of their outputs. It will also help them in processing and marketing their products as well as providing general services for the community.

Emphasis was also to be put on cost recovery of irrigation water and using special water distribution systems, both of which would help in rationalization of water use. The multipurpose communities will have treatment and recycling facilities for used water which would be applied for irrigation of trees and for cooling purposes in the manufacturing systems. Also available in each multipurpose community will be appropriate systems for anaerobic digestion of organic solid waste to obtain biogas (for energy) and organic fertilizer, in addition to means for recycling of domestic and industrial solid waste for other purposes.

The problem of over population in the delta and Nile valley is still considered the major obstacle in achieving sustainable development in Egypt. The following Table shows a decrease in the individual's share of agricultural land from 0. 53 feddan per person (2226m^2) in 1897 to 0.11 feddan per person (462m^2) in 2004 (Table 1).

While 2.9 million feddans of reclaimed lands has been added between 1897 and 2004, the increasing population necessitates further development. However, although the inhabited area of Egypt's land is only 12.5million feddans (5.25% of the total area), the problem is not because of the availability of land but because of the limited availability of water for irrigation and other activities.

Table 2 shows the amounts of water needed and available in 1997 when the total population was only 61 millions. It also shows the amounts of water needed in 2017 to satisfy the requirements resulting from increasing population and the aspiration of adding 3.4 million feddans of newly reclaimed lands.

Although there is hope for increasing the available water through the Gongli canal (in southern Sudan) and through technical and social rationalization of

Table 1. Change in the per capita agricultural land in Egypt, 1897-2004.

Year	Population (millions)	Agricultural land (million feddan*)	Share per person (feddans)
1897	9.4	4.90	0.53
1966	33.2	6.00	0.20
1976	38.2	6.12	0.16
1990	55.0	7.00	0.13
2004	71.0	7.80	0.11

** 1 Feddan = 0.4 ha*

Table 2. Actual amounts of water needed and available in 1997 and 2005 and the anticipated need in 2017 because of the anticipated addition of 3.4 million feddans of land through reclamation. (Source: Ministry of Water and Irrigation, Government of Egypt, GOE).

Water needed (billion m^3)	1997 (actual)	2005 (actual)	2017 (anticipated)
Agriculture	52.13	58.0	67.80
Domestic uses	4.54	4.80	6.60
Industry	7.42	7.60	15.00
Navigation	0.15	0.20	0.20
Evaporation losses	2.10	2.50	2.90
Total	66.34	73.20	92.50
Water available (billion m^3)			
Egypt's share of Nile water	55.50	55.50	
Ground water (Valley / Delta)	4.80	6.20	
Reuse of agricultural waste water	4.90	8.10	
Decreasing losses in Mediterranean	0.15	0.15	
Savings from irrigation upgrading	0.15	0.15	
Desert ground water	0.57	1.00	
Treated sanitary water	0.20	1.10	
Rain water on the North coast	1.00	1.16	
Total	67.27	73.36	

water use, as well as by increasing the re-use of agricultural waste water and treated sanitary water, the scope for further expansion of cultivated area in the desert is still uncertain; it could be between 1.3 and 3.4 million feddans by the year 2017, taking into consideration the huge expansion projects already initiated by the GOE in Toshka and Sinai. An additional 20 billion m^3 of water would be needed by 2017 in case an additional 3.4 million feddans were reclaimed by that time.

While vast strides have been made during the last two decades in adopting modern agricultural techniques which helped in increasing land productivity, attracting a good number of young men and women to work and live in the desert continues to be a big challenge despite some governmental programs to encourage migration to reclaimed desert land and desert cities.

In order to achieve this goal and sustain the development of this fragile ecosystem, several actions are necessary as shown in Fig. 2 and briefly described below:

1. Upgrade physical conditions, improve infrastructure and supporting services

Shortage in supporting services and infrastructure has resulted in citizen unsettlement in the newly reclaimed desert areas and the poor ability of these areas to attract citizens originally living in the delta and Nile valley. The strongest factor for the out-migration in the newly reclaimed lands is the feeling of isolation of the individuals because of lack of communication with family and friends outside the area. This includes lack of easy and inexpensive means of transportation, telephone, mail and emergency services, especially health and first aid facilities, as well as attractive and cheap housing and recreational facilities. It is not enough to build a hospital without reliable doctors, nurses and necessary medical supplies. It is not enough to build a club without the equipment and budget to run it. It is also not encouraging to move to an apartment in the desert which is not different from that in the overcrowded city. The experience of the Desert Development Center in building beautiful, environmentally compatible, and comfortable housing has not yet been adopted by the Government, although some private companies have done so to a limited extent. The use of renewable energy (solar, wind, biogas), which has proved successful and environmentally attractive by DDC, is still not developed by the GOE.

2. Develop democratic community structure and strengthen capacity of the community

There is a need to develop democratic community structure and strengthen local organizations so as to enhance their ability to participate in sustainable human and economic development in the area.

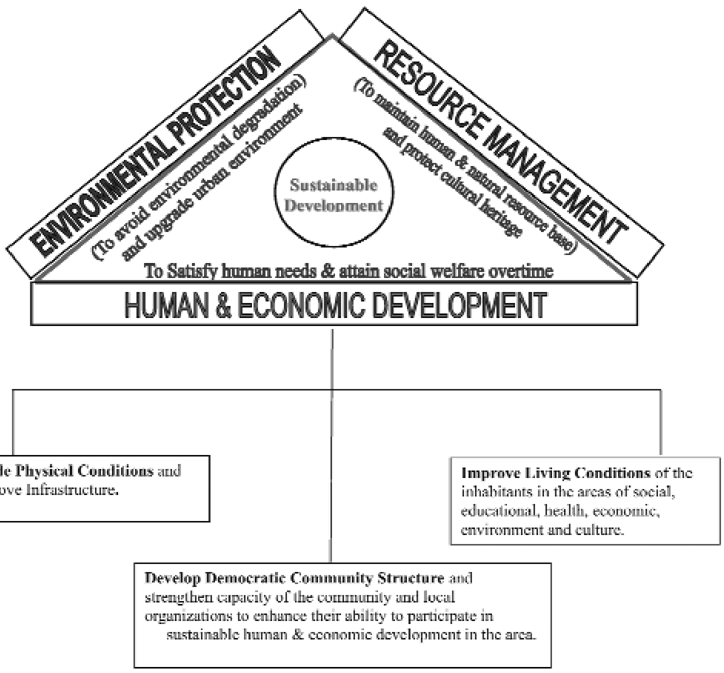

Fig 2: Measures taken to attract settlement and sustain development of fragile ecosystems.

FEDA proposed the formation of five 'Specialized Committees' in each location, namely: water and irrigation; infrastructure and services; education and youth; health and environment; women and gender. Each committee consists of 5 members of the community and a representative of FEDA. The head of each committee is chosen from the community by its members. Each committee is responsible for identifying the problems in their field of specialization and to propose solutions. A committee of the five heads along with a representative of FEDA constitutes a 'Follow up Committee'. Its major role is to list the problems identified by the different committees according to their community priorities. This forms the basis of the agenda to be adopted by the 'District Committee' which is chaired by the Head of the District or an equivalent authority and has the membership of the concerned governmental departments as well as some members of the ' Follow up Committee' and FEDA representative. In order to ensure the sustainability of projects initiated in the area, FEDA forms a local NGO from members of the community who are keen to continue the work for the area. Capacity building programs are offered for the members of the five 'Specialized Committees', the 'Follow up Committee' and the 'District Committee' as well as members of the Board of the local NGO. This enables them to respond to the needs of their community and sustain the development activities.

3. Improve living conditions

The inhabitants have to be provided social, educational, culture, health, environment and economic support through training, technological upgrading and providing necessary services and facilities. Some examples are given below:

a) Illiteracy alleviation activity: A number of farmers migrating to the desert are not literate. The first step is to train some of the university graduates having land in the same area to teach these farmers. This is followed by offering a number of classes for illiterate men and women. Some incentives should be given to those who succeed.

b) Computer training program: Training courses are provided for students in the neighborhood and for university graduates who are not computer literate. The program covers introduction to the use of computers and accessing Internet, which would help them get well connected.

c) Environmental awareness and education: In addition to conducting environmental awareness meetings with students in the area, it is imperative to offer some training sessions to teachers in the schools of the area. Based on dialogues and group discussions as well as theoretical and applied presentations, the participants are introduced to different environmental topics covering natural resources, types of ecosystems, pollution, environmental changes, etc. This should be followed by identifying environmental topics already found in the syllabus, how to introduce the environmental dimension in different courses, and the ways to achieve this. The topics of water use rationalization as well as restrictions on the use of pesticides and fertilizer selection are very important not only to the students but also to their parents. Environmental awareness for women is most important since it impacts their role as a mother and wife as well as a field worker.

d) Health program: While it is a major requirement to ensure the availability of good doctors, nurses, and assistants as well as medicines and functioning equipment in the health units of the area, it is also important to offer health awareness seminars to women and to school children in the area. Well stocked First Aid facilities in the Health Units and in schools and other institutions in the area are essential. In addition, a training course should be given every six months to women, who should also be provided a medical health kit.

e) Educational facilities: One of the main reasons for low rate of settlement in reclaimed desert areas and desert cities is the lack of appropriate educational facilities for the migrant's children. It is recommended that the proposed holding companies, in cooperation with civil society and the Egyptian Government, should initiate a program for improving school environments and constructing educational institutions with attractive facilities and promising staff in order to encourage migrants in the desert areas to bring their families with them and enroll their children in these schools.

Conclusions

FEDA has adopted the DDC integrated approach and has dealt with the problem of scarce migrant communities in reclaimed desert lands or new desert cities. This includes upgrading physical conditions and improving infrastructure and supporting services; developing democratic community structure and strengthening capacity of the community and local organizations, and improving living conditions. This can best be implemented through the local government in cooperation with the private sector and civil society and would thus lead to sustainable desert development.

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Progress in the aeolian desertification research of China

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Abstracts

Aeolian desertification is land degradation characterized by wind erosion mainly resulting from excessive human activities in arid, semi-arid and some sub-humid regions in northern China. The research on aeolian desertification has been underway for more than 5 decades along with the establishment and development of China's desert science. Researchers in this field have made a great contribution to the national economic development and environment protection. This paper focuses on presenting major progress and achievements in the field of aeolian desertification research during last 50 years, covering the stages of study on aeolian desertification, background environment of aeolian desertification and its changes, the concept, causes, process, monitoring and assessment of aeolian desertification, the vegetation succession, landscape ecology, plant physiology, impacts on ecosystem, highly effective use of water and land resources and sustainable development in aeolian desertified regions, and aeolian desertification control models and techniques. We suggest that the key fields of desertification research of China in the future should be the blown sand physics, process of sand storm formation and movement, ecology of desert environment and desertified region restoration, water and land resource utilization and agricultural sustainable development in desertified regions, and desertification reversion and control models.

Introduction

Desertification is one of the most serious environmental and socio-economic problems facing the world today. As the rapid expansion of desertification has resulted in serious environmental degradation, economic loss, instability in the local political situation, and social upheaval, it has become a very topical issue. During the late 1960s and early 1970s, as the catastrophic drought in western Africa greatly accelerated the development of desertification, the desertification became a matter of global concern. Therefore, the United Nations Conference on Desertification was held in 1977 in Nairobi, which discussed the scientific research needs and practical activities for implementing a worldwide plan of action to combat desertification. Since then, many projects on desertification have been carried out and have yielded very positive results. In China, thanks to the serious efforts of scientists and other experts, the desertification research has made a significant progress (CCICCD, 1996).

Stages of study on aeolian desertification in China in the last 5 decades

Desert and aeolian desertified land occupy about 1.67 million km^2, or 17 % of total land area of China (Fig.1; Wang et al., 2003). Some 5 decades before, scant attention was paid to the study of this wide territory, apart from some reference to and information about its archaeology, geology and other fields. Since 1950's, the management of sand deserts and aeolian desertified lands necessitated detailed studies on the climatic variation in arid and semiarid regions, formation and development of desert and aeolian desertification, and various measures to use the natural resources in desert and to combat wind erosion and aeolian desertification. This furthered greatly the studies of desert and aeolian desertification in northern China (Zhu and Wu, 1979; 1980).

The studies of aeolian desertification in China carried out in the last 50 years can be divided into the following three stages:

First stage, from 1950 to 1958: The studies on wind erosion were conducted for establishing local windbreaks, sand breaks and sand-accumulating fences. For instance, studies on the Mu Us Sandy Land (Luo, 1954; Yan, 1954; Zhen, 1957), that extends from Yulin, Jinbian to Dingbian in the north part of Shaanxi Province, were carried out with the aim of establishing a wide protective shelterbelt in that region. These studies concentrated on the origin of the sand materials of dunes, types of sand dunes and their movements, and means to control the movement. Aerial photos taken during this stage were used for the analysis of the features of wind erosion, sand dunes and their morphological types. Meanwhile, some experiments were conducted to measure the movements of blown sand and sand-drifting winds, in order to find out which conditions influenced sand movement, to verify the effect on sand stabilization if the sand surface was a plain field, and to test the sand-holding capability by mechanical means. These experiments were carried out along the railway from Zhongwei to Gantang of the Ningxia Hui Autonomous Region.

Second stage, from 1959 to 1965: A professional desert survey team comprising more than 800 scientists and technicians of various specialties was organized by the Chinese Academy of Sciences (CAS) in 1959. The greatest emphasis was on integrated surveys of natural conditions in arid and semiarid regions in the light of demands for taming sand desert and desertified land in the six provinces of Northwest China, namely, Xinjiang, Qinghai, Gansu, Ningxia, Shaanxi, and Inner Mongolia. The Taklimakan Sandy Desert (Zhu et al., 1960), Gurbantunggut Sand Desert (Chen, 1963), Badain Jaran Sand Desert (Yu et al., 1962; Tan ,1964), Tengger Sand Desert (Wu, 1960; Guo et al., 1962), Ulan Huh Sand Desert (Hou and Yu, 1973), Hobq Sandy Land (Li et al., 1962), Mu Us Sandy Land (Hou, 1973), Otingdag Sandy Land (Chen et al., 1962) and Horqin Sandy Land were included in this program and researches on the origin of desert sand, the changes of sand deserts (Zhu, 1963), and the patterns of movement of blown sands and sand-drifting winds were carried out during this stage (Wu and Ling, 1965; Zhu,1980). Methodologically, ground surveys and aerial-photo-interpretation were used for comprehensive investigations. Furthermore, some fixed stations of observation and experiment on the wind erosion process were built in the southern part of the Tarim Basin in the Xinjiang Uyghur Autonomous Region in Minqin county of Gansu in the Shapotou region of Ningxia and in Dengkou of Inner Mongolia.

Third stage, from 1965 to the present time: Large-scale surveys came to an end and the researches are shifting to special studies on the process of aeolian desertification and to protect soil from wind erosion and reduce wind-sand hazards. The changes in geomorphologic conditions and the physical and biological processes, which initiated the aeolian desertification, were studied intensively. The Desert Research Institute of CAS,

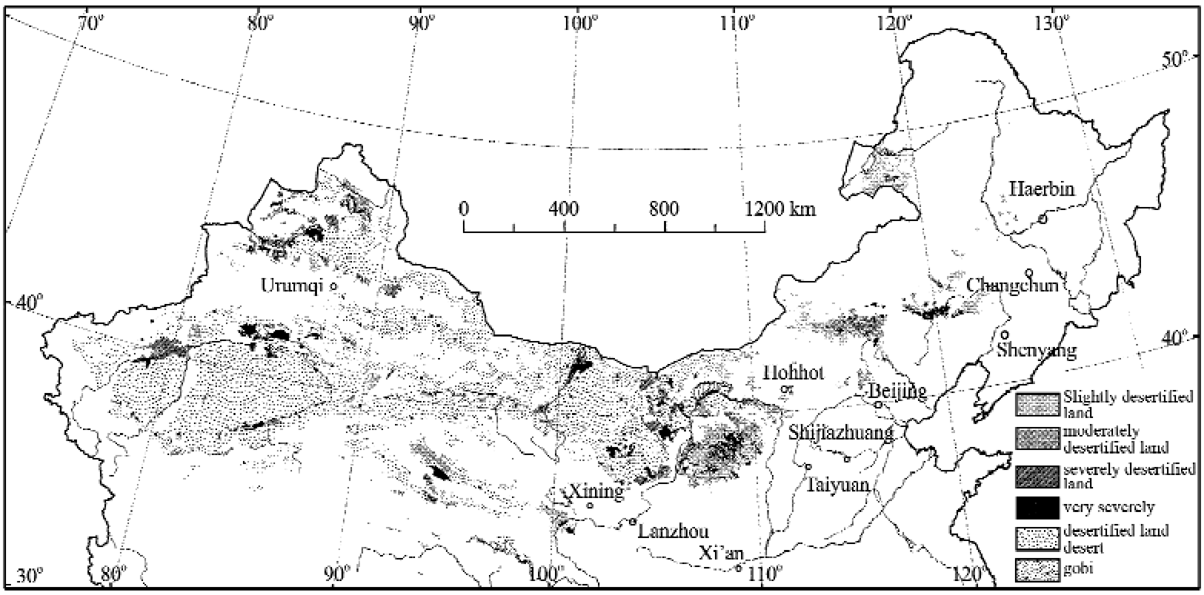

Fig1. Map of the deserts and aeolian desertified land in northern China.

and nine research and experiment stations were set up in different zones for studying and combating the process of aeolian desertification and these have produced a large body of scientific results and have gained much practical experience (Di et al., 1982; Liu et al., 1996; Zhu, 1989; Wang et al.,2003). Moreover, a wind tunnel has been specially designed and constructed to conduct experiments to throw light on the factors governing blow sands and sand-drifting winds that would be useful in protecting railways, highways, farmland and open mine fields against sand encroachment and wind erosion. Also, high-speed dynamic photography, PDV (Particle Dynamics Analyzer), and PIV (Particle Image Velocity-metry) are being used to study the movements of sand grains in the sand blown air in the wind tunnel.

The studies on the aeolian desertification in China mainly include the following aspects: (1) Studies on the background environment and its changes, occurrence, developmental process, and types and characteristics of aeolian desertification in arid, semiarid and some parts of sub humid regions in northern China; (2) Studies on the present status and distribution of aeolian desertification and the environmental changes; causes, damage and indicator system; (3) Establishment of demonstration bases for experiment and research in the rehabilitation of aeolian desertified land in different natural conditions selected in the regions seriously affected by aeolian desertification; and (4) Monitoring, mapping and assessment of aeolian desertification by remote sensing.

Initial study and research achievements on aeolian desertification in China

Concept of aeolian desertification

Desertification in China is caused by land degradation from aeolian desertification (wind erosion), water erosion, and silinization. Aeolian desertification is land degradation characterized by wind erosion mainly resulting from the excessive human pressure. This concept implies the following:

(1) Temporally, the desertification occurred during the period of human history, and got particularly accentuated in the past one century.

(2) Spatially, the desertification occurred in the arid, semiarid and part of sub humid zones with loose sand surface, where windy season and drought occur simultaneously.

(3) The above-mentioned natural factors and excessive pressure on natural resources by human activities (over cultivation, overgrazing, over cutting, overuse of water resource, etc.) are the main causes for desertification. Man is the maker as well as the victim of desertification.

(4) From the landscape point of view, desertification is a gradual process. Once human activities destroy the fragile ecological balance, wind becomes the driving force to rework the ground landscape of desertification. Therefore, ground features resulting from sand drift activities; wind erosion and deposition can be used as landscape marks of desertification processes and indicator of the degree of development of desertification.

(5) The developmental trend of desertification is related to desertification intensity, spatial distribution, and human and livestock pressure on land. Under the influences of these interacting factors and wind force, desertification automatically spreads.

(6) As a result, ground surface is gradually covered by sand dunes, land biological productivity is greatly decreased, and large areas of available land resources are lost. However, these lands also have the possibility to undergo self-recovery, which depends on the natural conditions (especially the water condition), landscape complexity of desertified land, and intensity of human activities.

Here, one should distinguish between the concept of deserts and desertification as the spatial scopes of desert and desertification research is different:

(1) Deserts in China mainly developed in different stages during the Quaternary Period and are mostly distributed in arid zones, with vast, complex and huge aeolian shapes. Desertification mainly occurred in the period of human history, especially in the past one century due to irrational human activities. Desertified lands are therefore not only distributed in arid zone but also in semiarid and sub humid zones, some times in relatively small area showing a patchy and interlacing distribution patterns on dry farmland and rangeland with small and simple aeolian sand features.

(2) Deserts are formed by natural factors, while desertification is man-made under natural factors conducive for it. The former occurred because of the climatic changes during the Quaternary Period; as the climate became cold

and dry, the desert expanded and fixed sand dunes turned into moving sand dunes; as the climate became warm and wet, the desert shrank or fixed. Such changes often had a large time scale. The development and reversion of the desertified lands generally occur under same climatic conditions with in a short time interval. In the past several decades, desertification in northern China developed rapidly due to excessive human activities rather than the climatic changes.

(3) Desert reactivation and expansion or fixation and shrinkage were controlled by climatic changes. Under modern climatic conditions desert formation is impossible. Only by adopting artificial measures can we fix sandy land or use the water resources in the desert region, for example, in the establishment of new oases. The development of desertified land is mainly controlled by human economic activities. Therefore, through readjusting land use structure and eliminating human disturbance from the desertified lands the former non-desert landscape or productivity level can be recovered. If some effective measures are adopted the restoration process can be accelerated.

Background environment of aeolian desetification and its changes

An important challenge is to understand what kind of background environment and its changes impacted the process of aeolian desertification during the last century in northern China. Some efforts have been made to understand the environmental changes and distribution of desert and sandy land in China since the last interglacial cycle.

Last interglacial period (130-70 kaBP): During this period there was warm and humid climate in northern China. Brown red paleosols or drab paleosols, which indicate forest-grassland environmental conditions, widely developed in the east, northwest and southeast sand region, Qinghai-Tibet plateau, and central sand region. Leaching-induced calcareous hardpans and concretions developed in Qinghai-Tibet plateau sand region and northwestern part of central sand region, and litter and burned layers formed at riverside and lakeside with high water table in the west sand region. This shows that the east, northwest sand region, Qinghai-Tibet plateau sand region, and the southeastern part of central sand region at that time were in a semiarid steppe, sub-humid forest-grassland or even humid forest environments, and the southeast sand region was entirely in a humid forest environment. Furthermore, magnetic susceptibility is also relatively high. All these reflect a warm and humid forest grassland climate (Dong and Li, 1986). Viewed from the climatic proxy indices such as pollen contents and magnetic susceptibilities in various sand regions and stratigraphic data (Dong et al., 1995; An. et al., 1991; Fang et al., 2002), the mean annual air temperature during last interglacial period was 4~6°C higher and annual precipitation was 50% higher than at present. The limit of desert was dominated by mobile dunes and the boundary of semiarid steppe (200 mm isohyet) retreated northwards to the line extending from China-Mongolia border to northwest edge of Badain Jaran Desert, northwest edge of Qaidam Basin and south slope of Kunlun Mountain. The 200 mm isohyet shifted northward and northwestward for 5-7° latitudes or about 500~700 km. The south of semiarid steppe (400 mm isohyet) shifted northward and northwestward to the line extending from China-Mongolia border to north Hetao and Qinghai Lake; the limit of sub-humid forest grassland and humid forest zone also greatly shifted northward. The north limit of sub-tropical evergreen and deciduous broadleaved mixed forest reached the region north of the Qinling Mountain; and the tropical rain forest extended beyond the line from the Nanling Mountain to Wuyi Mountain. The area of desert dominated by moving sand in China during last interglacial period greatly reduced, and it only occurred in the Taklimakan, Kumtag and north-west part of Badain Jaran desert regions. But the area of fixed and semi fixed aeolian land greatly expanded. The area of mobile desert during last interglacial period is equivalent to two-thirds of today's mobile desert area in northern China.

Last glacial maximum (21~16kaBP): During last glacial maximum (LGM) the climate in China was extremely dry and cold, aeolian sand widely deposited in the west, central and northwest sand region, Qinghai-Tibet plateau sand region, and east sand region, or even ancient aeolian sand wedges or ice wedge pseudomorph occurred (Dong et al., 1986). This suggested that vast sand region in China at that time had the arid desert and hyper-arid desert bioclimatic conditions. Furthermore, the semiarid steppe and arid desert steppe retreated to the east sand region. Analyses of pollen and stratigraphic data show that during the last glacial maximum the mean annual air temperature was 8-12°C lower than the current mean annual temperature, or even lower; and the annual precipitation was lower than one-third of the present average (Yang, 1985; Xu, 1982; Chen, 1990). The limit of arid desert dominated by mobile dunes and the boundary of semiarid steppe dominated by semi fixed and fixed sand dunes shifted southward to the line extending from Shandong Peninsula to Jinan and Xian. The 200mm isohyet shifted southward for 4-6° latitudes or 400~600 km, the south limit of semiarid steppe (400 mm isohyet) roughly reached the line extending from Nanjing to Wuhan and the sub-humid and humid forest grassland climatic zones also correspondingly shifted southward and thereby resulted in the disappearance of tropical rain forest in the continent of China. During LGM, thick and high-maturity ancient aeolian sand widely deposited in the strata of desert and aeolian land in China. The area of desert dominated by mobile dunes was much larger than that of today and intense mobilization of sand dunes in the west sand region, northwest sand region and central sand region resulted in the spread of mobile dunes. The moving sand widely spread in the east sand region or the process even occurred in the exposed continental shelf of the Bohai Sea and Huanghai Sea in the southeast sand region (Zhao, 1995). The area of desert dominated by mobile dunes during the last glacial maximum was about twice more than today.

Holocene megathermal (Hypsithermal, 8–3kaBP): During Holocene megathermal the climate in China was warm and humid; 1-3 layers of black paleosols widely developed in the east, northwest and central sand regions and southeastern part of Qinghai-Tibet plateau sand region. Semi fixed and fixed shrub sand mounds or flood deposits formed in places near the rivers and lakes with high water table in the central sand region and northwestern part of Qinghai-Tibet plateau sand region, which suggested that the majority of China's sand regions had semiarid steppe, sub-humid forest grassland or even humid forest bioclimatic conditions. From pollen and magnetic susceptibility data and stratigraphic records it can be inferred that mean annual air temperature during Holocene megathermal was 3-5°C higher than today and annual precipitation was one-third to two-thirds higher than the present average. The limit of arid desert dominated by mobile dunes and the boundary of semiarid steppe (200 mm isohyet) shifted northward to the line extending from China-Mongolia border to Jiayuguan, Qidam Basin, and mid-north Qinghai-Tibet plateau. The 200 mm isohyet shifted westward for 4–5° latitudes, or 400–500 km, while the south limit of semiarid steppe (400 mm isohyet) roughly reached the line extending form Erenhot to north Hetao, Xitao, Xining and Lhasa. The area of mobile dunes during Holocene megathermal was about three-fourths of the area of today's mobile dunes.

Viewed from the spatial changes of desert and sandy land in China during different characteristic cold and warm intervals since the last interglacial period; the west sand region, central sand region and northwestern part of Qinghai-Tibet plateau sand region belonged to arid desert no matter it was in cold and warm interval. In the west sand region, central sand region and northwestern part of Qinghai-Tibet sand region, especially in the east sand region and south sand region sand dune mobilized, moving sand area expanded during cold interval but in the warm interval sand dunes were stabilized and moving sand area reduced. Therefore these sand regions were alternately fluctuating steppe-type sand land. When the Holocene megathermal came to an end the average position of bioclimatic zone where desert and sandy land lie and the characters and features of various sand region were roughly same as present. Hence, the Holocene megathermal is virtually the establishment period of the spatial distribution patterns of desert and sandy lands in China.

Causes of aeolian desertification in northern China

Aeolian desertification is a process of land productivity diminution, land resource loss, and desert-like landscape development in arid, semiarid and parts of sub-humid region. What causes this type of desertification has always been a major topic in the research. Only when the cause of aeolian desertification is correctly understood can one put forward effective control measures to solve the degradation problems. The causes can be divided into two categories, namely natural and human.

Occurrence and development of aeolian desertification is a common phenomenon in arid and semi-arid region of China. For example, wind erosion and moving dune encroach the oases and river terraces and cause natural vegetation destruction in the wind gap area. Global climate change, especially the climatic warming and aridification in the mid-latitude regions, is a major ecological condition favoring the development of aeolian desertification. The presence of some adverse factors such as dry climate, erratic precipitation, sandy soil texture, erodible land surface, and especially the strong and frequent wind, that provides dynamic force for the erosion, are the other major natural factors. However, there always exists a certain self-regulating capacity in the nature and earth surface system, and once this system suffers from slight damage it can be self-regulated by its internal feedback mechanism and thereby maintaining the stability of the system. Aeolian desertification from natural causes often occurs on a small scale, is low in severity and can be easily reversed.

Human cause is considered as major factor of the aeolian desertification in northern China. Studies done in China have shown that the aeolian desertification mainly occurred during the period of human history and developed particularly rapidly during the last century. The changes in natural conditions, particularly the climatic fluctuations, over a century are generally small and therefore insufficient to cause great changes in the natural environment. However, rapid increase in human population pressure and disturbance to natural environment caused by increased economic activities can lead to serious deterioration of eco-environment and rapid development of aeolian desertification. Many archaeological data and field investigations have proved this. When the arid and semiarid regions in northern China were occupied by nomadic people, there was almost no pressure on the eco-environment and the land, but after the nomadism was replaced by agricultural production the eco-environment suffered great damage. It is generally accepted that rapidly increasing population-induced over-cultivation, over-grazing, over-cutting of fuel wood, over-exploitation of groundwater, etc., coupled with poor ecological management, destroy the land cover and finally lead to wind erosion and aeolian desertification. Destruction of natural vegetation by human activities accelerates the development of aeolian desertification. For example, such human impact can increase wind erosion by 4 to 10 times in contrast to that occurring because of natural factors. Along with the aggravated aeolian desertification, there is 3 to 10 times acceleration of loss of soil nutrients, bio-diversity, and bio-production in contrast to what could occur naturally (Wang et al., 2002). Man-made destruction of ground cover reduces soil water-holding capacity, suppresses airflow rise and convergence, enhances surface albedo, intensifies descending airflow and finally leads to climatic aridification. The aeolian desertification induced by anthropogenic causes can bring much faster and severe damage to the ecosystem than the natural factors.

According to field investigations and remote sensing data analysis of various types of aeolian desertified lands in northern China, over-cultivation-induced aeolian desertified land area occupied 25.4% of the total aeolian desertified area, over-grazing-induced area was 28.3%, over-cutting fuel wood-induced area was 31.8%, that caused by misuse of water resources and vegetation destruction due to industrial construction was 9%, and that resulting from sand dune encroachment occupied 5.5% (Zhu and Wang, 1990). Thus, the human factors are the most important in affecting aeolian desertification process. But, the human activities can also reverse the aeolian desertification by adopting rational land use and various measures of prevention and cure for combating aeolian desertification.

Studies on aeolian desertification processes in northern China

Aeolian desertification is a complex eco-environmental degradation process, which occurs as the ecosystem suffers from serious disturbance leading to ecological imbalance and vegetation destruction. Progress has been made in China in research on aeolian desertification processes as described below.

Vegetation degradation research: Vegetation degradation due to human interference is mainly manifested in the reduction of plant biodiversity, height, coverage and biomass. As the time passes, small bare spots develop on the surface, perennial grasses gradually decrease, non-palatable annual species and shrubs or sub-shrubs become dominant, and plant communities become simple and sparse. The bare ground spots gradually expand and coalesce to form larger areas. However, if external disturbances are removed, some plants in the shrub lands or inter dune depressions can gradually recover.

Soil degradation research: Soil degradation is mainly manifested in the soil skeletonization, impoverishment and desiccation under the influence of wind erosion. Sandy soil has coarse texture; sand grains larger than 0.05 mm generally occupy 95% or more of total max, clay particles smaller than 0.001mm usually less than 1%. There is poor cohesion. Once the threshold wind velocity is reached, fine soil particles and organic matter on the non-vegetated surface begin to blow away, rendering the soil coarser and sandier. The soil water-holding capacity and soil moisture content decrease. Once a drought event occurs, plants wither or even die. As the plough layer gets eroded by wind, crop production becomes impossible due to serous water and fertility loss (Zhao et al., 1998).

Aeolian sand landform research: The central problem is to elucidate the laws that govern the occurrence and development of surface sand drift activities, i.e. the physical processes of wind-sand stream. Great progress has been made in several areas in this regard. Studies on the development process of sandy surface features under wind force have revealed that under the interaction between wind force and exposed surface, surface particles begin to roll and initiate saltation or are transported in suspension to form wind-sand stream and further initiate the wind erosion and depositional geomorphologic processes. Studies on reactivation of fixed sand dunes have shown that wind erosion takes place on the windward slope to form reactivated spots-blowout-wind eroded scarps. Windward slopes of blowouts become gentle and grass coppice dunes occur at the downwind side. Small shifting sand patches, semi shifting sand patches, moving dunes, and mobile grass coppice dunes are typical moving dune landscape. Studies on sand dune migration processes around the fringe of sandy desert under wind force have shown that as wind blows over the windward slope of moving sand dunes, saturated wind-sand steams form and much of the sand gets deposited on the leeward side due to vortex disturbance and wind velocity reduction. This makes the sand dunes to advance gradually. Aeolian desertification process is also a sand drift movement process dealing with wind erosion, transportation and deposition, which occurs following the man-made upset of ecosystem balance and destruction of vegetation. The blown-sand physical processes include: (1) developmental processes of sandy surface features under the action of wind force; (2) reactivation processes of fixed sand dunes; and (3) sand dune migration processes around the fringe of sandy desert under the action of wind force.

Aeolian desertification indicators and its monitoring and assessment

For using remote sensing data to monitor aeolian desertification, the first thing is to establish the classification indicator system of aeolian desertification. Our studies (Wang, 1986; Wu, 1997; Wang and Wu, 1998; Wang et al., 2004) showed that useful indicators for the desertification processes and environmental conditions can be divided into natural, biological and social indicators.

Natural indicators include the dynamic data of wind-eroded land, sand land or sand dune spread, seasonal and annual change of precipitation, wind direction, wind velocity, effective soil thickness, organic matter content, groundwater depth and quality, surface albedo etc. Biological and agricultural indicators include vegetation cover, biological production, key plant species distribution, land-use regime (e.g. farming, grazing, fuel collection, industrial water resource use, etc.), crop yield, livestock composition and number, and various economic input). Social indicators include inhabitant population, structure, variation processes and developmental trend, health indexes, mandatory policy or stage-specific policy etc.

According to desertification processes in northern China, human activity characteristics and existing monitoring results, we summed up the following directly usable indicators, which can be obtained and analyzed by remote sensing and computer means: a) Wind-eroded land area or moving sand area percent in the total land area of a region; b) Annual percent increase in the area of wind-eroded land or moving sand in the total land area of a region; c) Vegetation cover mainly in case of grassland and forest land; and d) Biological production. From this we can give out a general classification of degree of land desertification and their indicator. According to mapping analysis and calculation of aerial photographs taken in the late 1950s and mid 1970s, aeolian desertification in northern China was expanding at an annual rate of 1560 km^2. This is mainly attributed firstly to aeolian desertification of rain-fed farm land which was reclaimed in the steppe and desert steppe regions, and secondly to reactivation of fixed sand dunes due to cultivation, overgrazing and uncontrolled removal of natural vegetation. By the late 1980s, desertified land area in China reached 33.4x10^4 km^2, of which very severely desertified land occupied 10.2%; severely desertified land 18.3%; moderate aeolian desertification land 30.5%; slightly and potential aeolian desertification land 41.0%. The development trends showed that aeolian desertification in local places had been reversed. However, on the whole, it was still expanding. From the mid 1970s to the mid 1980s, desertified land area increased by 2.1x10^4 km^2, an annual increase of 2100 km^2 (Zhu and Wang, 1990). It was mainly distributed in three regions: the over cultivation regions in Bashang area of Hebei Province, Ulanqab grassland and Qahar grassland in Inner Mongolia; the reactivation regions of fixed sand dunes in east Korqin Sandy land of Inner Mongolia due to overgrazing, over cutting and over cultivation; and the energy source base in the sandy steppe region, for example, the Shenfu coalfield, etc. These are also the key regions needing rehabilitation in the future.

Rehabilitation of aeolian desertified lands

According to natural and economic characteristics, desertification developmental trend, and problems and experiences in the utilization and rehabilitation in northern China, the rehabilitation should seek a unified objective of ecological, economic and social benefit, follow the ecological principle of conservative use and multi-project complementation, and be integrated with utilization. In the mixed agro-pastoral desert region, with scattered ecological households, such measures as grazing exclusion, readjusting rain-fed cropland use structure, expanding forest and grass land area, establishing farmland forest net and inter-dune patchy forest have been adopted. In the grazing grasslands, efforts should be made to define rational stocking rate, carry out rational rotation grazing, establish artificial grasslands and fodder banks, dig wells for drinking water and build roads. In the arid zones, an overall planning with water basin as an unit should be worked out, to rationally distribute water, establish farmland forest net inside oases and tree shrub sand break belt around the margin of oases, and set up mechanical sand fences to form a comprehensive protection system. In addition, the traffic lines in the dense sand dune regions should be protected by sand fences and sand –fixing plants, laying emphasis on fixation in combination with blocking and diversion (Zhu and Chen, 1994).

Chinese scientists have thus made some encouraging achievements in the field aeolian desertification research and provided scientific basis for working out the aeolian desertification control planning in the country. China’s experiences in this area have attracted widespread attention from international communities, especially the developing countries. Entrusted by UNEP and ESCAP, the Lanzhou Desert Research Institute of the Chinese Academy of Sciences has organized 12 training seminars and international symposiums on aeolian desertification control and sent expert groups to Mali to forge cooperation and help in aeolian desertification control planning.

Progress in aeolian desertification research in China in the last 10 years

There were many encouraging results from the studies on aeolian desertification during the last decade (Wang et al, 1999; 2002). A summary is given below.

Fundamental research on aeolian desertification

Blown sand physics and sand drift control engineering: The dynamics of wind-sand, gas-solid two phase flow, aeolian bed form movement theories, soil wind erosion theory, theory of similarity concerning aeolian sand experiment, sand drift control engineering have been studied. These researches contribute to a better understanding of the physical principle of aeolian desertification. In particular, some clear picture of single grain movement has been obtained and the related mathematic models have been established; the physical and mathematic models of wind-sand, gas-solid two phase flow movement were preliminarily established on the basis of classic multi-phase fluid mechanics; and a set of theoretical parameters of similarity on sand drift experiment were put forward.

Desert evolution and climatic changes: In this respect much work has been conducted on desert deposits, types, climatic features and their environment significance. Desert were divided into three ages, their spatial distribution patterns, regional differentiations and development patterns were studied, and the emphasis was placed on the climatic environments and causes of formation of pre-Quaternary red desert and Quaternary yellow desert. In addition, the developmental history, present status and future development trend and countermeasures of modern aeolian desertification were explored.

Micrometeorological study on aeolian desertification: Comparative studies on farmland, grassland and sandy land showed that aeolian desertification has significant influences on micrometeorology. In the aeolian desertification processes, surface radiation balance, heat balance, and soil water balance are greatly altered due to the change in underlying surface. For example, wind velocity profile over vegetated area shows a logarithm distribution, surface boundary layer thickness in daytime is 2.7 m, in night 5 m or more and surface drag coefficient $3.2x10^{-3}$. Wind velocity profile over moving dunes shows a logarithm distribution in night but bends toward IN axis in daytime. Surface boundary thickness is less than 0.7m and surface drag coefficient $1.9x10^{-3}$. As a result, sand dune surface receives greater wind stress and sand grains are prone to deflation. In the aeolian desertification process, with destruction of vegetation, surface reflectivity sharply increases, while net radiation and latent heat exchange decrease. Surface reflectivity over non-desertified land surface is generally less than 0.15-0.20; the figure over degraded land surface ranges from 0.25-0.30 and shifting sand area 0.35-0.40. With the establishment of artificial vegetation on sand dunes, the surface reflectivity decreases and vertical wind stress reduces. The presence of vegetation dissipates much of airflow momentum and rising temperature and humidity protects sand surface from direct deflation and therefore is favorable for sand dune stabilization (Zhao, 1997).

Dynamic monitoring and assessment of aeolian desertification in northern China

Much work has been conducted on the development, distribution and damaging processes of aeolian desertification in northern China using remote sensing and GIS techniques, making the aeolian desertification research enter quantitative analytical and economic assessment stage. Based on 1:4000000 map of aeolian desertification disaster risk, a pilot run system of aeolian desertification disaster monitoring and assessment has been established. Researches have shown that effective aeolian desertification monitoring indicators are: (1) Natural indicators — changes in wind eroded land, sand land or sand dunes, dust storm, seasonal and yearly changes in precipitation, wind velocity and direction, effective soil layer thickness, organic matter content, table and quality of ground water, surface reflectivity, etc.; (2) Biological and agricultural indicators – vegetation cover, biomass, main plant species distribution and frequency, land use status, crop yield, livestock composition and quantity, etc.; and (3) Social indictor – population changes and trends, residential form, public health index, mandatory or special policies, etc.

The monitoring results of aeolian desertification in 2000 showed that the total aeolian desertification area increased by 46740 km^2 from 1988 and reached at least 38.57×10^4 km^2, or an annual increase of 3600 km^2 in northern China. Among this the slightly aeolian desertified land occupied the largest percentage, about $13.93\times104km^2$, accounting for 36.1% of total aeolian desertified land area and 5% of total monitoring land area. This was followed by moderate land, about 9.977×10^4 km^2, accounting for 25.9% of total aeolian desertified land area and 4% of total monitoring land area; severely desertified land 7.909×104 km^2, accounting for 20.5% and 3.0% respectively; very severely desertified land 6.756×10^4 km^2, accounting for 17.5% and 3.1% respectively. Slight and moderate degrees of aeolian desertified land occupied over 60% of total desertified land area, this shows that in the arid and semi-arid zones with fragile eco-environment in northern China large areas of land have entered the initial stage of desertification and are in danger of severe desertification (Wang et al., 2003).

Aeolian desertification and vegetation succession and landscape ecological research

Aeolian desertification and vegetation succession research: Recent studies show that sandy land vegetation succession differs from that of grassland; the former is mostly associated with degree of aeolian desertification. Sandy land vegetation succession contains both gradual and sudden processes and is controlled by the degree of aeolian desertification and its own structural function (Li et al., 1997). Among different types of desertified land, vegetation often shows different kind of change; on the same type of slightly desertified land a gradual change occurs while the seriously desertified land shows a sudden change. On the overgrazing-induced desertified grassland biodiversity, vegetation cover, grass height and yield decrease rapidly; perennial grasses first disappear, followed by palatable annual forage species, and these are replaced by non-palatable plants; then small bare spots occur on ground surface and gradually they expand to connect to each other, finally leading to large area of aeolian desertification. Grass aeolian desertification process, resulting from sand drift damage, and water condition deterioration, and overgrazing-induced aeolian desertification have some similar features but also some obvious differences. For the former, from north face slope to south face slope of sand dunes, from wet land to dry land, and from fixed dune field to moving dune field, vegetation deteriorates rapidly, and the rate of deterioration is much higher than for the latter. However, vegetation height and yield do not necessarily decrease. Under favorable conditions, in degraded vegetation on sandy land positive succession may occur, i.e. the species composition, vegetation cover, and height increase, and the percentage of herbage in the community also increases greatly (Liu et al., 1996).

Aeolian desertification and landscape ecological research: Research has shown that aeolian desertification process is closely related to the changes in landscape structural characteristics (Qiu and Shi, 1993). Viewed from landscape scale, initial small-scale aeolian desertification is related to surface erosion and deposition processes, but does not affect landscape characteristics. As the desertification reaches moderate degree, both sand dune stability and landscape characteristics change with out affecting landscape attribute. As a large-scale aeolian desertification occurs, landscape elements (patches, for example) will split into different attribute landscape elements. Of the artificial sand fixation area, enclosed protective area, and moving sand dune area, the first area has most complex spatial pattern and high landscape heterogeneity, followed by the enclosed protective area, and moving sand dune area has simplest landscape pattern (Chang and Li, 1998). In the aeolian desertification developmental process, sandy land landscape pattern tends to become simple; in the desertification reversion process landscape pattern tends to become complex and heterogeneity increases. Patches in different landscape types show different kinds of changes. In the artificial sand fixation area patch diversity increases, including fixed sand dune, semi fixed sand dune, semi shifting sand dune and moving sand dune. Hence patchy pattern tends to become complex due to the influence of sand stabilization measures. In the enclosed protective area spatial structures of fixed sand dune and moving sand dune patches are most complex and have high patch pattern diversity due to the influences of seasonal grazing, wood cutting and natural restoration. Semi-fixed and semi-shifting sand dunes have lower patchy diversity and simple spatial structure. Accordingly, we can assess the degree of aeolian desertification developmental on different time and space scale in accordance with aeolian desertification trend and landscape indicators.

Research on desert plants stress physiology

In the past the researches in this respect mainly focused on physiological characteristics of desert plants. In the last ten years considerable attention has been paid to the relations between aeolian desertification and plant physiological changes and plant adaptive mechanism to desertification. Some useful conclusions have been reached regarding the plant anatomical feature, photosynthetic rate, protective enzyme system, osmotic regulators, plasma membrane permeability, membrane lipid peroxidation, plant stress succession, etc. For example, under dry and high-temperature conditions, desert plants show a bimodal photosynthetic curve and lower photosynthetic rates; under wet condition they show a unimodal photosynthetic curve and higher photosynthetic rate. Plants with higher moisture content have higher photosynthetic and transpiration rates, and vice versa. Under dry high-temperature conditions water loss of higher drought-resistant plants is less and slow; once it regains water, soluble sugar and proline contents increase rapidly, activity of protective enzyme improves rapidly and shows a negative correlation with membrane lipid peroxidation. For weakly drought-resistant plants the situation is just opposite. During the process from shifting sand land turning into fixed sand land, plants evolve from drought-avoiding species to physiologically drought-resistant species, from sand drift-resistant species to drought-resistant species, and from single way of propagation to diversified modes of propagation.

Research on the influence of aeolian desertification on ecosystem

In the farm aeolian desertification processes surface soil becomes coarse, soil fertility and water-holding capacity decline, diurnal changes of surface temperature become intense, plant photosynthetic efficiency drops, plants become weak and they have lower water-use efficiency even under normal precipitation or irrigation conditions. As a result the productivity of ecosystem falls, even leading to collapse of the farmland ecosystem. As for the grass land ecosystem, the aeolian desertification intensifies sand drift activity, deteriorates microenvironment, and reduces wind-sand resistance; hence tall and broad-leaved plants disappear, biodiversity declines, community structure becomes simple and sparse, vegetation cover and leaf area index drop, energy input in grassland ecosystem decreases, and material conversion is limited. Hence productivity decreases. As for the artificial ecosystem on shifting sand land, with the increase in vegetation cover, soil moisture condition becomes worse and thus the growth of pioneer plants is adversely affected. The formation of micro-biotic curst also hinders germination; as a result, the pioneer plants decline and are finally replaced by other species.

Research on water and land resource use efficiency and sustainable development

In recent years, some thematic research has been undertaken, including water resources and forest construction in northwest China, carrying capacity of water resource in Hexi Corridor region, and classification of blown sand soil, arid soil and irrigated soils, to help in the regional development and environmental rehabilitation in the desertified regions. With river basin as a unit, a series of studies on resource use, human activity, economic development and environmental issues have been carried out and principles for rational use of water and land resource have been elucidated, to facilitate development planning of several typical river basins. Other research projects include influence of climatic change on dry land agricultural system and water resources, water balance and sustainable development of desert oases, economic development, and eco-environment protection in Hexi regions. Demonstration of high-efficiency agriculture, based on rain-water harvesting and ecological agriculture of sandy land, has been done in Huang-Huai-Hai Plain.

Research on aeolian desertification rehabilitation models and techniques

In past ten years, in accordance with the demand of national economic and eco-environmental development, some new comprehensive rehabilitation models and techniques of aeolian desertification were developed. A widely used model is the three-level village, hamlet and household comprehensive rehabilitation model consisting of “ecological net”, “multivariate system” and “micro biosphere”. It is used in the semiarid mixed agro-pastoral region of Naiman. According to this model, a large windbreak and sand break forest net should be established in the village; such measures as making structural readjustment and grazing exclusion, establishing sand break forest, constructing capital farmland and developing agro forestry and animal husbandry should be adopted at hamlet level; and at household level scattered peasant households should set up farming districts in inter-dune depressions with better water and heat conditions, as well as forest belt, buffer grassland and grazing land. Such three-level model has proved to be an effective aeolian desertification rehabilitation system. Other newly developed aeolian desertification control and sandy land farming techniques include film-lined rice cultivation in sandy lands in the semiarid regions, wheat cultivation in sandy lands, licorice and Chinese ephedrine cultivation in alpine cold region, water-saving farming in oases, and brackish-water irrigation technique.

About 10 % of the aeolian desertified land has been recovered to become farmland and grassland again and about 12% of the land has been improved. In some typical regions of the aeolian desertification, e.g. Horqin Sandy Land and Mu Us Sandy Land that had had been damaged severely before 1987, the desertification has been controlled through rehabilitation projects during 1988-

2000. The spatial distribution changes of aeolian desertification in Horqin Sandy Land, over the past 50 years, can be summarized as follows: the aeolian desertified land increased from 42300 km^2 in 1959 to 51384 km^2 in 1975, to 61008 km^2 in 1987 and then decreased to 50198 km^2 in 2000. That is to say, it decreased by 17.7% in past10 years compared to the area of the previous stages. The very severely and slightly desertified land area increased by 393 km^2 and 1749 km^2 respectively, while severely and moderately desertified land area decreased by 488 km^2 and 12463 km^2 respectively. The overall reversal of aeolian desertification in Horqin Sandy Land is attributed to the fact that the local government, farmers and herdsmen are becoming increasingly aware of the seriousness of land desertification and have therefore put large amount of man power, material and financial resources to rationally readjust land-use structure and intensity, cut down extensively-managed cultivated land area, increase intensively-managed fertile land area, return croplands to forest and grassland, close large area of pastureland to livestock grazing and arrest overgrazing. The use of all these effective measures not only has slowed down the rate of spread of land desertification but also improved large area of desertified land.

Prospect for the aeolian desertification research in China

Blown sand physics and desert environment research

These are the areas of fundamental research on aeolian desertification. Using field experiment stations, indoor wind tunnel and field wind tunnel, we will thoroughly study natural and human factors, feedback effect of aeolian desertification on these factors, their contribution on different time scales to the process of aeolian desertification; and establish identification and operational mechanism models of various driving factors in current aeolian desertification processes. Using the laws governing the mass and energy flow at adjacent ecosystem interface and the research results of future human activity and global change trends, we will establish the dynamic model of aeolian desertification processes coupled with natural and human factors to precisely predict the future trends in the development of aeolian desertification.

Ecology of restoration of desertified land

The following research will be conducted: (1) The ecological process of dry land fragile eco-environmental evolution and biological mechanism of aeolian desertification; (2) Structural function, energy flow, mass flow and information flow at different levels and scales of the ecosystem; (3) Dynamic stability of landscape pattern and biodiversity time-space changes and their maintenance mechanism in aeolian desertification and its reversion processes; (4) Adaptive mechanism of desert plants species to harsh environment.

Utilization of water and land resources and sustainable development in agriculture in the desertified region

Main research projects in this area include:
(1) Different time and space scale water balance in typical regions, ecological risk analysis of water and water exploitation in desertified regions, changes in environment and resources under the background of global changes and their quantitative prediction. (2) Optimization of allocation of water and land resource and models for transformation from resource advantage into economic advantage in desertified regions. (3) Agricultural engineering techniques, cultivation techniques of traditional and high-yielding crops and regional sustainable development strategies.

Aeolian desertification reversion process and rehabilitation models

Various reversion strategies, rehabilitation models and technical systems for different types of aeolian desertified lands will be studied at field experimental stations in different zones, and pilot plots will be established to demonstrate the use of successful techniques in the regional aeolian desertification control.

Establishing aeolian desertification monitoring, assessment, decision-making and management system.

Further studies will be conducted, employing 3S techniques and other modern techniques, to establish the natural resource and environmental information system, to achieve rapid information processing and upgrade, to enable the regional sustainable development.

Acknowledgement

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Role of traditional hydro-technology in dryland development: Karez, Qanat and Foggara

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Abstract

***Karez* (Kan-er-jing) in Xinjiang, China is a well known traditional underground water carrying system, which is still used in Turpan basin. However, introduction of pumping well and open canal system in the area has serious impact on this traditional system. Similar phenomena are occurring in the case of traditional underground systems in Iran (called *Qanat*) and North Africa (called *Foggara*). Recently, international organizations such as UNU, UNCCD, UNESCO, EC (European Commission) have paid increased attention to rehabilitation and sustainable development of these traditional systems. The author has been working on this subject for the past 50 years around the world, and discusses key issues on this subject in this paper.**

Introduction

Water is the most precious natural resource for the general well being of the people. It is a basic commodity not only for direct consumption but also as an essential input in the production of food through agriculture and fishery (Coopey, 2005). Scarcity of water is a major constraint to sustainable development in the dry areas. The security of livelihood of the people in dry areas depends upon their ability to have access to water. No wonder therefore that people living in the dry areas have developed, in the long past, ingenious methods for getting dependable supply of fresh water from long distances for meeting their domestic and agricultural needs. The system has been variously named – *Qanat* in Iran; *Qanat Romani* in Syria and Jordan; *Karez* in Afghanistan, Pakistan and Turkmenistan; *Kahn* in Baluchistan; *Kanerjing* in China; *Falaj* in Oman and other parts of the Arabian Peninsula; *Foggara* in Algeria and other North African countries; *Khettara* in Morocco; and *Galleria* in Spain. This traditional knowledge has been passed on from one generation to the other and has become an invaluable human heritage.

Unfortunately, modern technological and social developments are taking a heavy toll of such systems and it is important that this knowledge is preserved and harnessed for sustainable use of the limited fresh water natural resource in the dry areas. Good news is that lately there is growing international interest in assessing and reviving the use of these methods in the countries where they once were so effectively used.

The *Qanat* system

Qanat is an ancient subterranean water channel system in dry areas that serves as a source of water for irrigation, drinking and other domestic uses. It taps underground mountain water sources trapped in and beneath the upper reaches of alluvial fans. It thus channels to the surface the ground water from cliff or base of a mountainous area, following water-bearing strata, or even from a river, through underground tunnels. It differs from normal aqueducts in that the water is already there and it is not brought up to the surface but brought out to the surface. The tunnels run roughly horizontal with the slope to allow water to emerge out to the surface by gravity to lower and flatter agricultural land or an oasis. Vertical openings or air shafts, ranging from 10 to 60 meters in depth, are provided every 15 to 50 meter, to remove the mined soil, clean the tunnels of silt deposits and to ventilate them. One of these shafts is called the mother well or *Madaar chah*, which represents the source of water. The subterranean nature prevents evaporative losses, prevents water pollution and thus allows maintenance of good quality of water.

Qanat is a Persian word, pronounced Kanat in Arabic and Karez in Pashto. Common variant spellings of Qanat in English include khanat, kunut, kona, konaait, ghanat, ghundat, etc. It is a water management system par excellence to provide reliable water supply in arid and semi-arid climates all over the world (Troll, 1963; Beaumont et al., 1989). The widespread distribution of qanat, known in different places by their own names, as already indicated before, makes it difficult to identify the place of origin of the system.

In all probability, the system developed in ancient Persia (Kobori, 1964) some 2500 years ago, and then spread to Afghanistan and eventually, through the Silk Road, as far east as China as well as by Arabic cultures as far west as Morocco and Spain (Wikipedia Encyclopedia, 2006). The earthquake of December 2003 uncovered an old city and the Qanat system in Bam, Afghanistan dating to more than two thousand years, belonging to the time of the Seleucids-Achaemenids, who are credited with the origin of the system to bring water to remote areas through out their empire (Sankaran Nair, 2004). Persians, while ruling Asia, promoted the spread of technology by adopting a political initiative of giving the right for five generations to a person to cultivate a land that previously was un-irrigated if that person brought a supply of water there. This encouraged people to undertake great efforts in digging underground channels to bring out water from long distances. The slave trade must have also helped. Besides ancient Persians, the Romans and Moors spread the technology west of Persia.

Qanats in different countries

Afghanistan

Some 300, 000 ha or 10% of total irrigated-agriculture area in Afghanistan depends on ground water from traditional sources for irrigation. These systems include springs, wells and Karez. There are some 15,000 operative Karez in Afghanistan. Some of the mother wells are as deep as 20 meters or more while the horizontally tunneled conduits may run several km (http:// www.temple.edu/env-stud/PAGES/news_item/Afghanistan.html).

China

China has a long history of using Karez (Photo 1).The Turpan oasis in the deserts of northwest China in the southern foot of Tianshan Mountain, which was an important trade center along the northern route of the Silk Road, still uses water provided by Karez. Photo 2 shows Karez in Turpan, Xinjiang. The historical record of the karez system extends back to Ming Dynasty. There are more than 1000 karez systems in Turpan basin with total length extending 5,000 km (Wikipedia Encyclopedia, 2006). Photo 3 presents sketch of the vertical transect for Luohui canal system in China, an underground tunnel near the river.

An excellent description of the past, present and future of Karez in China is provided in the "Proceedings of the International Conference on Karez Irrigation" held in 1990 in Urumqi, Xinjiang, China, published in 1993. The author has organized Sino-Japanese joint research missions for Karez in Xinjing since 1987 and the results of the joint research are exhibited in the Turpan Karez museum (Kobori, 2005).

Photo1. Ling Tso Shu's scripts describing Karez.

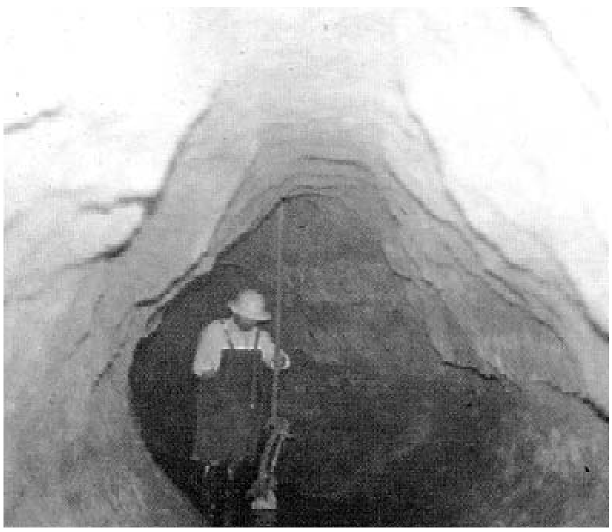

Photo 2. Inside Turpan Karez.

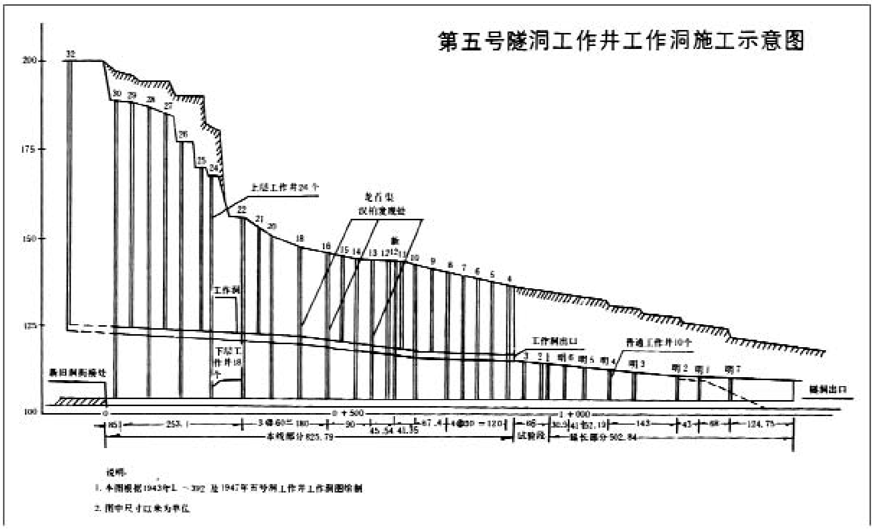

Photo 3. Luohui Canal – a kind of underground tunnel near the river.

Iran

About four-fifth of water used in plateau regions of Iran, particularly in the central plateau (Husseinieh, Ishfahan) is underground water. (Fig.1). The oldest and largest known qanat is in the Iranian city of Gonabad which after nearly 2700 years still provides drinking and agricultural water to nearly 40,000 people. Its mother well is 310 meters deep and the length is 45 km. Yazd and Kerman areas also have an extensive qanat system (Wikipedia Encyclopedia, 2006). A water museum in Yazd has a rich collection of Qanat tools and documents related to old traditions and regulations in the use of water brought out by the Qanats (Photo4). The Government of Iran is lately giving much attention to qanat system, which had been declining because of modern pumping out of underground water, so that the indigenous knowledge was not lost. The first International Qanat Research Conference was held in Yazd in 2000, which has brought to light the work done on Qanat system in Iran and other arid areas. As a result of the recommendations of this Conference, the Government of Iran has established an International Qanat Research Center in Yazd in collaboration with Afghanistan and Pakistan and with support from UNESCO (Kobori, 2005).

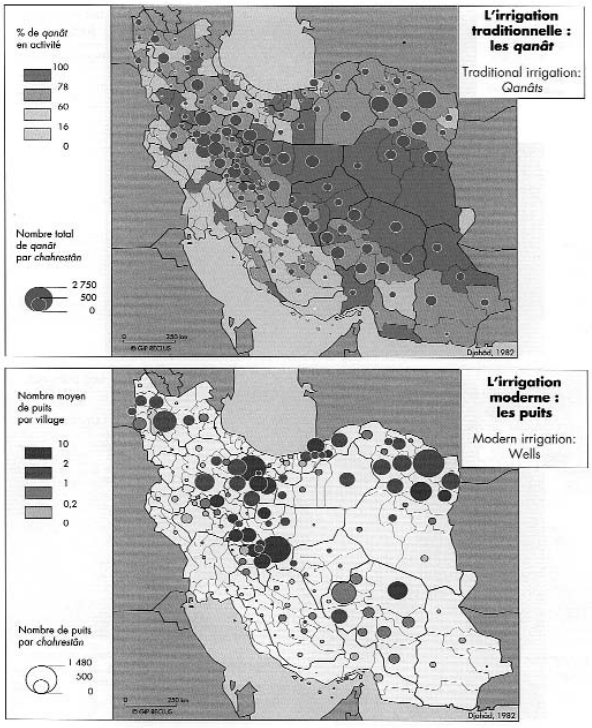

Fig. 1. Distribution map of Qanat and modern well in Iran as developed by Hourcade.

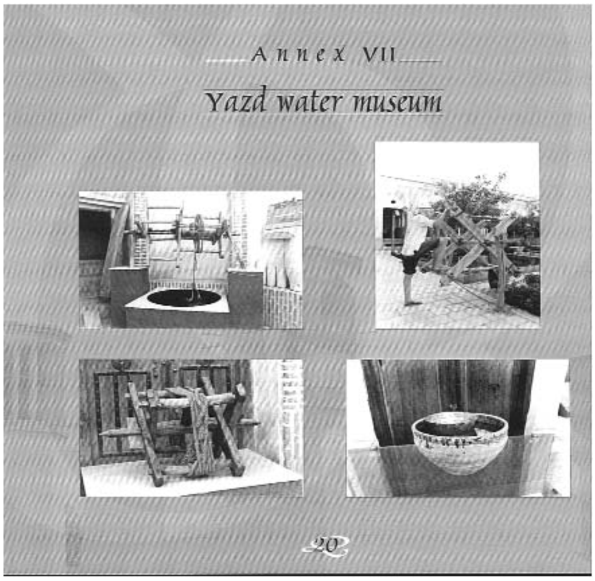

Photo 4. Artifacts in the Yazd Water Museum, Iran.

Syria

Qanats, known as Qanat Romani, have been used in Syria for centuries, possibly from Roman times as the name suggests. The system was particularly widespread in the oases in Syrian deserts. Many of these, especially around Damascus, Selemiya, Palmayra, and Taibe, have been examined in details in published reports (Collelo, 1988; Caponera, 1954; Gobolot, 1979; Kobori, 1980; 1990; Lightfoot, 1996). A century ago, an abandoned Byzantine water tunnel was discovered and brought to operation for the benefit of the life of inhabitants of the village Shallalah Saghira. Qanat system has been found in Umm al-Kelajed, north west of Damascus, half way to Palmyra.

Lightfoot (1996) developed maps of Qanat sites in Syria based on field work done in 1993/1994. Of the 67 qanat sites examined, comprising a total of 239 individual qanat galleries, only 12 % still flowed (29 qanats at 16 different sites) and most were on the verge of drying up. Of the 210 separate dry qanats, 193 dried up after the introduction of pumped tube wells. This shows that there was widespread abandonment of the system, possibly because of the depletion of ground water.

Arabian Peninsula

Al-Falaj or Falaj were common in several countries in the Arabian Peninsula and several of them are still operating. The history of Falaj in Oman (Photo 5) goes back to Persian era, thousands of years back, when the Persian settlers introduced the system there. A ribbon of oases, watered by Falaj extends the length of Oman plain, extending about ten kilometers inland. Nizwa, the capital city of Oman proper, was built around a Falaj, which is used till today (Wikipedia Encyclopedia, 2006). The oasis of Al Ain in the United Arab Emirates still has the tradition Falaj irrigation for palm-groves and gardens and evidence suggests that the technology must have been in use for 3000 years. Falaj system has also been found in Bahrain, Saudi Arabia and Yemen

Egypt and North Africa

Of the four main oases in Egyptian desert, Kharga Oasis has been extensively studied and there is evidence that as early as 5th century BC qanats were being used for bringing out water used for irrigation.

In North Africa, the qanats are called Foggara or khettara. They have been found in Zella in Libya, in Algeria (at Germa, near the Tademait plateau of south-central Algeria, at Gourara and Touat spread over a thousand kilometers), in Morocco (Tafilat oasis on the margins of Sahara desert), and Tunisia (in the foothills of eastern range of Atlas Mountains). (See Photos 6 and 7).

Photo 5. Al-Falaj in Oman.

Photo 6. Foggera in Southern Tunisia.

Photo 7. Foggera in the Algerian Sahara

Mediterranean Europe

There are many examples of qanat systems - known as galleria - in Spain (Turrillas in Andalusia and Granada), probably introduced by Moors when they occupied the Iberian

Peninsula (Wikipedia Encyclopedia, 2006). In Palermo, Italy qanat system is an important tourist attraction (Photo 8).

Latin America

The qanat system was most probably introduced by Spaniards into Mexico. The system can also be found in the Atacam region of Peru and at Nazca (Photo 9) and Pica in Chile (Wikipedia Encyclopedia, 2006).

Photo 8. Qanat in Palermo, Sicily, Italy.

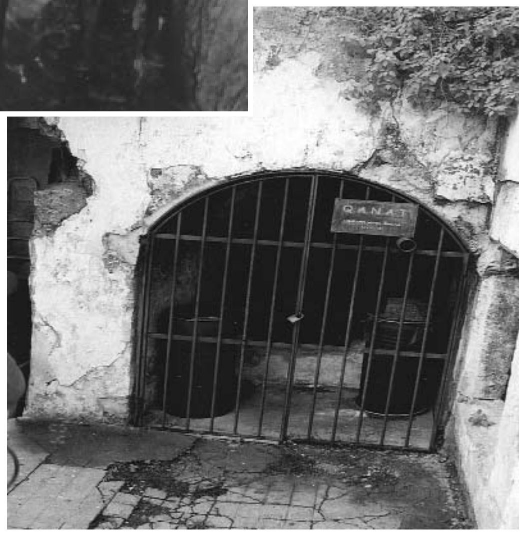

Photo 9. Qanat (Poquio) in Nazca, Peru.

Japan

Qanat system, called Manbo, has been found in Japan as well (Photo 10).

Threats and challenges

This ancient system of sustainable water management in the arid areas has been seriously threatened because of a series of causes. Falling water

Photo 10. Manbo (qanat) in Japan.

table and depletion of aquifer because of indiscriminate pumping has desiccated the qanats with the result that initially the flow is reduced and later they completely dry out. Silt sedimentation because of lack of cleaning and improper regulation of flow has been another cause. Moving sends in the deserts have also been obstructing the mother wells and closing the shafts which are necessary for cleaning the qanats. There are socio-economic changes that have affected the system to a great extent. The work of maintaining the qanat system needs painstaking efforts, perhaps not as labor-intensive as the digging of the system anew, and with increasing migration of the people, particularly male youth, from rural to urban areas, there is little attention being paid to the system in most of the countries where it used to be a very important system for the communities in the oases. No wonder hardly any new qanats are being dug and the number of people knowledgeable about digging is dwindling.

Future perspectives - need for global collaboration

Fortunately, there is revival of interest in several countries where these systems have been declared as the national heritage and have got support from regional and international agencies for their resurrection and sustained use. There is growing realization that the qanat system provides ecosystem goods and services, on which the traditional community life has depended in different oases for ages. The system has permitted the conservation of agrobiodiversity available in the harsh desert environments. Realizing the importance and continued relevance of the qanat system, some promising efforts have been made to revive the effective use of the system. For example the Song Yudong group, in close collaboration with Xinjiang local authorities, have come up with several practical suggestions to revitalize existing Karez systems including over all plan for protection and improvement of existing system in Turpan Prefecture in China, within the overall hydrological plan taking into consideration the hydro geological conditions of the area and socioeconomic considerations of the people living over there (Kobori, 2005).

Recently, international organizations such as UNESCO, and the United Nations University (UNU) have shown interest in promoting studies on Qanat system through the International Hydrological Program that covers member states and the Traditional Technology in Drylands Program that supports young researchers in countries with long tradition and heritage of Qanat system to undertake systematic studies. Within the latter program, six young researchers from Syria, Oman, Tunisia and Yemen have received fellowships for undertaking such studies. The establishment of an International Qanat Research Center in Yazd, Iran, in collaboration with UNESCO is another very significant development.

Besides the national efforts in restoring and improving the qanat systems, there is need for basic research on the origin and diffusion of the system and on how the modern tools of science could further help in reviving this traditional practice. Increased cooperation between the developing and developed countries is absolutely essential in this regard. It should not be restricted to holding workshops and conferences but should proceed to the exchange of researchers, actual technical workers having expertise in digging qanats (the Moqqanis in Iran or the Kunchang in China), and the policy makers

For international networking it would be desirable to prepare a directory of researchers and a detailed bibliography of literature on qanat in different regions. Also, literature in different languages will have to be translated for making them accessible to all.

Finally, there is a need to prepare the new generation to be able to understand, use and conserve this indigenous knowledge. For this, information on this sustainable system of water management should be included in school curriculum and the children should be exposed to the system at a fairly early stage as they grow and get overwhelmed with the modern technologies.

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Jatropha curcas L., an excellent source of renewable energy in the dry areas

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Abstract

Developing a reliable source of renewable energy is attracting a major global attention because of the increasing prices and finite amount of fossil fuel and the release of green house gasses associated with its use. Several crop- and tree species can be a source of bio-fuel. In the arid and semi-arid regions, particularly on the degraded lands, physic nut (*Jatropha curcas* L.) has proved to be a promising oil-bearing tree. The seeds of this Euphorbiaceae tree contain more than 30 % oil, which can be used for making bio-diesel. The seed cake produced after oil expulsion is rich in nitrogen (> 5 %), phosphorus (>2.5% P_2O_5) and potassium (1% K_2O) and can be converted into valuable organic manure for improving physical and chemical properties of the soil. The plant propagates freely from seeds as well as from cuttings and can start producing fruits in two to three years after establishment. It is well adapted to the harsh environments of desert margins, and once established with the help of supplemental irrigation it can withstand drought in the dry areas. Preliminary studies have shown its promise in rehabilitating degraded areas and protecting the land from wind erosion when introduced in dry areas within the framework of watershed management. A well established plantation of *J. curcas* could produce, on good soil, on an average about 5 tons seed/ha/year giving 1500 kg/ha oil and 2500 kg/ha seed cake. However, under marginal conditions a yield of 1.5 tons seed/ha can be expected. The crop is being promoted on degraded drylands in several developing countries for producing bio-fuel and the government of India has an ambitious program for exploiting its potential for meeting the growing need of energy in the country.

Introduction

Population growth and increasing industrialization in the developing world is leading to spiraling increase in the demand for fossil fuel (Francis et al., 2005). India's population , for example has more than tripled in last 50 years, exceeding the one billion mark. Its economy has also been growing rapidly. As a consequence, there is increased demand for vehicular transportation of freight and people. More fuel is needed to energize these vehicles, farming equipment, as well as, the industrial plants that are spearheading the economic development and increasing the gross domestic product of the country. Same is happening in China. It is estimated that by 2020, China and India would become the largest consumers of energy after the USA. However, both these giants of Asia are highly dependent on outside import of fuel. For example, India imports nearly 70% of its petroleum demand (India, 2004) from the world petroleum market, which, as the recent events have shown, is highly volatile. Even making the assumption that the peace and political goodwill will eventually prevail in the world to reduce the uncertainties in supply and prices of petroleum, the increasing demand of emerging economies can not be met on sustained basis because of the finite nature of fossil fuel reserves. The petroleum importing countries, therefore, have to develop alternatives to achieve energy independence. In addition, the green-house gas emissions from fossil fuel are taking a heavy toll of the environment and contributing to global warming, which is occurring at much faster rate than what was earlier predicted. Prudence, therefore, demands that energy security has to be balanced with environmental security.

Alternative sources of energy

Exploiting atomic energy is not a very attractive alternative because of the hazards associated with it. Use of solar power through photovoltaic cells, wind power, and the ocean waves continues to remain limited and no technological break-though seems to be occurring which could permit these alternatives to contribute substantially to meeting the increasing energy demands of the developing world.
Developing a reliable source of renewable energy is therefore the way to achieve a balance between energy security and environmental safety. Using the primary productivity of green plants, the biomass, as a source of energy in the form of bio-fuels, is thus the most potent alternative. No wonder, the subject is therefore attracting increasing global attention (Badger, 2002 ; Becker and Francis, 2003; Becker and Makkar, 1999; Bhattachrya and Joshi, 2003; Francis et al., 2005; Hill et al., 2006; Jones, 2004; Reddy et al., 2005; Wani et al., 2006).

Bio-fuels

The current commonly produced bio-fuels are bioethanol from sugars or starch derived from vegetative biomass or grains, and bio-diesel from edible and non-edible plant oils and animal fats. Biethanol dominates the current bio-fuel scene and is being commercially produced in several countries such as Brazil (from sugarcane), China (from corn and other cereal grains and cassava), France (from sugar beets and cereal grains), India (from sugarcane molasses and cassava) and the USA (from corn). Brazil has made particular headway in ethanol production. Bio-diesel is produced by transesterification of oils by adding ordinary alcohol (15% by weight) and using an alkali as catalyst. It is currently being produced from rapeseed and sunflower oil in Europe, and with soybean oil in the USA. Use of bio-diesel reduces CO_2 emissions by 100% as compared to the petroleum diesel, and hence, when blends are used, the reduction in emission is commensurate with the proportion of bio-diesel in the mixture. Compared with petroleum diesel, bio-diesel reduces particle emissions by 30% and sodium monoxide by 50% and it is non toxic and biodegradable (Jones, 2004).

While plants yielding green fuels (ethanol and biodiesel) would contribute a great deal to securing environment because of the carbon sequestration and little emission of CO_2 in the use of bio-fuels derived from them, they might enter in direct competition with the production of vital food and feed crops if the arable land was to be used for raising them. In general, and for the developing countries in particular, this might not be a feasible option economically and from the view point of the food security. Therefore, such plant species are needed that would not compete with commercial and food crops for land, would not require much input of fertilizers and pesticides produced with much use of petroleum-based fuels, would thrive on degraded and marginal lands, and prevent further land degradation.

Jatropha curcas

Jatropha curcas Linnaeus is one of the plant species that meet most of the criteria for an ideal crop for sustainable bio-diesel production. It is drought resistant and can grow in the arid and semiarid areas on degraded and marginal lands, which are unsuitable for economic crop production. Its introduction in wastelands can lead to rehabilitation of degraded lands, environmental protection, and development of habitat for sustaining other flora and fauna. It does not need much inorganic fertilizers and pesticides for its growth and makes good use of nutrients from soil and organic residues. The plant can also be grown as a hedgerow to protect cultivated field and orchards from animals. It can also be raised with other shrubs and trees adapted to the region. Annual crops can be intercropped in the *Jatropha* plantations. Seeds of *Jatropha* contain around 30% oil, which is suitable for production of bio-diesel. The de-oiled seed cake is rich in nitrogen, phosphorus and potassium, and can be used for making valuable organic manure. The byproducts from transesterification process can be further used in producing a whole range of other products. The plant leaves and other tissues yield substances that have phytoprotective and medicinal properties.
Introduction of *Jatropha* plantations in the dry, marginal areas can generate employment opportunities and can thus contribute to improved livelihoods for the marginalized people there.

Botany of *Jatropha curcas*

Heller (1960) has reviewed the botany of the plant. *Jatropha curcas* L. (2*n*= 22 chromosomes) belongs to family Euphorbiaceae. This species is the most primitive form of genus *Jatropha*. It is a deciduous large shrub or small tree (3-5 m in height) with smooth grey bark, which, when cut, exudes whitish watery latex. It has green to pale-green leaves which are alternate, broad, ovate, cordate, usually palmately 3 or 5 lobbed, and glabrous. The plant is monoecious and flowers are unisexual; rarely hermaphrodite. The inflorescence is formed in the leaf axil. Small yellowish green flowers are born in loose penicles of cymes. Flowers are formed terminally, individually, with female flowers usually slightly larger. Pollination is by insects. The staminate flowers open later than the pistillate flowers in the same inflorescence, promoting cross-pollination. After pollination, a trilocular ellipsoidal fruit is formed. The exocarp remains fleshy until the seeds mature. Each inflorescence yields a bunch of fruits. Fruits are 2-5 cm long and ovoid in shape. As the seeds mature, the capsule color changes from green to yellow, which is generally after 2-4 months from fertilization. The capsule color may eventually become black. Yellow fruit harvested 57 days after anthesis gave higher germination, root length and vigor index at Bawel in North India (Kaushik and Kumar, 2004). The matured seeds are grayish in color, ovoid oblong in shape and 400 to 700 mg in weight. They resemble the seeds of castor (*Ricinus communis*). The root system of *Jatropha* depends on the way the plant is propagated. When propagated from seed, usually five roots are formed, one central and four peripheral, going down straight and deep in the soil. If propagated vegetatively, no tap root is formed and the roots do not go that deep. The plant starts yielding fruits from second or third year of its establishment. If the moisture and temperature conditions are favorable, it may yield more than one crop a year. The productive age of the trees could be above 30 years.

Origin, center of diversity and ecological adaptation

Based on an analysis of the available information, Heller (1996) has concluded that, although the true center of its origin has still to be found, *Jatropha curcas,* in all probability, originated in Mexico, Central America and the Caribbean. From the Caribbean, this species was probably distributed by the Portuguese to countries in Africa and Asia. In these countries it is regarded as the ‘castor oil plant’ or ‘hedge castor oil plant’ which indicates that it was brought in and planted in hedges for producing oil. The plant is widely distributed now in tropical and several subtropical countries (Muench, 1986)

The plant is adapted to a wide range of environmental conditions, and is able to grow on poor and marginal lands and dry sites in South and West Africa and South East Asia. It establishes well on degraded, gravelly, sandy or saline soils having low nutrient content. In the drier regions of the tropics it grows well in areas with 300 to 1000 mm rainfall. It usually occurs at low altitudes (less than 500 m amsl). Being a species of arid and semi-arid regions, it can survive with low rainfall and high temperatures, but its growth is better with slightly cooler temperatures and higher rainfall. It can withstand light but not sever frost.

Vernacular names

There are numerous vernacular names for *Jatropha curcas*, as compiled by Heller (1996), pointing to its antiquity and wide distribution: dand barri, habel meluk (Arabic); mupuluka (Angola); mundubi-assu (Brazil); yu-lu-tzu (Chinese); coquille, tempate (Costa Rica); bagani (Cote d’Ivoire); purgeernoot (Dutch); porghere, pigeon d’Inde (French); physic nut, purging nut (English); Purgiernuss, Brechnuss (German); pinon (Guatemal); bagbherenda, jangaliarandi, safed arand (Hindi); jarak budge (Indonesia); fogiola d’India (Italian); nanyouaburagiri (Japan); pinoncillo (Mexico); kadam (Nepal); butuje (Nigeria); pinol (Peru); tubing-bakod (the Philippines); tartago (Porto Rico); purueira (Portugese); kananaaeranda, parvatararand (Sansktit); tabanani (Senegal);sabudam (Thailand).

Uses

The whole plant of *Jatropha* is widely used in Africa and Asia as a living fence in fields and settlements to keep the animals away as they do not browse this species, as a rodent repellent, for preventing soil erosion, as a support to other plants (e.g. vanilla in Madagascar), as green manure, and as a provider of fire wood. The bark of the plant provides tannins and certain dyes. The fruit husk and seed shell can be used as fuel and for mulching. In some places, young leaves of the plant are boiled and eaten. The leaves are also used in silviculture with special kind of silk-worms. Because of the deciduous nature of the tree, the leaves falling in the winter serve as mulch and enrich soil with organic matter. The seeds are however toxic as they contain several toxins (phorbol esters, trypsin inhibitors, lectins, phytates, etc.), and cases of human poisoning have been reported when 30-40 seeds were consumed. In the Papantla region of Vercacruz State in Mexico, a non toxic variety has been found, seeds of which are suitable for human consumption (Becker and Makkar, 1999). That may explain why in some parts of Mexico the boiled and roasted seeds of *Jatropha* are eaten.

All parts of the plant have been known to be used in traditional medicine for treating various human and animal ailments. As the name of the plant in vernacular in several countries suggests, its seed oil, has strong purgative properties and it is also used to treat skin diseases and rheumatic pain. Antiseptic/ antimicrobial properties of the leaf decoction and whole plant sap are known. Tender branches are used as chewing sticks for oral hygiene in some African countries. The roots provide a yellow oil, which has high anathematic property.

Extracts from all parts of the plant including seed extract have insecticidal and antifungal properties, thus showing a promise for use in making soft plant pesticides. The ground seed has shown molluscicidal property.

The major technical usage of *Jatropha curcas* is based around its seed. The seed comprises shell (around 40% by weight) and kernel (the rest 60%). The whole seed composition is as follows: moisture 20%, protein16%, fat 38%, carbohydrates 17%, fiber 15.5%, and ash 5.3% (Kaushik and Kumar, 2004).The air-dry kernel may contain about 50% crude fat, 24% crude protein, 2.5% crude fiber and around 5% ash (Ferrao and Ferrao, 1984). The oil can be extracted either hydraulically, using different kinds of presses, or by solvent extraction, the latter giving above 95% oil recovery. The oil contains 21% saturated and 79% unsaturated fatty acids. The de-oiled seed cake can be used as rodent repellent, only in limited quantities as protein supplement to feed animals, and, more importantly, as a valuable organic manure as it is rich in nitrogen (around 5% N) and also contains about 2.5% P_20_5 and 1.0% K_2O. The protein component in the cake can be used for making plastic and synthetic fiber. On seed weight basis the oil content is 30-35%.

The traditional use of *Jatropha* oil in the past was in the lamps for illumination and for making soaps. Now it is used not only for bio-diesel production but also, directly after filtration, in running several kinds of diesel engines (pre-chamber injection as well as direct-injection engines), the production of soaps, other cosmetics, lubricants, candles, and edible oil. The bio-pesticidal and medicinal properties of the oil have already been mentioned earlier. The bio-diesel from *Jatropha* seed oil can be produced after the oil is transesterified, and it can be used in any diesel engine. The process of transesterification requires special conditions for which reason it is generally carried out in large centralized units (Foidl et al.,1996). However, if the bio-diesel production has to be decentralized to benefit the rural communities in the areas of *Jatropha* plantations, small-scale units would be needed. It has been reported (Jones, 2004) that a UK-based company (D1 Oils plc), which is planning to harness the potential of *Jatropha* plant for bio-diesel production in large rural communities in the developing countries, has commissioned a compact processing unit (3.3m wide, 10m long and 4m high) capable of producing 22,000 liters of bio-diesel per day.

Production agronomy

Production system

Jatropha can be grown as a pure stand, as intercropped plantation, as a hedgerow or fence, as an alley crop, or in agroforestry systems of different kinds. The system would depend on the land options available for its cultivation (Bhattacharya and Joshi, 2003). On arable lands of high economic value, intercropping with shade loving vegetables, medicinal herbs, and other adapted crops is possible.

In the ravine undulating lands in India, intercropping with such medicinal plants as *Asparagus racemosus* (shatawar) and *Commiphora mukul* (gugul) is posible. For slope stabilization on undulating uplands it can be combined as alley crop with *Glaricidia* and *Leucaena leucocephala* planted along the contours for fodder production and for enriching soil with biological nitrogen fixation. On denuded hill slopes it can be grown with forage grasses (*Andropogan*, Dinanath, Guinea, Hybrid Napier, *Congo signal*, *Stylosanthes hamata*, and *Vetiveria zizaniodes*), using various conservation structures such as field trench-bunds, broad-based trenches and loose boulder plugs.

In the mid- and foot hills it can be planted in dense stands of 1x1m in different storeys with common fruit trees such as aonla (*Emblica officianalis*), mango, guava, sapota, custard apple, cashew nut, etc., planted at 4x4m spacing, depending on local ecological conditions. It can also be planted at 4x4m spacing with other tree crops such as teak (*Tectona grandis*) for wood, and neem (*Azadirachta indica),* mahua *(Madhuca indica)* and karanj *(Pongamia pinnata)* for non-edible oil and other products, and in alternate rows with subabul *(Leucaena leucocephala*) planted in between at 1x1m spacing for producing fodder and firewood. On rainfed farm lands with poor soil depth and productivity and low rainfall, *Jatropha* can be interplanted with mulberry (*Morus alba*) and ber (*Zizyphus* sp.), the former for raising silkworms and the latter for lac production, in alternate rows at 2x2m spacing. In the mined out areas and over burdens, *Jatropha* can be grown with other hardy species such as *Pongamia pinnata, Acacia auriculiformis, Prosopis juliflora, Gravillea robusta* and *Cassia siamea.*

Propagation

The plant can be propagated from seed (generative propagation) as well as vegetatively from cuttings. Methods given below are based on the experiences of researchers in Haryana, north India (Kaushik and Kumar, 2004). For generative propagation, matured capsules can be picked by hand from superior plants in the month of October and November and seeds separated from capsules, cleaned and dried in shade before storing them in gunny bags in dry and cool place. As the seeds can retain viability for long, even older seeds can be used, but for best results it is safer to use freshly harvested seeds. Seedlings can be raised in nursery beds (12m x 1.5 m). Seeds are sown at a distance of 2-3 cm in shallow (2 cm) furrows opened 25-30 cm apart. After placing the seed the furrow should be covered with a thin layer of soil. Deep sowing is to be avoided. After germination, the seedlings can be transplanted either in to polyethylene bags or directly in to the field during the rainy season. The other method of generative propagation is to sow the seeds in polyethylene bags, as this facilitates transfer of seedlings to long distances without any damage to the roots. Bags of 22.5x12.5 cm, with drainage holes, are filled with growing medium comprising sandy-loam soil mixed with compost or farm yard manure (FYM) in a 1:1 ratio. One or two healthy seeds are sown 1.5-2 cm deep, preferably after a 24-hour presoaking in cold water. Sowing is done in Feb/March and September/October in north India. Light but frequent irrigation using rosehead is given. Thinning should be done one month after sowing.

Vegetative propagation can also be done using 2-3 cm thick branches cut from lower portions of the shoots of the mother plants. Cuttings taken from the base of the stem give better results than the cuttings taken from tip or middle portion of the stem. Cutting length may be 30-40 cm. These should be prepared in the month of March. Longer and thicker cuttings give better results. For hedgerow planting, cuttings up to 2 m length can be used. Cuttings can be planted in nursery beds at 30x30 cm spacing, and the beds should be kept moist by frequent irrigation if no rain occurred.

Before lifting the plants from nursery they should be thoroughly watered to loosen soil and avoid desiccation during transportation. Care should be taken to avoid exposure of bare rooted seedlings to sun and wind for long period. Hence keeping them in shade and sprinkling water on them during transportation would be desirable.

Transplanting

Transplanting is north India is done during rainy season in the center of the 45x45x45 cm pits dug out in May or June. The transplanting can also be done in Feb and March. Each pit is filled with a mixture of soil, 1-2 kg FYM, and 40-50 g methyl parathion (2%) dust, the latter to prevent seedling damage from termites. Direct seeding can also be done in the pits at the onset of monsoon by putting 2-3 seeds per pit. Thinning should be done after 40-50 days, and thinned out plants can be used for gap filling.

Planting distance should be 4 x 2 m or 3x 3m or 2.5x2.5m for pure stands. A wider plant spacing (4x4m to 6x6 m) can be adopted if intercropping is to be done. For hedgerow planting the spacing should be 25 to 30 cm apart in single or double rows.

Cultural operations

During the first year of establishment it is essential to irrigate the transplants regularly if there are no rains. A drip irrigation system would be helpful in enhancing water use efficiency. In 2-3 year-old plantations, irrigation may not be necessary if the rainfall was above 700 mm and water harvesting was properly done. For ensuring water harvesting on sloppy lands, crescent-shaped micro-catchments should be developed around the pit. Plant basin must be kept weed free by hoeing as and when needed. Micro-catchment area should also be kept weed free.

For good establishment and faster growth on poor fertility soils, inorganic fertilizers should be applied. A dose of 20 g urea, 120 g single superphosphate and 16 g muriate of potash should be applied per pit after the establishment of the plant. Urea should be applied in 2 splits. *Jatropha* seed cake can also be applied for recycling nutrients as it is rich in N, P and K. *Jatropha* plants have been reported to develop mycorrhizal root system, which can help in improving nutrient and moisture uptake under poor soil conditions. Inoculation with appropriate microbial inoculant to promote mycorrhizal association has been reported to improve establishment and productivity in marginal lands.

The plants should be trained and pruned to give good yield. To develop more number of branches, the first pruning is done in the first year at a plant height of 40-60 cm by cutting down the main shoot. This will lead to the development of a bush rather than a tree. During the second year, 2/3 top portion of each side branch should be pruned out, retaining only 1/3 length of the branch on the plant. The pruning should be done when the trees shed leaves and enter the phase of dormancy. Care should be taken to avoid peeling of bark during pruning. The pruned material can be used as a mulch around the base of the tree to reduce evaporation and permit soil enrichment with organic matter. The aim of the pruning is to have 8 to 12 side branches on a tree and obtain a tree structure that is open to intercept solar radiation and facilitate crop harvest.

Normally, the plants are free of insects. However, some insects such *Spodoptera litura* and other lepidopterous larvae, *Julus* sp. (millipede), spider mite and *Bamisia tabaci* (white fly) have been reported to damage the foliage and *Calidea dregei* (blue bug) and *Nezara viridula* (green stink bug) to feed on the fruits. Amongst the diseases are root rot caused by *Fusarium monoliforme*, and leafspots caused by *Helminthosporium tetramera* and *Cercospora jatrophae-curces*. Integrated pest management, based on physical control and use of botanical pesticides, is recommended.

Flowering occurs generally in August to December in north India. Here, the fruits mature nearly 57 days after anthesis and turn yellow. This is the stage when they should be plucked. The fruits are allowed to dry out in shade, till they start cracking. At this stage the seeds are taken out and further dried in shade to reach a moisture content of 5-7%. At this moisture content they can be stored in gunny sacs in cool, dry place for further use. The produce for seed needs particular care in this regard. Storage at higher moisture content and in the sun would lead to loss in viability. Also, storage beyond 15 months after harvest has been reported to result in 50% reduction in the viability. Hence, the seeds from fresh produce should be used for sowing purpose. Once the mature seed has reached 5-7% moisture content by air drying in the shade, it has no dormancy and can be used for planting.

Yield and economic returns

The plants start fruiting from the second year of plantation. The productivity increases as the plants grow but stabilizes from the fourth to fifth year onwards. The trees remain productive up to 40 years. A well established plantation on good soil could yield on an average about 5 t seed per ha per year, which would provide about 1.5 t oil and

2.5 t de-oiled cake per ha per year. However on marginal lands seed yield of about 1.5 to 2.5 t per ha per year can be expected.

The National Bank for Agriculture and Rural Development (NABARD) in India has done a cost and benefit analysis of *Jatropha* cultivation on marginal lands. For establishing a plantation of 1666 tree/ha (3x2m spacing), under rainfed conditions, the total cost of cultivation including cost of land preparation, digging of pits, plant material and planting, manure and fertilizer, interculture, watering during plant establishment, pruning and plant protection came to Indian Rs. 25,826 per ha (US$ 1.0 = Rs. 43) in the first three years. Majority of the cost is in the first year (Rs. 16,220/ ha) when the plantation is established, and the costs goes down to Rs. 5825 and 3780 per ha in the second and the third year when some pruning, interculture, and fertilizer application is done. The crop would start yielding from the third year, with seed yield levels of about 0.5, 0.5, 1.0, 1.5, 2.0, 2.5 kg/tree in the third, fourth, fifth, sixth, seventh and eighth year, respectively. Assuming that only 1500 plants survive, this would amount to an yield of 0.75, 0.75, 1.5, 2.25, 3.0, 3.75 t/ha, respectively. If the seed is sold at Rs 5000/t, the entire cost of establishment of the plantation would be paid up by the end of the sixth year. The NABARD therefore found that the bank could provide loans to farmers for developing the *Jatropha* plantations in the marginal areas.

Becker and Francis (2003) have also carried out cost-benefit analysis of *Jatropha* plantations, over a productive period of 30 years, using production and cost parameters for the conditions of wasteland cultivation in India. Assuming that 1200 plants were established per ha, the average productivity was 1.5 kg seed per plant over the 30 year period, and the seed was sold at US $ 0.1 per kg, the establishment cost was US $ 435 per ha in the first year and the recurring costs were US $ 109 per year including the cost of land leasing, they found that the internal rate of return was about 20.6%.

Perspective

Considering all the potential benefits that could emanate from the widespread adoption of *Jatropha curcas* on the degraded and marginal lands, it is clearly an outstanding source of renewable energy for the tropical and subtropical dry areas. Its production technology is rather simple and production costs low. Its production can create new employment opportunities and thus prevent out migration of populations from marginal rural areas in search of employment. It could thus become an invaluable source of clean energy while contributing to rehabilitation of degraded lands and generating new employment opportunities for the marginalized people in the dry areas. There are large tracts of degraded lands in several developing countries in Asia and Africa that could be profitably used for *Jatropha* production without the fear of displacing the conventional crops from arable farming systems in these countries. The government of India, having recognized its potential, has an ambitious plan for promoting the cultivation of *Jatropha* on the degraded and marginal lands in the country and is formulating policies that would support the initiative on sustainable basis. However, for harnessing full potential of this plant there is need for considerable research on its genetic resources; crop enhancement for stress resistance, yield and quality of its various products; ecological adaptation and crop physiology; and production agronomy. At the same time, technological aspects need to be researched to add value to various byproducts obtained in the course of bio-diesel production. The results of these research efforts would go a long way in making *Jatropha curcas* as an outstanding source or renewable green energy.

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Living with deserts: CWANA-Plus Partnership

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Abstract

The CWANA-Plus (CWANA+) Partnership is a joint initiative by United Nations University (UNU) and the International Center for Agricultural Research in the Dry Areas (ICARDA). The intent is to foster South–South cooperation on sharing experts and facilities, training scientists, and promoting the best practices among centres of excellence in sustainable dryland development across the vast CWANA (Central and West Asia and North Africa) region plus neighbouring dry areas in Western China, South Asia, and Sub-Saharan Africa. The strategy used is to capitalise on the existing networks of ICARDA and UNU to link relevant centres of excellence in research and capacity building; identify the research gaps, and select partners to reach out in these areas. The anticipated key outcomes of the CWANA+ network are: (1) An extensive regional network for information exchange and sharing of successful experiences in sustainable management of drylands; (2) Development of collaborative activities amongst partners in the network, through the identification of research gaps and available financial resources; and (3) Enhanced capacity building and academic cooperation within the network and with the rest of the world. Three examples of the ongoing activities will be used to illustrate the operation of the CWANA+ Partnership.

Introduction

This paper introduces an informal network of academic and research institutions in the dryland region, including the CWANA (Central and West Asia and North Africa) targeted by the International Center for Agricultural Research in the Dry Areas (ICARDA), plus neighbouring dry areas in Western China, South Asia, and sub-Saharan Africa. The network focuses on the people and ecosystems of drylands in the region and emphasizes exchange of knowledge and technology, particularly through South-South exchange of information. It is a joint initiative by UNU and ICARDA. The intent is to foster South–South cooperation on sharing experts and facilities, training scientists, and promoting the best practices among centres of excellence in sustainable dryland development across the vast CWANA plus region.

Rationale

The peoples and communities in the CWANA+ region face many common challenges related to poverty alleviation and combating desertification. An effective response requires bringing together the different expertise and scientific resources of the region into a partnership to address these common challenges through the sustainable management of drylands. Such a partnership could assemble the best, but widely dispersed, experts and help to alleviate intellectual isolation in the region. It would create a critical mass of expertise to meet the common challenges as well as help rationalize use of the scarce scientific resources of the region by setting the priority research agenda and avoiding duplication of effort. This partnership could also incorporate the expertise of other regions and provide quality training *in situ*, thus making a direct contribution of that training to the problems “on the ground” and minimizing the risk of “brain drain” from the region.

The region (Fig.1) is large as well as very diverse. It is home to several cradles of the world’s ancient civilizations: the Nile basin, the Mesopotamian basin, the Indus basin, and the Yellow basin. Rich cultures have flourished in the region over many centuries — for example, those along the famed

Silk Road. Many communities in the region have long continued to live in harmony with deserts. While the need for combating the process of desertification is pressing, it is equally important to draw on the diverse experiences of the region and to promote the best practices for sustainable management of drylands across this vast region.

The CAWANA+ Partnership is consistent with the Spirit of Bandung, the core principles of which (solidarity, friendship, and cooperation among the countries of Asia and Africa) are reconfirmed in the New Asian-African Strategic Partnership (NAASP). Poverty and under-development, gender mainstreaming, communicable diseases, environmental degradation, natural disasters, drought and desertification, the digital divide, inequitable market access, and foreign debt are identified as issues of common concern for closer cooperation and collective action. The Action Plan of NAASP also calls for "developing a network among universities, libraries, research institutions, and centres of excellence in Asia and Africa (including linkages with existing regional, inter-regional, and international agencies) with a view to sharing and expanding the pool of resources, skills, and knowledge, as well as developing mechanisms for scholarships and exchanges."

The CAWANA+ Partnership is also in line with "Beijing Framework for Action on Combating Desertification" that was adopted at the Asia-Africa Forum on Combating Desertification in Beijing, China (from 5–11 August 1996), which provides guidance to mobilize cooperation between African and Asian countries for implementation of the United Nations Convention to Combat Desertification (UNCCD). Such cooperation between Asia and Africa should be pursued based on equality and mutual respect, and guided by the desire to learn from each other. The cooperation also should promote a two-way flow of experience.

The Beijing Framework calls for cooperation on capacity building, such as human resources development, through training, education, and building of the capability of scientific personnel. The second Africa-Asia Forum on Combating Desertification in Niamey, Niger (2–5 September 1997) re-confirmed the need for networks of centres of excellence in developing countries, as well as supporting the exchange of students, researchers, scientists, and technologists among developing countries. The recent South Summit of G77+China in Doha, Qatar (12–16 June 2005) underscores these plans for South–South cooperation for implementation of the UNCCD.

The CWANA+ Partnership fits well in the missions of UNU and ICARDA. UNU's mission is to contribute, through research and capacity building, to efforts to resolve the pressing global problems that are the concern of the United Nations, its Peoples and Member States. ICARDA's mission is to improve the welfare of poor people and alleviate poverty through research and training in dry areas of the developing world, by increasing the production, productivity, and nutritional quality of food while preserving and enhancing the natural resource

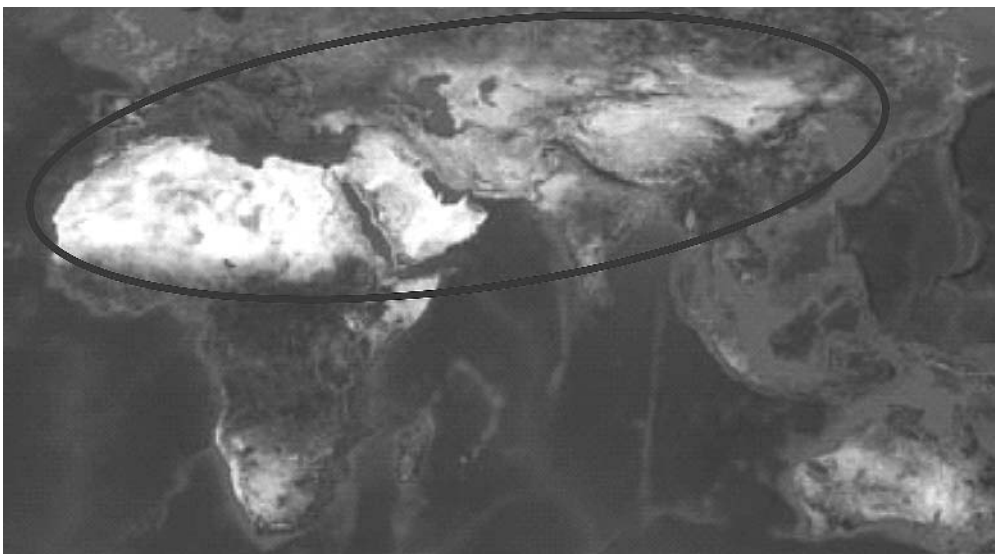

Fig. 1. The CWANA+ Region.

base. Integrated land and water management in dry areas is a priority theme shared between UNU and ICARDA. Close cooperation between the two organizations is already established in the field of land management, and an agreement of cooperation between UNU and ICARDA was signed in 2003 to strengthen their collaboration.

The UNU dryland programme applies a network approach to reach out relevant stakeholders, especially in developing countries in Africa and Asia. Over the past few years, UNU has established a network of universities and research centres in the drylands of CWANA and China through technical workshops, often in cooperation with ICARDA and UNESCO. This research network serves as the basic framework for the implementation of the UNU dryland programme.

The ICARDA programme also works through a network of partnerships with national, regional, and international institutions, universities, non-governmental organizations, and ministries in the developing world, and with advanced research institutes in industrialized countries. By providing technical backstopping and training to national partners and fostering regional and inter-regional networks, ICARDA continues to devolve research responsibilities to national agricultural research systems as they gain maturity in their research capabilities and strengthen their research infrastructure. ICARDA has established six regional programmes to reach out to the national agricultural research systems (NARS) throughout the CWANA region.

The UNU/ICARDA joint initiative, in particular by linking relevant research networks and regional programmes, can bring about a synergy in reaching out to a wide range of stakeholders for sustainable management of drylands in the vast dry areas, reaching from sub-Saharan Africa through the Middle East to Central, South, and Northeast Asia.

Objectives

The main objective of the CWANA+ Partnership is to develop a network of universities and research centres in the region for the purpose of sharing experts and facilities, training scientists, and promoting the best practices in integrated land and water management.

Strategies

The following strategies will be applied to develop the CWANA+ Partnership:

1. Based on the existing networks of UNU and ICARDA, link relevant centres of excellence in research and capacity building;
2. Identify the research gaps, and select partners to reach out in these areas; and
3. Establish a secretariat for the Joint Initiative in ICARDA to facilitate the integration and synergy of relevant networks.

The CWANA+ Partnership will foster the following components:

- Collaborative research on common priority issues
- Exchange of staff and students, and sharing of research facilities
- Training of a new generation of scholars and professionals
- Workshops and symposiums
- Dissemination

The initial funding for the secretariat will come from ICARDA and UNU. The funding for joint activities will be shared among the partners and sought from potential donors.

Outcomes

The anticipated key outcomes of the CWANA+ Network are:
1. An extensive regional network for information exchange and sharing of successful experiences in sustainable management of drylands;
2. Development of collaborative activities amongst partners in the network, through the identification of research gap and available financial resources; and
3. Enhanced capacity building and academic cooperation within the network and with the rest of the world.

The following annexes list ongoing activities of UNU and ICARDA that could possibly work together to form the basis for the operation of the CWANA+ Partnership.

Annex 1. Current UNU networks in the region

The UNU undertakes four different types of activities in order to advance knowledge and capacity towards resolving the pressing global challenges to human security and development. UNU undertakes: (i) research, (ii) foresight and policy studies, (iii) capacity development, and (iv) dissemination. In the implementation of these activities, UNU is increasingly working with external partners and developing a system for tendering for UNU programs/projects. The breadth of its cooperation with universities and research institutes, particularly in developing countries, is widening primarily by involving these institutions in one of UNU's existing or newly initiated networks.

In order to be effective for a large dryland region across Asia and Africa, the UNU dryland program has adopted a network approach to link centers of excellence in the region and to promote a South-South cooperative approach of learning from each other. The approach aims to build on and pool together the existing and different expertise of centers of excellence for sustainable management of dryland ecosystems. This approach also avoids a relatively high cost of training young professional in developed countries, makes a direct link of their studies to the problems on the ground, and minimizes the risk of "brain drain", which is a threat to many dry areas. The dryland research network brings together the best, but widely dispersed experts and alleviates intellectual isolation in developing countries. The network complements and provides an added value to the ongoing research and training programs at the national centres of excellence through cross-fertilization, learning from each other. It gathers a critic mass of expertise for new knowledge to combat desertification and helps to save very scarce resources for national centres of excellence by avoiding duplication of research in the region and through the scale of economy.

1. "Sustainable Management of Marginal Drylands (SUMAMAD)" is a joint international project between UNU-INWEH, UNESCO and ICARDA, and bringing together national partners from North Africa through the Middle East to Asia. The project uses a harmonized methodological approach for selected study sites in the countries involved to compare results and share knowledge. The project aims to identify people's adaptation and traditional knowledge in coping with adverse dryland conditions. The project fosters the rehabilitation of degraded drylands, using community-based approaches. Training, capacity building and interaction with landowners and farmers, with a focus on sustainable and indigenous dryland management practices, are a key element of the project. The SUMAMAD project is currently funded by the Flemish Government of Belgium, and includes the following country partners:

   Peoples Republic of China
   • National Committee for UNESCO-MAB Programme at the Chinese Academy of Sciences
   • The Cold and Arid Regions Environmental & Engineering Research Institute (CAREERI) of the Chinese Academy of Sciences, Lanzhou

   Egypt
   • University of Alexandria and Omayed Biosphere Reserve, Alexandria

   Islamic Republic of Iran
   • Fars Research Center for Natural Resources and Animal Husbandry, Shiraz

   Jordan
   • Royal Natural Conservation Society of Jordan and Jordanian National Committee for UNESCO-MAB Programme, Amman

   Pakistan
   • Pakistan Council of Research in Water Resources (National Committee for UNESCO-IHP Programme) and National Committee of UNESCO-MAB Programme, Islamabad

   Syria
   • ICARDA, Aleppo

   Tunisia
   • Institut des Régions Arides (IRA), Medénine

   Uzbekistan
   • Samarkand University, Samarkand

2. Joint Master's Degree Program in Integrated Land Management in Drylands (MS Program). The MS Program is an international program

designed for capacity enhancement in developing countries to facilitate management of their drylands resources as well as for promoting centre of excellence in developing countries. It is intended to provide young professionals and scientists with an international perspective on resource management approaches in drylands. The program participants will take multidisciplinary courses in Tunisia and China, as well as conducting applied research in their home countries. The pilot phase of the MS Program with five fellows, one each from China, Egypt, India, Sudan and Tunisia is in progress. The program partners include:

Tunisia
• The Institut des Régions Arides (IRA), Medénine
• The Institut National Agronomique de Tunisie (INAT), Tunis

China
• The Cold and Arid Regions Environmental & Engineering Research Institute (CAREERI) of the Chinese Academy of Sciences, Lanzhou

The next phase will include additional partners:

Syria
• ICARDA

Japan
• Tottori University

3. UNU Project on Traditional Water Management in Dry Areas. The project aims to underscore the importance of traditional water management systems through focused research and field activities, including comparative evaluation of these systems in different settings; evaluate the relationship between local communities and traditional water management systems, including evolution of these systems in contemporary societies; build the capacity of local researchers to undertake community-oriented field research; perform focused research on means and ways for improving traditional water management systems according to evolving socio-economic patterns, particularly highlighting South-South collaboration; and raise public awareness on key issues pertaining to utilization of traditional water management technologies. So far, the research fellows of the project have come from the following countries:

• Tunisia
• The Netherlands
• Pakistan
• Yemen
• Oman
• Japan
• China

4. The UNU/UNEP/GEF project on Sustainable Land Management in the High Pamir and Pamir-Alai Mountains - an Integrated and Trans-boundary Initiative in Central Asia (Tajikistan, Kyrgyzstan), aims to address the interlinked problems of land degradation and poverty within one of Central Asia's critical mountain 'water towers' and biodiversity hotspots. This will be achieved through a trans-boundary approach that will seek to improve the technological, institutional, policy and legislative environment required for enabling mountain communities to take primary responsibility for the productive and sustainable management of their local ecosystem resources. The principle global environmental benefit will be the development of a replicable 'model' for an integrated development strategy that can be used to address the problems of land degradation in similar mountain environments. The project will play a major role in mainstreaming sustainable land management concerns within the national environmental law, policy and institutional systems of both Kyrgyzstan and Tajikistan. It will also focus on regional level harmonisation of the respective legislative and policy systems with a view to create an effective enabling environment for the improved management of trans-boundary mountain ecosystem resources. ICARDA will be also involved in the project implementation. Institution involved are;

Tajikistan
• State Directorate of protected areas "Tajik National Park", State Committee on Environment Conservation and Forestry
• Tajik Academy of Agricultural Sciences, Soil Research Institute

Kyrgyzstan
• National Center for Mountain Regions Development
• Kyrgyzstan International University

Annex 2. ICARDA networks in the region

ICARDA seeks to improve and integrate the management of soil, water, nutrients, plants and animals in ways that optimize sustainable agricultural production. Within the management of natural resources, emphasis on on-farm water-use efficiency is an important component of ICARDA's research philosophy. Much of this is done by providing technical backstopping, research planning support, and training to national partners and fostering regional and inter-regional networks. By using this philosophy, ICARDA continues to devolve research responsibilities to national agricultural research systems as they gain maturity in their research capabilities and strengthen their research infrastructure. This is done through the following regional programs:

1. North Africa Regional Program (NARP): Algeria, Libya, Mauritania, Morocco, and Tunisia.

2. Nile Valley and Red Sea Regional Program (NVRSRP): Egypt, Sudan, Ethiopia, Eritrea and Yemen.

3. West Asia Regional Program (WARP): Cyprus, Iraq, Jordan, Lebanon, Palestine and the lowlands of southern Turkey.

4. The Arabian Peninsula Regional Program (APRP): Bahrain, Kuwait, Qatar, Saudi Arabia, the Sultanate of Oman, the United Arab Emirates, and the Republic of Yemen.

5. Highland Regional Program (HRP): highland areas of West Asia (Afghanistan, Iran, Pakistan and Turkey) and North Africa (Algeria, Morocco and Tunisia).

6. Central Asia and the Caucasus Regional Program (CACRP): Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.

Agricultural water consumption management in Iran considering aridity and drought incidences

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Abstract

The Islamic Republic of Iran is located in one of the most arid regions of the world. About 64.7% (105 million ha) of country's total area has an arid to semi-arid climate. The average annual precipitation is 252 mm, which is one-third of the world's average precipitation. This low amount falls with high temporal and spatial variability. Beside aridity, drought is also a potential threat to agricultural productivity in Iran. Therefore, food and agricultural production in Iran is highly dependent on proper use of water in agriculture. Analysis of past meteorological data indicated that average rainfall during 1995-2000 was less than the average of the last thirty years. The agricultural sector in Iran is one of the most important economic sectors of the country, and water scarcity is the most limiting factor for agricultural expansion and higher production. Due to limitation in water resources and low possibility to increase new water resources, the needed increase in agricultural production can be obtained only by the use of technical and scientific methods to increase agricultural water productivity. The overall agricultural water productivity, which is defined as the amount of crop production per unit amount of water applied for irrigated crops or per millimeter of precipitation for dry land farming crops, presently is about 0.8 (kg/m^3). This is very low and needs to be increased to about 1.6-2.0 kg/m^3 by year 2020 to meet the projected demand of food and other agricultural products. Use of crop varieties with higher drought resistance and changing the cropping pattern to get better use of environment as well as improvement of farm-management practices are key factors to increase WP in Iran. Overall, we need to adapt our agriculture with aridity and drought and WP concept would have a key role in our decision making process.

Introduction

To develop appropriate solution to the water scarcity problems being faced by many developing countries, a better understanding of the use of water for food production is needed. The challenge of water scarcity for food production is likely to intensify in the future as the global population is projected to increase to about 7.8 billion in 2025, and the pressure would be especially high in the developing countries where more than 80% of population increase is expected to occur. Irrigated agriculture has been an important contributor to increase in the national and world food supplies, particularly in the arid and semi-arid areas. However, irrigation accounts for about 72% of global and 90% of developing-country water withdrawals and water availability for irrigation may have to be reduced in many regions because of the rapidly increasing non-agricultural water uses, for example in the industry and at the household levels. With increasing competition for water from different sectors, the challenge to produce more food with less water would further grow. This can only be met if appropriate strategies are developed for saving water and for making more efficient use of water in agriculture.

An important strategy to cope with water scarcity in agriculture is to increase the water productivity (Molden, 1977; Molden et al., 2003). Water productivity (WP) is defined as the physical or economic output per unit amount of water applied. De

Wit (1958) was among the first who applied this concept. He expressed the water use efficiency as kg crop production per m^3 of water transpired. It should be emphasized that the issue of water productivity is multidisciplinary and involves multiple scales. Molden et al. (2003) introduced a conceptual framework for better understanding of WP and water accounting across scales (plant, farm, project, basin and country level). They pointed out that highest WP at one scale might not necessarily result in highest WP at another scale.

Using an integrated water and food model, Cai and Rosegrant (2003) estimated that the WP of cereals (excluding rice) will increase from 1.0 kg m^{-3} in 1995 to 1.40 kg m^{-3} in 2025 in developed countries while in the developing countries the increase would be from 0.56 kg m^{-3} to 1.0 kg m^{-3}. The model showed that in the developing countries the WP of irrigated cereals (excluding rice) would always be higher (more than double) than that of the rain-fed WP over the period 1995 – 2025, whereas for the developed countries the difference would be less. This could be explained by the existence of relatively favorable rainfall conditions for crop growth and high input use in the rain-fed crops in developed countries compared with the developing countries (Rosegrant and Cai, 2001).

The objective of this paper is to show how much increase in WP should be achieved between 1995 and 2025 in order to meet the food demand in a predominantly dry and semi-arid country like Iran and how this increase could be achieved.

Methodology, data and assumptions

In this study WP (kg m^{-3}) is defined as the marketable crop yield over irrigation water applied at the country level:

$$WP = \frac{Yact}{ET} \tag{1}$$

where Yact is the actual marketable crop yield (kg ha^{1}) and ET is the seasonal crop water consumption (m^3 ha^{-1}) at the country level. When we consider the applied water at a field level then

$$WP = \frac{Yact}{ETact} \tag{2}$$

where ETact is the actual seasonal crop water consumption by evapotranspiration at a field level (m^3 ha^{-1}). When considering this relation from a physical standpoint, one should consider transpiration only. The partitioning of evapotranspiration in evaporation and transpiration in field experiments is, however difficult. Moreover, evaporation is always a component related to crop specific growth, tillage and water management practices, and this water is no longer available for other usage or reuse in the basin. Since evapotranspiration is based on root water uptake, supplies from rainfall, irrigation and capillary rise are integrated.

A database has been established of WP data collected from field experiments, results of which have been reported in the research reports of the Agricultural Engineering Research Institute of Iran (AERI, 2005). The field experiments were conducted at experimental stations under varying climatic and soil conditions and different cultural practices such as irrigation, fertilization, and other agronomic practices. Another data set used was on country level, which considered total available water in the country (including precipitation and amount of water from the rivers flowing across the borders), loss in evaporation, and water consumption by different sectors such as agriculture, urban use, industry, and miscellaneous uses (Allen et al., 1998; Ministry of Jahad-e-Keshavarzi and Meteorological Organization, 1998).

Yield was defined as the marketable part of the total above ground biomass production; for example for wheat, barely and corn total grain yield was considered, and for alfalfa total above ground biomass yield.

Results and discussion

Iran is located in the Northern Hemisphere, between 25° and 40° N and 44° to 63° E. Agriculture plays an important role in the economy of Iran. It accounts for one-fourth of the Gross Domestic Product (GDP), one-fourth of employment, more than 80% of food requirements, one-third of non-oil export and 90% of raw materials used in the industry.

Out of 165 million hectares of the country’s areas, about 37 million hectares are suitable for agriculture including 20 million hectares irrigated and 17 million hectares as rainfed. Of this area, currently 14.5 million hectares are devoted to horticulture and field crops production. Some 6.1 million hectares are under annual irrigated crops, 2.37 million hectares under horticultural crops, and about 6.03 million hectares are under annual dry lands crops, while the remaining 3.7 million hectares are left fallow. The total natural vegetative cover and rangeland areas are about 101.4 million hectares including 90 million hectares as pastures (in various level of forage productivity) and 11.4 million hectares as forests.

Climate, agriculture drought and aridity

Iran is situated in one of the most arid regions of the world. The average annual precipitation is 251 mm (less than one-third of the world average), of which 179 mm is directly lost in evaporation. The annual potential evaporation of the country is between 1500 to 2000 mm. The altitude varies from -40 to 5670 m above the mean sea level and this and the latitude have a pronounced influence on the diversity in the climatic conditions in different parts of the country. Although most parts of the country are arid to semi-arid, the country enjoys a wide range of climatic conditions. This is shown by the spatial variation of annual precipitation (50 mm in the central desert and 1600 mm in Gillan province, situated at the southern coast of the Caspian Sea) and a wide range of temperatures (from -44°C in Borojen in Chahar Mahal Bakhtiari province, located in the central Zagruos range mountains to 56°C in the south along the Persian Gulf coast) (Table 1).

Table 1. Distribution of precipitation in Iran.

Annual precipitation (mm)	Area (km^2)	Percentage of total
<50	100000	006
50-100	285000	017
100-200	456000	028
200-300	370000	023
300-500	280000	017
500-1000	130000	008
>1000	18000	001
Total	1648000	100

Based on long-term statistics, Iran faces drought in two out of every ten years. The prominent drought events occurred in 1970-71, 1972-73, 1983-84, 1997-98, and 1999-2001.

Unfortunately, in the past 6 years, particularly in the year 2000, some parts of the country have severely suffered from drought (Table 2). In these years the average annual precipitation was much lower than the thirty-year annual average precipitation (it was 80%, 62%, and 72% lesser than the longer average, in 1999, 2000, 2001, respectively).

Beside high aridity, the distribution of precipitation in Iran is very irregular and uneven. The north, west, and southwest regions of the country, which cover only 30% of the total area, receive around 56% of the total precipitation. The central and eastern parts of the country, which cover 70% of the total area, receive only 44% of the total precipitation (Table 1).

Based on national reports in 2001, drought affected more than 2.6 million ha of irrigated agriculture, 4.0 million ha of rain-fed agriculture and 1.1 million ha of orchards. The production of wheat and barley in 2001 got reduced between 25-30% and in some rain-fed areas there was no yield. Damage to orchard products was estimated to be around 520 million US dollars.

Water resources and agricultural water consumption

The precipitation is the main source of water in Iran, in the form of both rainfall and snow (70% rainfall and 30% snow). It is estimated to be about 413 billion cubic meters (BCM). About 71.6% of the total rainfall (295 BCM) directly evaporates, and by taking into account 12 BCM of water entering from the bordering countries (transboundary rivers) the total potential of renewable water resources has been estimated to be about 130 BCM. Currently, the total water consumption is approximately 92.5 BCM, out of which more than 92% (85.2 BCM) is used in agriculture, while less than 7% is allocated to urban and industrial consumption (Table 3).

Table 2 shows the percentage reduction in the annual rainfall during the recent drought years in different provinces.

Surface water resources provide 37.5 BCM water (about 42% of the total water consumed) for different purposes in the country. More than 60 percent of total water consumption in the country (51

Table 2. Percentage change (- reduction, + increase) in annual rainfall during 1998-2001 from 30-year average for each province of Iran.

Province	Change in annual rainfall (%)			
	1998-1999	1999-2000	2000-2001	Average
Ardebil	-30	+ 3	-20	-17
Azarbayejan Gharbi	-41	-35	-32	-36
Azarbayejan Sharghi	-33	-33	-28	-31
Boosher	-45	-55	-57	-52
Chahar Mahal Bakhtiari	-37	-44	-39	-40
Fars	-29	-61	-47	-46
Ghazvin	-53	-15	-12	-27
Ghom	-31	-14	+47	+ 1
Gilan	-34	-30	+25	-13
Golestan	-33	- 7	-25	-22
Hamedan	-56	-41	+19	-26
Hormozgan	-43	-55	-51	-50
Ilam	-53	-52	-16	-40
Isfahan	-14	-58	-11	-28
Kerman	-27	-60	-58	-48
Kermanshah	-49	-51	-29	-43
Khorasan	-10	-52	-40	-34
Khouzestan	- 3	-42	-26	-24
Kohghiloyeh Boyerahmad	-16	-51	-39	-35
Kordestan	-49	-25	-45	-40
Lorestan	-43	-32	- 7	-27
Markazi	-56	-35	- 2	-31
Mazandaran	-13	- 9	-30	-17
Semnan	-42	-41	- 5	-29
Sistan va Balochestan	-30	-76	-78	-61
Tehran	-43	-37	-20	-33
Yazd	+83	-83	- 6	- 2
Zanjan	-45	-17	-27	-30

Table 3: Estimated water consumption (billion cubic meters, BCM) in Iran in year 2004, and the long-term horizon (year 2020).

Consuming Sector	2004		2020	
	(BCM)	(%)	(BCM)	(%)
Agriculture	85.2	92.1	99.7	85.3
Urban and industry	6.2	6.7	8.7	7.4
Environment	-	-	6.3	5.4
Miscellaneous	1.1	1.2	2.3	1.9
Total	92.5	100	117.0	100

BCM) is extracted from groundwater resources. According to agricultural statistics, the irrigated areas are about 8.4 million ha. For irrigation of these areas, 85.2 BCM of water is used. Overall irrigation efficiency in Iran ranges from 33 to 37%, which is much lower than the average of the world. On the other hand, the International Water Management Institute (IWMI) has reported that the average net irrigation requirement in Iran for cereals and other field crops is 5,100 and 8,100 m^3 ha^{-1}, respectively, which is higher than the average of the world. A comparison of the application of irrigation water in Iran for different crops with the world application is shown in Table 4.

Table 4. Average of water application for different crops in Iran (data for the year 1994), in comparison with the average in the world.

Crop	World (m^3 ha^{-1})	Iran (m^3 ha^{-1})
Wheat	4500-6500	6400
Melons	7000-10500	17900
Sugar-beet	5500-7500	10000-18000
Rice	4500-7000	10000-18000
Sugarcane	15000-25000	20000-30000
Corn	5000-8000	10000-13000

At least 1.6 and 1.8 million ha of the irrigated areas in Iran suffer from severe and moderate water stress level, respectively. About half of the fully irrigated areas are equipped with modern irrigation-system network and operated by governmental organizations. Irrigation efficiency in such systems is very low, between 20 and 30%. The main reason is that this water is free; therefore, there is no economic incentive for farmers to save water. The other half is operated by the private sector and the water is supplied from ground water resources. In this case, the irrigation efficiency is also rather low, at about 35%. The remaining irrigated farms in Iran, which are under severe to moderate water stress level, belong to the small farm holders who in fact do not save water but their irrigation efficiency is high, between 55-65%. It may be mainly due to the deficit irrigation usually practiced by them. These farmers have enough land and the area they cultivate is much larger than the water available to them. They usually get more benefit from extensive farming with deficit irrigation rather than with intensive farming and full irrigation.

Agricultural water productivity

Obtaining more production with the same amount of water leads to an increase in water productivity and may allow the re-allocation of water from lower to higher value corps or from different sections of agriculture sector to others, where the marginal value of the water is higher.

There are, generally, four approaches for generating more agricultural output from utilizable water resources; increasing utilizable water, developing more primary water (increase in development of facilities or supply), consuming the developed water more efficiently (increase in basin efficiency), producing more output per unit of water consumed (increase in water productivity). The first two options are very limited in Iran. As for the third option, it is obvious that water conservation on those areas that receive full irrigation may be feasible. By proper water management and completion of water distribution networks, the irrigation efficiency is expected to increase up to 50 to 60%. In this case the area of such lands may respectively increase to 3.5 to 4.3 million ha, from the current 2.5 million ha. Although it is also possible to increase irrigation effectiveness in those areas that receive reduced irrigation, but no significant increase in cultivated areas can be expected. Thus, the major solution will be the fourth option which is “increasing water productivity”.

The average agricultural WP of the country is estimated to be around 0.80 kg m^{-3}. This value in dry land farming was 0.33 kg m^{-3} for wheat and barely and 1.3 kg m^{-3} for pulses. Values of measured WP for different agricultural crops in Iran are shown in Table 5.

Table 5. Measured water productivity for different crops at different regions in Iran.

Crop	Irrigation method	Yield (kg ha^{-1})	Applied water (m^3 ha^{-1})	Water productivity (kg m^{-3})
Wheat	furrow-border	5460	9900	0.55
Barley	furrow	6090	6120	1.00
Sugar beet	furrow-border 37700	14500	2.60	
Potato	furrow	37100	5140	7.21
Corn	furrow	7000	1080	0.65
Alfalfa	basin-border	10500	11660	0.90
Beans	furrow	5100	5600	0.91
Sesame	furrow	1432	7000	0.20
Tomato	furrow	16000	4800	3.33
Lettuce	furrow	4100	8600	4.77

Challenges to food production from limited water resources

Iran's population is estimated to reach 90.3 million by year 2020. Assuming a normal intake rate of 3270 KCal energy and 91 g protein per capita, the total agricultural production should be 172 million tons by 2020.

Of this, 160 million tons should come from irrigated agriculture, from a total water supply for agriculture of about 100 BCM. This means that by the year 2020 water productivity should reach to 1.6 kg m^{-3}. With opportunities for area expansion being almost exhausted, additional food production will have to be produced mainly through increasing water productivity.

To further highlight the importance of water and draw attention to the need to improve water productivity in the future, the main agricultural attributes in the baseline year 2004 and long horizon are presented in Table 6.

Possibility of increasing water resources in country is very limited (21.2% after 16 years). However, agricultural production in irrigated farming has to be increased significantly, by 337% in 2020. This implies that present water productivity (0.8 kg m^{-3}) has to be increased to 1.6 kg m^{-3} by year 2020 (Table 6).

Challenges and opportunities for improving WP

As already noted, the major consumer of water (more than 92%) in Iran is the agriculture sector. The present average water productivity of agricultural crops is 0.8 kg m^{-3}. Increase in economic value of water is one of the major objectives of the Economic Development Programs of Iran. Increase in the economic value of water will be possible when the yield or return per unit volume of water increases. For this reason it is preferable to use the supplied water for producing commodities with higher economic return, or to use it in the regions where the economic returns are higher.

In light of the above, the determination of the cropping pattern, crop water requirement, and finally the volumetric allocation of water for each region have been considered as important means for increasing the economic value of water. To ensure optimum use of water allocated to farmers, the following policies are important:

- Control of water resources and volumetric allocation of water to the farms based on crop water requirement and recommended irrigation efficiencies.
- Based on the law established in 1983 water charge of the regulated surface water is 1-3% of the gross value of the cultivated corps
- Based on the law established in Dec. 1993, pumping of groundwater resources must be in accordance with the crop water requirement and proposed cropping pattern in each region. In this case, 0.25-1.0% of the commercial value of crop yield is considered for the ground water supervision.
- Subsidizing policies for water and supervision charges for farmers whose yields are higher than average.
- Termination of water allocation to the farmers who in two successive years consumed water more than permissible level.
- Encouraging policies for the farmers who use less water and maintain their production at reasonable levels using proper management practices.

Table 6. Main agricultural attributes of Iran in the baseline year (2004) and long term horizon.

Attributes	Year	
	2004	**2020**
Population (million)	67	90.3
Volume of water allocated to the agricultural sector (BCM)	92.1	99.7
Total production from irrigated farming (million-ton)	68	189
Water productivity (kg m^{-3})	0.8	1.6
Increase in supply of water (%)	9.7	22
Expected increase in the production of the irrigated farming (%)	150	337
Total water allocated to the agricultural sector (%)	92.1	85.3

Conclusions

Agriculture sector in Iran is one of the most important economic sectors of the country. Recent droughts had major effects on reducing WP in dry land farming. Drought mitigation in the future should involve appropriate forecasting methods and management measures. Availability of water is the most limiting factor for agricultural production. Water productivity (WP) of irrigated agriculture is 0.8 kg m^{-3}. For ensuring food security in the year 2020 the agricultural production should be increased to 160 million ton. Assuming a maximum supply of 100 BCM of water for agriculture by that year, WP in irrigated agriculture should be increased to 1.6 kg m^{-3} to get that level of production. For getting optimum management of water in agriculture and increasing WP, the following measures and approaches are suggested: Enhanced operational management of irrigation and drainage networks, optimal improvements in irrigation efficiency and water use efficiency in irrigated fields, deficit irrigation, use of technical and management measures to reduce irrigation water losses especially in the first and second irrigation, provision of comprehensive plan for use of marginal waters in agriculture, optimal use of rain-fed areas and expansion of supplemental irrigation techniques, reduction of evaporation losses from soil surface in dry land farming, and paying special attention to the integrated use of water and other agricultural inputs (e.g., fertilizers, pesticides, etc.).

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Development and consequent desertification of Chinese dryland: A case study of Minqin oasis, northwest China, over the last 2000 years

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Abstract

Irrigated farming has affected most natural oases in the dryland of western China for over 2000 years since Han Chinese employed advanced agricultural techniques in such places. A typical example of the resulting overuse and ultimate desertification of oases is found in the Minqin basin along the ancient Silk-Road in the eastern part of Hexi Corridor and lower reaches of the Shiyang River. This study focuses on understanding the desertification process of the last 2000 years, using a multi-disciplinary approach, incorporating historical documents, archaeology, remote sensing and geographic information system (GIS). Our research shows that human activities in Minqin basin can be dated back to at least the Shajing culture, a Neolithic culture dated to around 2600 years ago. Since the area became part of the territory of Han Dynasty in BC 210, the natural oases quickly changed into farmland. Farmland occupied about 14,800 ha in the Han Dynasty (121 BC- AD 220) and 27,830 ha in the Wei and Jin dynasties (AD 220-420). Farmland deceased during the next 800 years from the South-North Dynasty (AD 420-581) to the Yuan Dynasty (AD 1271-1368) when nomadic people invaded the area. The second intensified development of Minqin oasis began in Ming Dynasty (AD 1368-1644) when the central government encouraged farmers in east China to migrate to the oasis, and the area of irrigated farmland reached 26,579 ha. This was followed by another more intensive development period in the Qing Dynasty (AD 1644-1911), with an irrigated area of 75,847 ha, the highest during the history. An intensive development period was always followed by a strong desertification thereafter. When a new dynasty promoted development of natural oasis into irrigated farmland, desertification occurred in the late stages of the dynasty with abandonment of villages and towns relying on farmland. The irrigated oases developed in different dynasties were located in different places, with the trend to increase in scale. Wars, population and climate change are the main factors of desertification.

Introduction

The empire of the Chinese Han Dynasty (206 BC–AD 220) expanded westward to the rim of the Tarim Basin, creating and maintaining the trade caravan routes known as the Silk Road. In support of this trade, the Han imposed military and civilian administration, encouraged immigration, and implemented irrigation projects in oases and along rivers. This allowed the introduction to desert oases of advanced agricultural techniques originating in central China. At first, agricultural production was very high and the new farming and trading communities flourished. But, eventually, desertification occurred, production decreased, and some oases were abandoned. The ruins of towns still standing in the desert, such as Loulan near Luobu Nor in Xinjiang found in 1930s, the Pochengzi of Dongshawo in Jinta, and archaeological sites K688, K710, K749 along the lower reach of Heihe River, are the clear proof of this process along Silk Road.

Indeed, the desertification of agricultural oases is a process that always accompanies the development of arid lands. After Han Dynasty, the oases distributed in the Hexi Corridor including Heishuiguo in Zhangye, Dongshawo in Jinta, and Yangguan in Dunhuang desertified in Tang Dynasty, and Gaogoubao in Wuwei, Juyan in Ejina, and Suoyang in Anxi in Ming and Qing Dynasty (Li, 2003).

As an important part of the ancient Silk Road, the Hexi Corridor formed a key channel for cultural exchange between China and other countries in ancient times (Li, 1995). During the historical period, a series of complicated environmental changes took place in this area (Dang, 2001; Feng and Wu, 1986; Pachur et al., 1995; Shi et al., 2002; Tang, 1980; Zhu et al., 1983; Wang, 2003). Land use and land cover changes have serious effects on global environment change (Turner et al., 1990; Turner and Meyer, 1990; Meyer and Turner, 1992). As a type of land cover changes, desertification also plays important roles in environment deterioration of dryland. This paper describes the processes resulting in desertification of the Minqin basin, located in the eastern part of the Hexi Corridor and lower reaches of the Shiyang River, over the last 2000 years. The desertification of Minqin oasis is typical of that occurring throughout arid China.

Geographical setting

Western China consists of high mountains, plateaus, gobies /deserts, rivers, terminal lakes and oases. Ecozones, from highest to lowest, include glaciers, tundra, conifer forest, grassland, low altitude wetlands (oases), and sand (shamu) and gravel (gobi) deserts. This region contains the world's second largest desert (Taklimakan), and the highest dunes (in the Badain Jaran Desert). Because the mountains of the Qinghai-Tibetan Plateau have relatively high precipitation and the tops are covered by glaciers and snow, rivers flowing northeastward from them into the desert provide a stable water flow and develop lush wetlands along streams and around terminal lakes (Fig.1). In ancient times, food, fodder and water from these oases supported the famous Silk Road.

Hexi Corridor is an important part of arid western China and there are three large catchments distributed along it. Among them, the Shiyang River is the easternmost, and it has supported a greater population than others. Originating in the Qilian Mountains, the Shiyang River flows through Wuwei plain and then northeastward into Minqin basin (Fig. 2). Wuwei and Minqin oases are fed by the Shiyang River.

Minqin basin is the terminus of Shiyang River (Fig. 2). The basin surface is quite flat with altitude between 1300 to 1400 meters asl, which slopes gradually from southwest to northeast. Except to the south, the basin is surrounded by the Badain Jaran and Tengger deserts. At present the area of Minqin oasis amounts to 120,000 ha with a population about 280,000. Minqin oasis is the key area for the economic development of Minqin County.

In prehistoric times (about 2200 BP), there existed a wide terminal lake named Zhuyeze in the end of

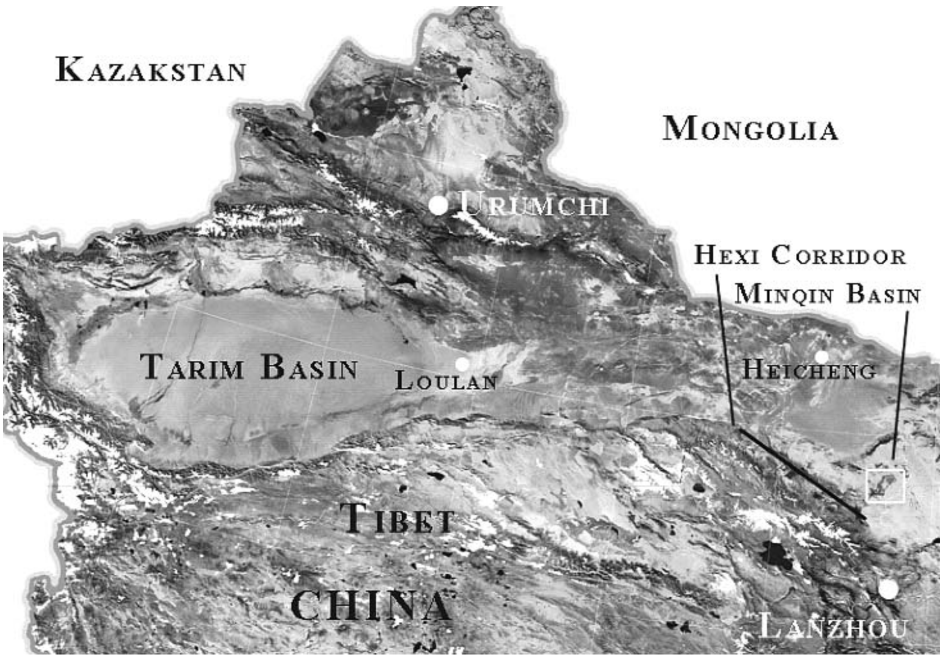

Fig. 1. TM image showing the general situation of dry northwest China. Location of Minqin basin is marked by square box.

Shiyang River in Minqin basin. The paleolake was found to be larger than 2000 km^2 during early Holocene (Shi et al., 2002; Chen et al., 2006a) with dry middle Holocene (Chen et al., 2003). Huge lake covered most part of the lake and even part of Tengger Desert formed during MIS 3 (Pachur et al., 1995). In the delta area of the lake and along the banks of the river, a large natural oasis developed (Feng, 1963). During the Western Han Dynasty, the local Hun people were driven out and the whole Hexi Corridor including Minqin basin, became a part of Han China. Thereafter, advanced irrigated agriculture was introduced and artificial oases i.e., farmland oases, were widely developed. At times over the last 2000 years, the lake shrank, the oasis moved, and as vegetation declined, the wind moved sand and the productive land that was suitable for planting and fishing became barren; many historical oases and towns were inundated by sand. Nevertheless, the human population of Minqin basin continued to increase, some old oases were abandoned, but new ones were established in the dried lake bed and beside river, and the oasis' centre moved further upstream (Xie and Chen, 2002). In the face of serious desertification, salinization and ecological crisis,

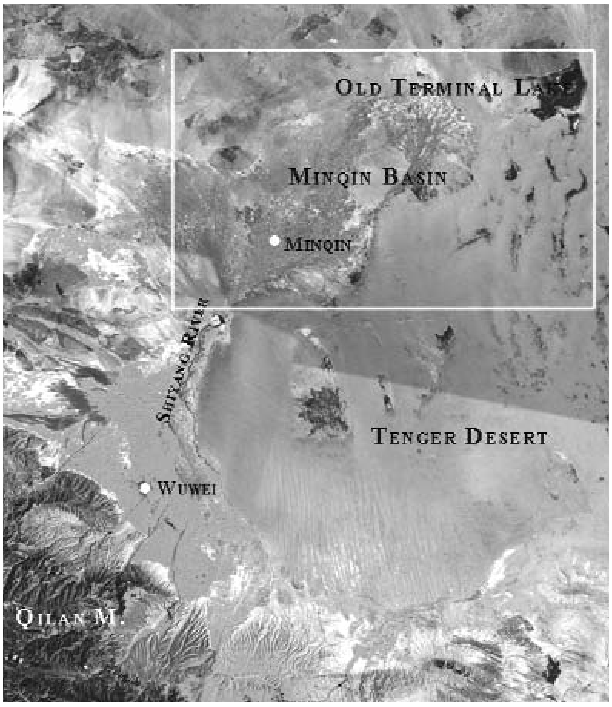

Fig. 2. TM image showing Shiyang River drainage and Minqin basin (white box). Note the Minqin oasis is surrounded by desert and gobi, and the high Qilian Mountains, Margin Mountain of Tibet Plateau, provide water resource for Minqin Oasis through Shiyang River.

sustainable development in the region now faces significant challenges (Zou and Wang, 1999).

Research methods

Information about environmental change in the ancient oasis is usually scattered and impossible to fully obtain using single means. This research employs methods of historical geography, in combination with geographic information systems (GIS), to synthetically analyze historical documents, archaeological materials, remote sensing images, maps and on-the-ground reconnaissance to reconstruct the farmland oasis changes and the course of desertification.

Archaeological survey

Archaeological survey is an important component of oasis study. Our fieldwork collected information on the distribution, scale, form, and period of occupation of ancient sites, towns, tombs or relics, along with their proximity to water and terrain situation. Archaeological and historical geographical experts provided us with technical assistance to determine temporal relations among archaeological sites and relics. Mapping was supported by data colleted by global positioning system (GPS) receivers. Archaeological survey results were classified into past town, village, site, tomb group, relics and past objects with the age between Han and the period of Republic of China (Minguo), which are shown in Fig. 3.

Remote sensing images

Over the last 2000 years, the oasis has covered an area ranging from a few to several dozen square kilometers. Observation and analysis of such a large-scale feature requires the use of remote sensing images. Two kinds of remote sensing images were employed in this study: 1:60000 aerial photographs taken in 1959-1960 and TM data obtained on September 5, 1994. Both were geo-referenced to 1:50000 topographic maps. Because the ancient oasis is mostly in desert now, the faint image color was computer-enhanced with ERDAS software.

Historical documents and maps

Three kinds of historic records were used in this study. One is the ancient and modern chorography

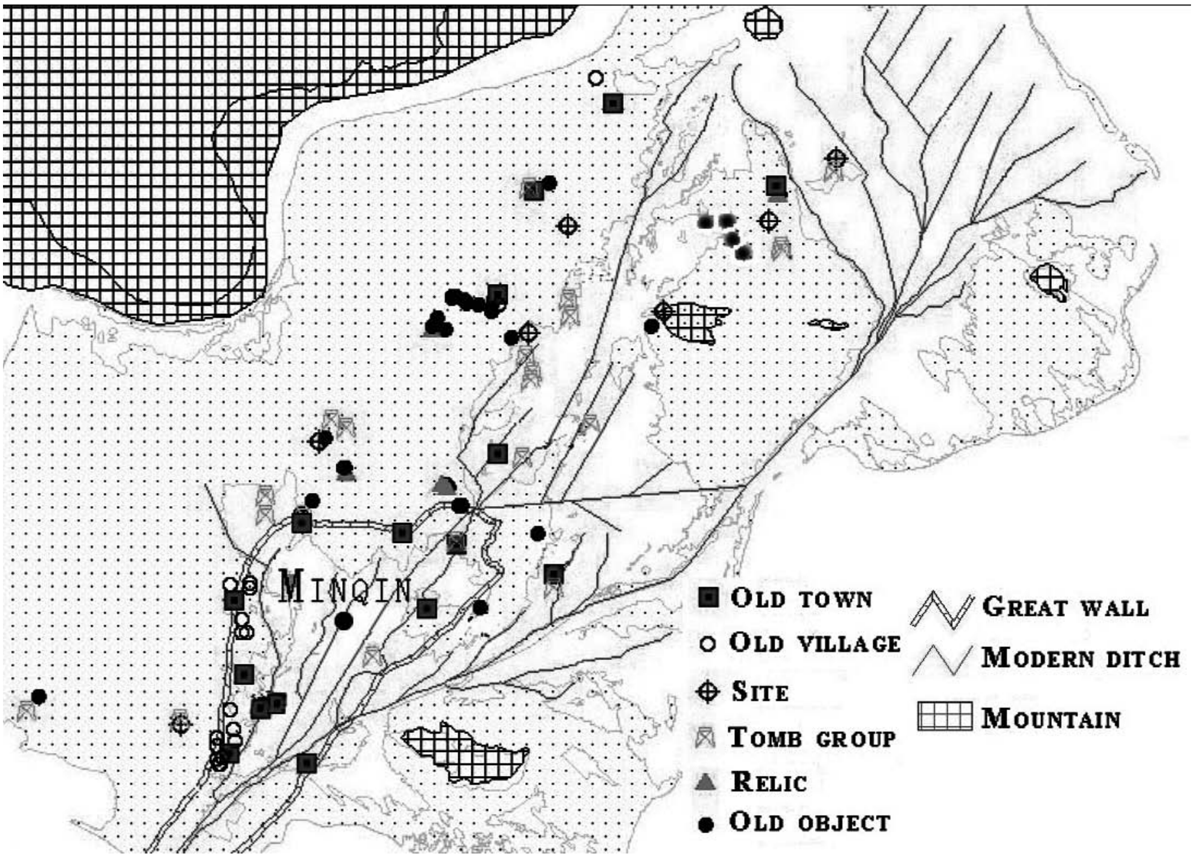

Fig. 3. Relic sites in Minqin basin; also showing the distribution of ancient agriculture oasis.

(the book about a region's history, geography, culture, economy etc. like an encyclopedia of the region). Among ancient documents, *Anecdotal almannac of old Zhenfan County* (old name of Minqin County*)* (Xie et al., 2000) is the most important, recording various kinds of historical incidents and natural phenomena year by year, spanning 600 years, from the beginning of Ming Dynasty to Minguo. An important modern work is the *Minqin County Chorography* (CCCMC, 1994), which fully incorporates new research achievements in history, geography, population, historical relics, and so on. A second source of information is the extensive published work of historical geographers focused on the Hexi Corridor (e.g., Feng, 1963; Li, 1995; 2003). A third source is archaeological literature: including *Historical Relic Catalogue of Minqin County* and *Brief Introduction of Historical Relics of Minqin County* (data, from the Historical Relic Archaeological Research Institute of Gansu Province). Besides written documents, modern regional maps, topographic maps at various scales, and historical maps such as Liangzhou Map of *China's Historical Atlas* (Tan, 1982) were also employed in the present study.

Evolution of the agricultural oasis

Before Han dynasty (before 121 BC)

During Chinese Spring and Autumn period (770-476 BC) and Warring States period (475-221 BC), non-Chinese Rouzhi people came to Minqin basin to live and get grazing for their livestock (CCCMC, 1994). Relics of the archaeological Shajing culture (about 2800a BP to 2600a BP) are common throughout Minqin basin, and are thought to relate to the Rouzhi. After that period, non-Chinese nomads called Huns drove the Rouzhi out and controlled the region and used the Minquin basin for grazing livestock. According to *Hun People Biography in Han Dynasty book* "Hun people migrated according to the water and grass without towns to live or land to plant". Therefore there was no cultivation activity in Minqin basin at the time of Hun occupation. The landscape of the oasis was basically in a natural state.

Han periods (121 BC- AD 220)

In the second year of Yuanshou (121 BC) of the

Hanwu Emperor's rein, the Hexi Corridor, including Minqin basin, came in to the administrative territory of the central government of Han. The Han developed this area by building frontier fortresses, reclaiming wasteland, moving the people, and setting up administrative units including four shires (Wuwei, Jiuquan, Zhangye and Dunhuang) and over 35 counties. Among these Wuwei and Xuanwei counties in Wuwei Shire were established in Minqin basin (Li, 1995; CCCMC, 1994; Sun, 1999; Liang, 1997). The Han government introduced advanced irrigated farming technology to this area and enormously changed the landscape and vegetation covers. As human activities gradually increased, natural wetlands of rivers and lakes dwindled rapidly, while artificial oasis and cultivated land expanded. However, the Shiyang River still had plenty of water to irrigate fields with a widespread network of artificial channels (CWCCM, 1994). With the rapid development of irrigated agriculture, the oasis was now focused on agricultural production (Chen and Qu, 1992).

All together, our data suggest that the artificially irrigated and cultivated areas during Han dynasty were mainly located on river terraces in what is now Xuebai Township and Gucheng site in Xishawo (the new name of the desert west of Minqin oasis). In addition, a small-scale military cultivation area lies in southwest of ruined ancient Sanjiaocheng Town. The distribution of Han oases is shown in Fig. 4a. Using GIS, the area of Han Minqin oasis is estimated to be about 14,800 ha.

Wei and Jin dynasties (AD 220-420)

Numerous relics of the Wei and Jin dynasties found during our fieldwork indicate that Minqin oasis was prosperous at this time. Our combined archaeological, remote sensing, and historical data suggest that the oasis was still distributed along both banks of the ancient river in Xishawo Desert, and had greatly expanded eastwards closed to river channel. The total reclaimed area was greater than that during the Han dynasty (Fig. 4b). GIS measurements indicate that the oasis occupied an area of about 27,832 ha in this period.

Northern and southern dynasties (AD 420-581) to Yuan dynasty (AD 1271-1368)

In the Northern Wei Period (AD 386-534), Minquin basin contained only one county (Xuanwei) with just 373 households (Liang, 1997). The agricultural oasis was extremely

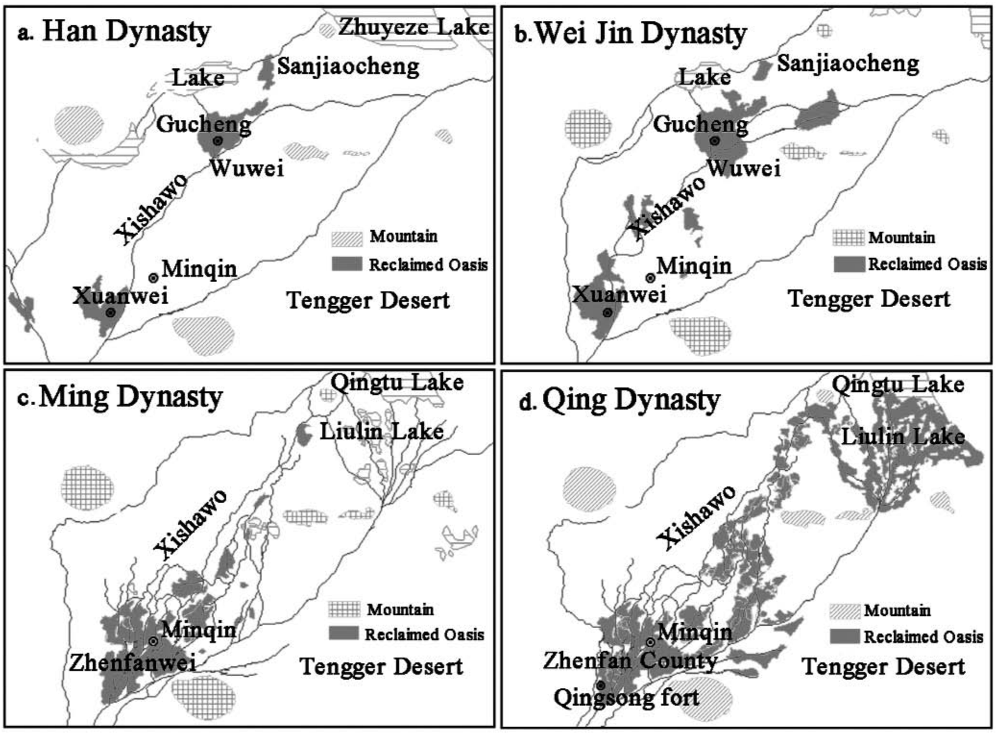

Fig. 4. Reconstructed distribution of the ancient agriculture oasis during several typical dynasties, i.e., Han Dynasty (121 BC-AD 220), Wei-Jin Dynasty (AD 220-420), Ming Dynasty (AD 1368-1644) and Qing Dynasty (AD 1644-1911) in Minqin basin.

limited at that time. From then to the period of Sui dynasty (AD 581-618), there was no county level government, and it is possible that Minqin was under the control of Turki people (Wang, 1991).

During the Tang dynasty (AD 618-907), the economy of Hexi Corridor achieved an unprecedented prosperity, but in Minqin basin there were only a few military organizations to guard frontier safety. After the Anshi Chaos, a war aroused by An Lushan and Shi Siming in Tang dynasty in AD 764, Minqin basin was occupied by the Tubo people (Tibetan) who did not do farming. The local people were robbed and enslaved and finally driven away. The oases developed from the Han dynasty to Wei-Jin dynasties were all abandoned and deserted because of the fragile ecology.

After the Tang dynasty, Minqin basin was ruled first by the Xixia (a kingdom established by Tangut speaking Dangxiang people from Tibet, AD 1038-1227) and later, by the Mongol Yuan dynasty (AD 1271-1368). The Dangxiang were nomadic and "followed the grass and water," and the Mongols were also not good at agriculture, so Minqin oasis was basically abandoned and there remained only one residential settlement named Xiaohetan Town (located in where is now the Minqin county seat). In the later part of Yuan dynasty, wars killed many people; those who survived, escaped and moved away, abandoning land and livestock, the only settlement remaining - Xiaohetan Town - became “an empty town” (CCCMC, 1994).

Ming dynasty (AD 1368-1644)

The second great period of agricultural development took place during the Ming dynasty. In the fifth year of Emperor Hongwu (AD 1372), "more than 2,000 people from Shanxi and Henan provinces were dispatched to this area; they were settled around Caiqi and Qingsong castle" to engage in cultivation (Xie et al., 2000). In the same year, Linhewei, a military unit, was established (in twenty ninth year of Emperor Hongwu, it was renamed Zhenfanwei). For soldiers stationed there, "3 of 10 were asked to guard and 7 to cultivate," and "every soldier was given 50 *mu* of land to plant"(*mu* is a unit of area, about 0.0667 ha). This policy enabled the cultivated area to expand and the population to increase, resulting gradually in the expansion of the oasis. The oasis of the Ming dynasty is shown in Fig. 4c. Using GIS, the total area of the Ming oasis was estimated to be around 26,579 ha. The cultivated area was mainly within the Ming Great Wall. The Xishawo reclamation areas developed in the Han and Wei-Jin period were totally abandoned and got desertified in this period.

During the period of Qing dynasty (AD 1644-1911) and Republic of China (AD 1912-1949)

The Qing oasis is the result of continued development after the Ming reclamation. Population increased to the maximum of the entire historic period, and the oasis reached its maximum size. Especially during the reign of Emperors Yong Zheng and Qianlong (AD 1723-1795), the lower reach of the Shiyang River (named Liulinhu) was reclaimed and cultivated fields expanded to the shore of the ancient terminal lake. The oasis of this period was located around the Minqin county seat, along the Shiyang River, and in the delta region of the old terminal lake (Fig 4d). The total area was about 75,846 ha, the highest in the entire historical period. The Qing dynasty reclamation established the framework of the modern Minqin oasis.

It is important to understand, however, that while the agricultural oasis was expanding into new places, the old reclaimed areas to the west and along the upper reaches of the river were abandoned because of strong desertification. For example, prosperous Qingsong fort, in which many people in the Ming dynasty lived, experienced desertification in this period. This situation grew worse during the period of the Republic of China.

Discussion

Spatial changes of agricultural oasis

Two thousand years ago, the Minqin basin was well watered by rivers and lakes, with large areas of surface water. Additionally, the population was low and agriculture undeveloped. The best land was reclaimed first and the reclaimed area was relatively small. In the Wei and Jin period (AD 220-420) reclamation was extended to a larger region. From the Northern and Southern dynasties (AD 420-581) to the Yuan dynasty (AD 1271-1368), Minqin basin was either occupied by nomads, or remained desolate and uninhabited, with the agricultural oasis abandoned. In the Ming dynasty, as the rivers changed course and the lakes became smaller, more dry land appeared. Because of its location on the border, and frequent intrusion by Mongols, the oasis was wholly contained within the Great Wall. In the beginning of the Qing dynasty, Minqin basin was politically stable and free of wars, the population increased there, and the reclaimed area extended to the lower reaches of the river. From then on, development of Minqin oasis was stable. Over the last 2000 years, the agriculture oasis shifted from west to east, from high latitude to river bank and lake shore, and from middle part of the basin to upward of river and downward of river.

The cause of desertification.

Over the last 2000 years, the artificial agriculture oasis of Minqin basin moved from place to place in the basin. Some irrigated lands developed in the early times were retained, but more were abandoned and became desertified. Typically, when a new dynasty was first established, development of natural areas into farmland oases began, but in the later stages of the dynasty, desertification of farmlands and abandonment of villages and towns often occurred, and left a lot of ruins in the desert.

This pattern is related to wars, population pressure and climate change. Wars can make oasis management difficult or even impossible and also rapidly reduce population, resulting in abandonment of the oasis. In the late Dong Jin dynasty (AD 317-420), war and chaos occurred continuously, and the political situation was confused; agricultural production was therefore impossible and the oasis was deserted.

In the earliest period of development, population was very important for agriculture oasis development, because nature oasis reclamation and agriculture oasis formation required large labor force. But in the later periods, rapid population increase had negative effects on the oasis. After the Ming dynasty, and especially in the Qing dynasty, the population of the entire Shiyang catchments increased rapidly (Fig 5a), a large area was reclaimed (Fig 5b, Table 1), and ever more water was needed to irrigate land (Fig 5). For the whole Shiyang River Drainage (Fig. 5), population increased rapidly during late 16th century. At Qianlong period of Qing Dynasty, the population density reached 8.8 per km² which exceeded the dryland critical density 7 per km² (Wang et al., 2003; 2005). The use ratio of water resource reached 72% which far exceeded the threshold 40% of water use in dryland (Wang et al., 2003; 2005). The shortage of water resource in Minqin basin inevitably happened because new agriculture area developed in middle reach of Shiyang River. Therefore, people in Minqin basin in the low reach of Shiyang River had to reclaim the land near terminal lake, while some land near the desert, facing the northwest wind, was abandoned on account of lack of water and sand encroachment.

Environmental changes also were important factors in desertification. Over the past 2000 years,

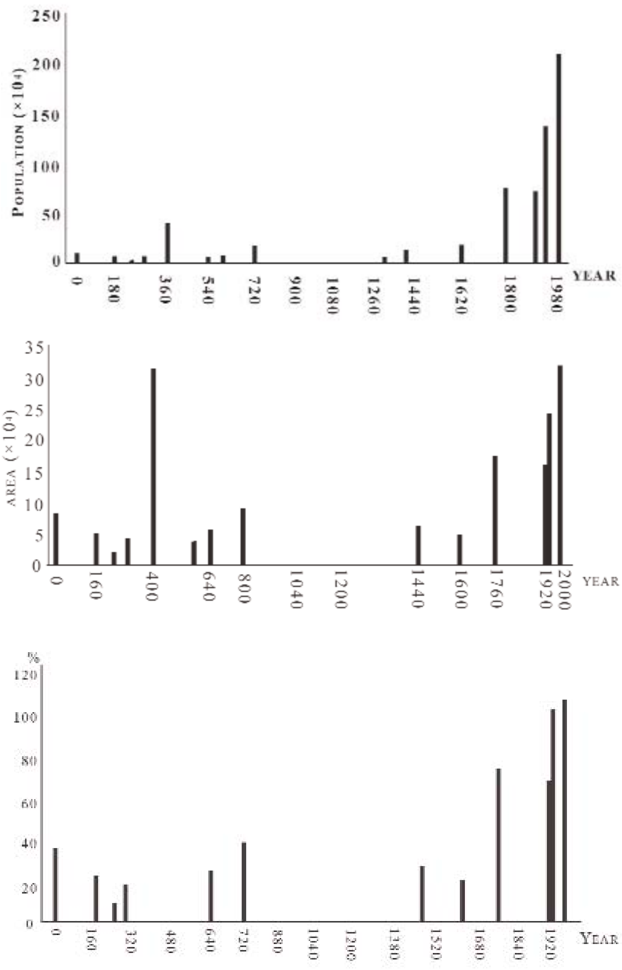

Fig. 5. Population (upper), farmland Area in mu (middle), and use ratio of water resources (low) in Shiyang River Drainage over the last 2000 Years. Note the rapid increases of population, farmland and water resource consumed. (Revised from Wang et al., 2005).

Table 1 Agriculture oasis areas in Ming and Qing dynasties documented by literature.

Period	Ming (Zhengtong) (1436-1449)	Ming (Jiajing) (1522-1566)	Ming (Wanli) (1573-1620)	Qing (Yongzheng) (1725)	Qing (Qianlong) (1736)	Qing (Jiaqing) (1820)
Area ($\times 10^4$ mu)	95	46	70	122	262	

the climate of northwest China has obviously changed. Climate in arid northwest China was not only warm but also humid at 2.2-1.8 ka BP (Yang et al, 2004), which well corresponds to the development of agriculture oasis in Han dynasty. Between 1400-1900AD, a 500-year period is the Little Ice Age (LIA) of China (Wang et al., 2006) which showed low temperature and cold climate in China (Yang et al., 2002). It was found that climate was humid during LIA in dry China (Chen et al., 2006b) with high precipitation and groundwater recharge around Minqin basin in Tengger and Badam Desert (Ma et al., 2003). High precipitation and humid climate could be favorable for the agriculture development in the dry Minqin basin. This well coincides with the second time development of the Minqin oasis under stable government in Ming and Qing dynasties. It is possibly that the weak monsoon and dry climate since end of 19th century at monsoon margin under global warming may be responsible for part of the oasis ruin with serious ecological crisis and strong dust storm in Minqin basin (Li et al., 2006).

Conclusions

(1) Changes in the area of Minqin oasis were largest in early and the recent periods, and smaller in the middle period over the last 2000 years. In the Han Dynasty (121 BC-AD 220), farmland reached to about 14,800 ha, and during the Wei-Jin dynasties (AD 220-420) to 27,830 ha. It then deceased during the following 800 years between the South-North dynasties (AD 420-581) and Yuan Dynasty (AD 1271-1368). The second period of expansion began in Ming Dynasty from AD 1368 to AD 1644 and the area reached 26,579 ha followed by another more intensive development period in Qing Dynasty (AD 1644-1911) when the total farmland area reached 75,847 ha, the highest in history.

(2) Over the last 2000 years farmland development and consequent desertification occurred in cyclic manner in the Minqin oasis. There were four periods of farmland oasis development when central government was strong and stable i.e. the periods of Han, Wei-Jin, Ming and Qing dynasties. Each period of development was followed by desertification during the transition between two dynasties because of unstable government and destruction of the water management system.

(3) The spatial change of agricultural oasis is remarkable. The oasis during the Han to Wei-Jin and Qing dynasty was distributed from upper to lower reaches of the river, but during the Ming dynasty it was contained within the Great Wall. In general, the oasis first shifted from the west (high latitude) to east (low latitude), then moved from north (upstream) to south (downstream), then north again. Once a farmland oasis became desertified, it was hard to bring it back to farmland again because of fragile ecological system, and the eolian sand and dune coverage.

(4) The causes of desertification in Minqin oasis are very complex, including wars, population growth and climate change. Climate change is always in the background of oasis development, while population factor has a two-sided effect. If there are too few people residing there, the oasis can not be maintained. If there are too many people, they produce pressure on the environment that ultimately leads to desertification. In Qing dynasty, the population living in the Shiyang catchment exceeded the critical number and caused environmental deterioration. Wars directly result in desertification by destroying the political and social ability to manage the oasis, and reducing population to the point of abandonment. From Han Dynasty to Yuan Dynasty, whenever population was reduced in the whole catchment and the Minqin basin, people had less ability to use or control water. In this case, the critical factor was man. During the Ming and Qing dynasties, obviously that human factor got the upper hand.

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Desertification and its control in India

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Abstract

Land degradation (including desertification in drylands) is estimated to affect at least one-third of the 328 million hectares (m ha) geographical area in India. Drylands, constituting about 223 m ha in arid, semi-arid and dry sub-humid regions, are more prone to degradation on account of climatic constraints, fragility of natural resources, and high pressure of humans and animals, as well as industrialization. Arid areas (49.5 m ha) are the worst affected, especially in the western part of Rajasthan state that includes the Thar Desert (20.87 m ha), as well as in arid Gujarat (6.22 m ha). Traditional practices of water storage and conservation and mixed farming - that integrated perennial trees and grasses with crop cultivation and livestock rearing - which proved as best practices for sustainability and resource conservation, are now disappearing. To combat the adverse impact of land degradation on finite land and water resources, India embarked upon a national policy to bring 33% of the country's land area under forest, as well as to implement desert and drought-prone area development programmes, which include sand dune stabilization, wind erosion control, soil and water conservation in peninsular India and river valley projects, watershed development, agro-forestry, social forestry and joint forest management, salinity control, etc., through state land development departments, forest departments, R&D institutions, NGOs, and people's participation.

The Central Arid Zone Research Institute is contributing to these efforts through research interventions. Its technology on sand dune stabilization through vegetative means has been used by the State to stabilize about 300,000 ha area of menacing sand dunes, especially on government-controlled land. Promising technologies for shelterbelts, border row plantation, plantation of tree belts across the wind and alternating with crop/grass rows that utilize remunerative native/exotic trees, shrubs and grasses for food, fuel, fodder, fruits, minor forest products like gum and resins, have also been developed for the farmers who are the major users of sand dunes in the region. Shelterbelts of a three-row wind break of *Acacia tortilis*, *Cassia siamea* and *Prosopis juliflora* as the side rows and *Albizzia lebbek* as the central row have proved promising. A number of diversified farming systems have been evolved for low-rainfall areas, which include agro-forestry, agri-horticulture and agri-silvi-pasture, to sustain livelihood during crop failure and to maintain livestock during drought. Improved practices for pasture and rangeland management, especially through silvi-horti-pastoral systems and rotational grazing, and rehabilitation of mine spoils through vegetative means have been developed and are being propagated by R&D institutions as well as state departments. For water erosion control on arable lands, contour cultivation, bunding, graded bunding and bench terracing are adopted in conjunction with minimum tillage, cover crops, inter-cropping, strip cropping, contour vegetative barriers, etc. For non-arable lands check dams, gully plugging, stabilization of gully heads and vegetative measures are advocated. These measures and appropriate land uses are integrated on catchment basis with due regard to capability of the land. Rain water conservation, its harvesting and efficient utilization are in-built in watershed management programmes. Combating desertification through land care while enhancing agricultural productivity is the underlying principle for sustainable land management in the drylands of India.

Introduction

Desertification is a slow process of land degradation that exacerbates the quality of land, leading to decline in its productivity and thus impacting the livelihood of the people depending on it. The term 'desertification' was first used by Lavauden (1927) to describe severely overgrazed lands in Tunisia (Dregne, 2000), and was then used by Aubreville (1949) to show excessive soil erosion due to deforestation in the French West Africa. Subsequently, alarmed by a long drought in the sub-Saharan Africa during the early 1970s, the United Nations Conference on Desertification (UNCOD) at Nairobi defined the term as diminution of the biological potential of land in any ecosystem (UNCOD, 1977). Implicit processes were drought and human-induced wind and water erosion, salinization, vegetation degradation, etc., which could ultimately lead to the formation of desert-like conditions. The definition was revised again during the 1992 UN Conference on Environment and Development (UNCED) as land degradation in arid, semi-arid, and dry sub-humid areas, resulting from various factors, including climatic variation as well as human activities (Anon., 1992). This definition is now being followed by the UN Convention to Combat Desertification (Anon., 1995).

Desertification scenario in India

Land degradation is a major problem in India. Estimates of land degradation in the country vary from 107 million hectare (mha) to 187 mha (Anon., 1994; 2001). A recent estimate suggests that 147 mha (44.7% of the country's total geographical area) is affected (Samra and Sharma, 2005). Drylands, which consist of the arid, semi-arid and dry sub-humid regions, and constitute >76% of the country's total geographical area, are most affected. It has been estimated that the states that are dominantly under drylands, comprise 37% of country's total area, and 83% of country's total degraded area. The most dominant process is water erosion, covering 68% of the total degraded land in the drylands (encompassing all the dryland states, but covering larger areas in Madhya Pradesh, Maharashtra, Andhra Pradesh, Gujarat, Karnataka, Jammu and Kashmir, and Rajasthan), followed by salinization and waterlogging (13%; dominantly in Uttar Pradesh, Andhra Pradesh, Rajasthan and Maharashtra), soil acidity (8%; especially in the dry sub-humid areas of Bihar, Jharkhand, Chhattisgarh and Madhya Pradesh), and wind erosion (7%; especially in the arid areas of Rajasthan, Haryana, Gujarat and Punjab).

Both natural causes and increased human activities are responsible for acceleration of the processes. Rainfed agriculture is the dominant occupation of the people in the drylands, practiced on 86.4 mha (68.4 mha fully rainfed; 18.0 mha partly under irrigation, using both surface and groundwater). Because of high population density and rapid expansion of agriculture, especially during the last three decades when due to success with Green Revolution food-crop-dominated subsistence agriculture was gradually replaced by cash-crop-dominated market-driven agriculture, the pressure on croplands and the marginal lands, including the fallow lands, other culturable lands, pastures, wastelands and forests has increased tremendously.

There has been change in energy use pattern (from draught animals to tractors and power tillers; electric and diesel pumps for irrigation), increase in intensity of cultivation, use of chemical fertilizers, pesticides, etc. Yet, agricultural land holding is declining (0.90-3.96 ha per capita in different states) due to increasing rural population. Consequently, more and more land is being degraded through soil erosion, salinization, soil pollutants, deforestation, vegetation degradation, groundwater depletion and degradation of its quality, etc., impacting the livelihood of the rural population through reduced productivity, loss of income, loss of wages to agricultural labourers, increasing rural indebtedness, migration to cities for non-farm employment, etc. The problem is further compounded by frequent droughts and scarcity of water, especially in arid region, resulting in total failure of crops, decline in animal wealth due to scarcity of fodder, and outbreak of diseases.

Desertification is more serious in the arid lands (15.5% of country's area) than in the semi-arid (37.3%) and the dry sub-humid (22.9%) areas, especially due to a hostile climate and limited availability of resources against the high human and livestock pressures in the region. Arid western part of Rajasthan state, which contains the Indian segment of the Thar Desert, and accounts for ~62% of the country's hot arid areas, suffers the most due to recurrent drought and increasing human and livestock pressures. Studies at the Central Arid Zone Research Institute (CAZRI) have revealed that the major physical manifestations of desertification in western Rajasthan is wind erosion/deposition (~75% of total area), followed by water erosion (~13%), as well as water logging and salinization (~4%; Table 1). Degradation of natural vegetation is widespread, and most of the permanent pastures have been very severely exploited for fuelwood and fodder. With time, industrial effluents and mining are also gradually becoming important factors of desertification. Mismanagement of land has been found to be a major cause of the problems (Singh et al., 1992, 1994; Kar, 1996; Narain and Kar, 2004). Overall, 30% area of western Rajasthan is slightly affected by desertification, while 41% is moderately affected, 16% severely, and 5% very severely. Thus, more than 60% area of western Rajasthan requires intensive management to contain desertification. Centuries-old and time-tested traditional wisdom of integrating agriculture with livestock farming, utilizing perennial trees and grasses to support animal wealth, and efficient systems of water harvesting and its use are now either forgotten, or are seriously threatened by modernisation. Under these circumstances the arid western part of Rajasthan is most vulnerable to desertification

Following section deals with problems and the control technologies evolved at CAZRI, with special reference to western Rajasthan.

Problems and their control

Wind erosion

Wind erosion is the most dominant problem in western Rajasthan, where the terrain is dominantly sandy with sparse natural vegetation cover, and summer wind speed is high (especially between March and June, before the monsoon rains set in). Broadly, the decreasing rainfall and soil moisture gradient as well as increasing wind strength from east to west, and high erodibilty of the aeolian

Table 1. Major processes of desertification in arid Rajasthan (area in km^2).

Degradation processes	Slight	Moderate	Severe	Very severe	Total degraded area
Wind erosion	52690	73740	25540	5800	157770
Water erosion	5930	11110	5980	4270	27290
Water logging			1140	320	1460
Salinization	4620	410	40	900	5970
Total	63240	85260	32700	11290	192490

Table 2. Suitable plant species for sand dune stabilization in western Rajasthan (after Venkateswarlu, 1993).

Annual rainfall (mm)	Trees	Shrubs	Grasses
150-300	*Prosopis juliflora, Acacia tortilis, A. senegal*	*Calligonum polygonoides*, Ziziphus nummularia*, Citrullus colosynthis**	*Lasiurus sindicus**
300-400	*A. tortilis, A. senegal, P. juliflora, P. cineraria*, Tecomella undulata*, Parkinsonia aculeata, Acacia nubica, Dichrostachys glomerata, Colophospermum mopane, Cordia rothii*	*Ziziphus mauritiana, Z. nummularia, C. polygonoides, C. colosynthis*	*Cenchrus ciliaris*, C. setigerus*, L. sindicus*, Saccharum munja**
400-550	*A. tortilis, P. cineraria*, P. juliflora, A. senegal, Dalbargia sisoo*, Ailanthus excelsa*, Albizzia lebbeck*, P. aculeate*, T. undulata*, D. glomerata, C. mopane*	*Z. mauritiana*, Cassia auriculata**	*C. ciliaris*, C. setigerus*, S. munja*, Panicum antidotale**

** Indigenous species.*

sediments determine the spatial pattern of wind erosion (Kar, 1993). High human and livestock pressures, reducing the plant cover through over-grazing and fuelwood collection, expansion of croplands to marginal areas without assured water supply, and deep ploughing of sandy terrain with tractors, even along the slopes of the sand dunes, have not only accentuated the erosion in the region, but is also enlarging its area. Thus, with each episode of dust-sand storm, the soils get gradually depleted of the already poor reserve of silt and clay as well as the plant nutrients. Broadly, the western-most part with finer soils is the major source of atmospheric dust, which is carried eastwards and gradually settles in the eastern part of Rajasthan and adjoining parts of Uttar Pradesh (UP) and Madhya Pradesh (MP). This pattern is reflected in the satellite-derived aerosol index over the region (Kar, under preparation). The problem becomes more glaring during the drought years due to reduced plant cover and drier soils. Apart from erosion of topsoil containing precious little organic matter, damages to crop plants, burial of good agricultural lands and infrastructures, and disruption of transportation network are the other major impacts of severe wind erosion (Kar, 1986, 1996).

Mechanical and chemical methods to control wind erosion are neither economical nor feasible in west Rajasthan, because the land, including sand dunes, belong mostly to poor farmers. Therefore, to combat wind erosion CAZRI has developed vegetative methods for sand dune stabilization and shelterbelt plantation, both of which are now widely adopted by the state agencies.

Sand dune stabilization technology includes: (a) protection of the area from human and livestock encroachment; (b) creation of micro-wind breaks on the dune slopes, using locally available shrubs either in a checker board pattern or in parallel strips across the direction of wind; (c) direct seeding or transplantation of indigenous and exotic species; (d) plantation of grass slips or sowing of grass seeds on leeward side of micro-wind breaks; and (e) management of re-vegetated sites (Kaul, 1985).

Sand dune stabilization has so far been largely a Government effort in public domain. Although approximately 300,000 ha area of sand dunes has been stabilised through CAZRI technologies, but people’s participation is still poor due to the choice of many exotic species that do not provide much returns to the farmers, except fuelwood. Replacement of exotic trees and shrubs by the locally adapted species (Table 2) can provide some economic return, and are therefore finding acceptance of the villagers. Shrubs and grasses are better sand binders than trees, but protection of grass cover is a problem, especially because of uncontrolled grazing on the dunes and sandy plains.

Farmers protect and manage their fields during critical periods through crop residue management, fencing and boundary plantation. Due to population pressure, the earlier practice of keeping a part of the dune fallow is becoming increasingly difficult. Many farmers prefer to cultivate their dunes regularly and accept some degradation and consequent dune movement, rather than leave the land for fencing and for less lucrative purposes like growing grasses. It has been estimated that if the Government is to continue this effort at the rate of Rs. 13,000 ha^{-1} (US $1= about 43 Indian Rupees), then at least Rs. 117,000 million will be required to cover the moderately and severely affected areas in western Rajasthan (Venkateswarlu and Kar, 1996). Therefore, sand fixation by government efforts alone appears to be a difficult task in near future, and people’s participation has to be invoked for its success on large scale. In the first place, technology should be cheaper and acceptable. Cost of fencing is a major cost, which could be neutralised by ‘social fencing’ through people’s participation. Involving people from planning to execution stage to evoke a sense of belonging to the community, and utilization of resources on community basis is necessary. Sharing of resources by the landowners and landless people on equitable basis in a transparent manner is needed. Farmers need to be educated about the tangible and intangible gains from the program. Demonstration models should be created through community participation.

Erection of shelterbelts along the boundaries of crop fields helps to reduce wind velocity in the lee of the shelter by ~76% at 2 to 10 times height distance (Raheja, 1963). It also reduces injury to the tender seedlings due to sand blasting and hot desiccating wind. CAZRI has recommended a three-row wind break of *Acacia tortilis*, *Cassia siamea* and *Prosopis juliflora* as the side rows and

Albizzia lebbek as the central row. Studies have also shown that plantation across the wind of a 13 m wide tree belt, interspersed with 60 m wide grass belt, provides the best results. Shelterbelts also reduce the loss of moisture from fields in the lee of shelters. At least 14% higher soil moisture and 70% more grain yield from pearl millet were recorded in the lee of shelters, as compared to that in areas without shelters (Gupta, 1993).

Despite such good results shelterbelts in arable lands are not very popular with farmers, because in many cases the trees are considered to be hindrance to agricultural operations and inter-field movement. It is now suggested to plant trees on field boundaries across the direction of wind. Vegetative hedges, which also serve the purpose of protecting crops from the animals, are other option for shelterbelts. Creation of shelterbelts is more a problem of education and extension rather than that of technology.

Water erosion and soil and water conservation

Water erosion, as sheet, rill and gully erosion, is a dominant problem in the wetter eastern part of the desert and in the semi-arid areas. Large parts of arid Gujarat and the foothills of the Aravalli ranges in arid Rajasthan have sloping terrain and >350 mm rainfall, making these areas highly vulnerable to water erosion. To tackle the problem, several soil and water conservation practices have been suggested and demonstrated. Contour bunding (low rainfall area), graded bunding (medium to high rainfall area), bench terracing, contour tillage, contour sowing, etc., are the suggested practices on arable land. Water logging in the vertisol areas can be reduced through ridge and furrow system, while deep ploughing at 3-4 years' interval in areas having hardpan at moderate depth ensures better water infiltration and root growth. In areas where gravel forms a significant part of the superficial material, but subsurface is less stony (e.g. in parts of arid Gujarat), periodic tillage has been found to reduce the chance of surface sealing, and hence the danger of water erosion. It also enhances moisture conservation. Mixing of crop residues and organic matter with light-textured soils helps to increase soil moisture and crop yield. Small and medium gullies on non-arable land can be reclaimed through clearing and levelling of gully bed, followed by construction of contour bunds and check dams. Gully plugging and stabilization of gully heads through peripheral bunds, chutes and forest plantation need also to be adopted. For deep gullies a closure-cum-vegetative measure, as well as check dams are to be followed.

Water conservation

Water is the most limiting resource in the arid regions. Inhabitants of western Rajasthan have some centuries-old practices for rainwater harvesting and conservation for household and agricultural purposes. These include 'tanka' (an underground cistern), which usually collects seasonal runoff from small natural or artificially created catchments, 'nadi' (dug out pond) of different capacities, and 'khadin', which is a water harvesting structure for growing winter crops through conserved moisture. Realising the need for improvement of these traditional structures, CAZRI has improved upon the designs of tankas for storing 10 000 to 630 000 L water for household and community purposes, and nadis with low density polyethylene (LDPE) lining for arresting seepage losses. Similarly, designs of khadins have been improved upon with inlet structures for efficient water intake and spill way systems for draining the excess water to the khadins down slope. Apart from improving the methods of such *ex-situ* water conservation, CAZRI has also made research interventions for *in-situ* water conservation through inter-plot and inter-row water harvesting, especially for improving soil moisture availability. Micro-catchments with a catchment to cropped area ratio of 0.5 resulted in high soil moisture availability in profile (Singh, 1985). CAZRI also provides research support to the state on integrated watershed management technologies, where treatments for runoff and soil loss, rainwater harvesting and recycling of water for irrigation, conservation forestry, agronomic treatments, groundwater recharge and management, etc., are being executed and demonstrated to the stakeholders for adoption.

Depletion of groundwater has become a very serious problem in western Rajasthan, where 6 out of 12 districts have over-exploited the groundwater (groundwater draft >100% of net available, and water level is falling). Much of this problem is due to overuse of water for irrigating high-value cash crops in the sandy terrain, which jeopardizes the plan for providing safe drinking water to the arid villages on a long term basis. The utilization increases manifold during the drought years (e.g., in 2002; Narain and Kar, 2005). So much water is now consumed for producing irrigated crops that the state government estimated that a mere 10% saving in the quantity would be enough to solve the drinking water problem. In the dryland states as a whole, barring those in the Himalayas, <50% replenishable groundwater is now available for future uses, the most critical states being Delhi, Punjab, Haryana, Rajasthan, Gujarat and Tamil Nadu. For the country as a whole, only 37% of replenishable groundwater is available for the future. As more fresh water is being exploited from the aquifer, there is increasing danger of saline and toxic water incursion, affecting health and soil quality, as has been noticed in parts of Rajasthan and Gujarat. Therefore, it is necessary to frame urgently a policy for strict regulation of the water use, and to adopt an action plan for artificial recharging of groundwater.

Water logging and salinity-alkalinity

Introduction of irrigated agriculture in western Rajasthan during the last four decades has gradually brought prosperity in the command areas, but has also brought in its wake the problems of water logging and secondary salinization. The problem is more serious in the northern part of the desert, where three canal systems, the Ganga, the Bhakra and the Indira Gandhi system, are operating. The most prominent among these is the Indira Gandhi Canal system that has been constructed to irrigate eventually ~1.54 mha area, although presently it irrigates ~1 mha, utilizing 8588 million m^3 water from the Himalayas. Over-irrigation, lack of proper drainage in a palaeochannel-dominated alluvial plain and seepage from the canals are the root causes for the rise in water table and build-up of salinity, the average rate of rise in the northern plains being 69 cm per year. In the Indira Gandhi Canal command area the rate of rise is 88 cm per year. Since the plains are underlain by a gypsum or calcium-rich hardpan at 5-8 m depth that hinders soil drainage, the problem is getting aggravated with the expansion of agriculture further southwest. Similarly, tank irrigation in the southern part is leading to salinity-alkalinity build-up, while irrigation with groundwater rich in residual sodium carbonate (RSC) is causing soil sodicity problem. To counter water logging in the canal command areas canal authorities are laying a system of deep vertical and horizontal drainage system. Bio-drainage through plantation of species like *Eucalyptus camendulensis, Dalbergia sisoo*, *Prosopis cineraria* and *Tecomella undulata* along the margins of the waterlogged stretches has also been taken up (Kapoor, 1997). The farmers are being educated about the judicious use of canal water, crop rotation and soil management practices. To reclaim the land degraded by high RSC water CAZRI has standardised the doses of gypsum application to soils (Joshi and Dhir, 1991). A variety of crops are now grown in the region with waters having high RSC, especially after the gypsum treatment of the soil.

Vegetation degradation

Despite the fact that western Rajasthan has ~5.5 mha of rangelands, much of it is in a highly degraded state, especially due to unrestricted grazing by a large number of livestock (23 million; density 113 heads per km^2), and use for fuelwood and other needs. The common grazing lands around villages, which include Gochar (culturable waste), Oran (permanent pasture, usually around a temple) and Agor (pasture around a pond), are also severely degraded as these are highly exploited, neglected and encroached upon. In order to reverse the process of grazing land degradation CAZRI has developed methods of their reseeding with useful grasses, shrubs and trees, depending on their soil and terrain conditions, and different management schedules, including grazing procedures based on carrying capacity. Improved varieties of nutritious grasses and legumes, including *Cenchrus ciliaris, Cenchrus setigerus* and *Lasiurus sindicus*, have been developed and released for mass production. Additionally, technology for bulk grass seed production and its pelleting has been developed. Improved silvi-pastoral systems, involving combinations of top feed species like *Ziziphus nummularia, Dichrostychus nutans, Colophospermum mopane, Prosopis cineraria*, etc., and the grasses like *C. ciliaris, C. setigerus, L. sindicus, Dichanthium annulatum* and *Panicum antidotale*, have also been evolved. A carrying capacity of 4.5-6.9 sheep ha^{-1} in sandy soils and 9.0-13.8 ha^{-1} sheep in loamy sand soils have been achieved with good management. The success of such plans, however, depends on the whole-hearted community participation, which is slowly picking up. Special work plan is also necessary to integrate the results of scientific research on pasture development with a system of management practices of the orans and gochars at the level of the elected village bodies like the Panchayats, as well as by the temple trusts, NGOs, etc.

Management of arable land

Since cropping is the major land use in the region, management of the arable lands is most important for combating degradation. A number of management practices have been evolved and successfully tried by CAZRI for controlling degradation of croplands and improvement in crop yield, and are summarised below.

Minimum tillage: In the sandy soils farmers normally practice deep tillage after every 3-4 years and a tillage pass of disking and harrowing to reduce clod percentage in surface soils. But this encourages wind erosion and hard pan development below the depth of tillage, often leading to surface crusting. A limited tillage after the first monsoon showers, on the other hand, has been found to be a better proposition in western Rajasthan (Gupta *et al.*, 1997). In loamy sand soil production of mung bean, clusterbean and cowpea increased with the limited tillage of one disking and sowing (Gupta, 1993). In a sandy soil the tillage needs to be further reduced.

Stubble mulching: It is widely practiced by farmers for controlling wind erosion from arable lands. Usually farmers leave the crop residues in field after grain harvest. Best results were found by put-

Table 3. Common tree, shrub, crop and grass combinations in western Rajasthan.

Annual	Habitat rainfall (mm)	Tree/shrub species association	Associations of crops/grasses
100-150	Sand dunes, interdunes	*Calligonum polygonoides – Haloxylon salicornicum – Leptadenia pyrotechnica*	Pearl millet, clusterbean; *Lasiurus sindicus*
150-200	Rocky, gravelly pediments	*Ziziphus nummularia-Capparis decidua*	Pearl millet, green gram, moth bean, clusterbean; *Cymbopogon jwarancusa, Aristida* spp., *Cenchrus ciliaris*
200-250	Sandy undulating plains	*Calotropis procera – C. polygonoides – Clerodendrum* spp.	Pearl millet,green gram, moth bean, sesame; *Cenchrus ciliaris* with *C. setigerus*
250-300	Alluvial plains, soils often with carbonate pans at 80-150cm depth	*Prosopis cineraria – Z. nummularia – C. decidua*	Pearl millet, clusterbean, green gram, moth bean, sesame; *Cenchrus ciliaris* with *C. setigerus*
250-300	Alluvial plains but soils are moderately saline	*Salvadora oleoides – P. cineraria – C. decidua*	Clusterbean, pearl millet and sesame and wheat (irrigated areas); *Cenchrus setigerus, Sporobolus* sp.
275-325	Sandy undulating plains	*P. cineraria – Tecomella undulata*	Pearl millet, clusterbean, green gram, moth bean; *Cenchrus ciliaris* with *C. setigerus*
300-350	Alluvial plains	*P. cineraria*	Pearl millet, clusterbean, green gram, moth bean; *Cenchrus ciliaris*
300-350	Alluvial plains (irrigated)	*P. cineraria – Acacia nilotica*	Sorghum, cumin, pearl millet, mustard, wheat

ting crop residues at the rate of 2-5 t h^{-1} and leaving pearl millet stubbles of 45 cm height in the fields (Misra, 1964). However, availability of crop residues in arid areas is low. Therefore, it is now suggested to uproot the perennial weeds and put these on soil surface as organic mulch.

Agroforestry

Traditional agro-forestry: In order to avoid the risk of frequent drought, farmers in western Rajasthan traditionally grow arable crops in association with perennial trees, shrubs and grasses. Besides ensuring some production even during the worst drought periods, the traditional agro-forestry components provide most of the requirement from the land, including food, fodder, fuel, timber, etc. The common tree, shrub, crop and grass combinations in the traditional agro-forestry systems in different rainfall zones of western Rajasthan are given in Table 3. *Prosopis cineraria* (Khejri) and *Ziziphus nummularia* (Bordi) are the two most important multipurpose woody components in the traditional agro-forestry system of the region.

Improved agro-forestry: CAZRI has developed a number of improved agro-forestry packages for the arid region. It has been found that the net economic returns are the highest from agri-pastoral system (Benefit:Cost ratio of 1.87), followed by that from agroforestry (1.69), silvi-pasture (1.66), agri-horticulture (1.46) and sole production of crops (1.24; Bhati, 1997). The higher returns from agri-pastoral system are especially because of the importance of livestock component in the farming systems prevailing in the region. It also safeguards the vulnerable terrain from drought and desertification.

The most dominant and useful tree in crop fields is *Prosopis cineraria*, whose shade effect on crop performance remains only up to 2-3 m from the tree trunk. A tree density of 100 to 200 plants ha^{-1} has been found optimum for minimum interference with the yield of various dryland crops. *Tecomella undulata*, *Hardwickia binnata* and *Holoptelea integrifolia* are the other important tree components. Growing of pearl millet and clusterbean with grasses *L. sindicus* and *C. ciliaris* between rows of *A. tortilis* and *Z. rotundifolia* were found to be highly compatible and remunerative in terms of grain and fodder yield (Gupta et al., 1997). A strip cropping of grasses and kharif legumes in 1:2 ratio has been recommended, with a strip width of 5 m. Silvi-pastoral system has been found to be best suited for areas receiving <200 mm rainfall, or in degraded rocky-gravelly areas. The most highly compatible trees with grasses are: *Acacia senegal, A. tortilis, Albizzia lebbek, Tecomella undulata, Colophospermum mopane, Dychrostasis nutans, Hardwickia binnata, Z. nummularia and Z. rotundifolia*. Among the pasture legumes *Clitoria ternatea* and *Lablab purpureus* showed good compatibility with *L. sindicus* and *C. ciliaris*. Production from a silvipastoral system with *A. tortilis* and *C. ciliaris* was higher than that from a pure pasture (Muthana et al., 1985). The carrying capacity of a pure pasture was found to be 3.9 sheep ha^{-1} after 9 years of establishment, while that from a silvi-pastoral system was 8.5 sheep after 7 years (Tewari and Harsh, 1998). Under goat grazing, *Z. nummularia* with grass strips in 1:2 ratio led to higher economic returns due to weight gain of the animals and higher wool production (Bhati, 1997).

Other major problems

With modernization, industrial effluents and mine spoils are becoming important sources of degradation. Although there are environmental laws banning release of the untreated wastes in the land or water, enforcement is very weak, which results in pollution of soil and water. In the vicinity of Jodhpur, Pali and Balotra towns untreated effluent discharge from the textile dyeing and printing industries is released into the ephemeral streams, contaminating the surface and ground water downstream. Use of such toxic water for irrigation has also degraded the cropland. To stop further contamination, a number of effluent treatment plants are now being installed. Mine spoils constitute a very small percentage of arid areas, but wherever present, these pose a serious threat to surface water flow and agricultural operations. CAZRI has demonstrated technologies for successful rehabilitation of limestone, gypsum and lignite mine spoil areas that include slope stabilization, profile modification, preparation of micro-catchments for soil and water conservation and raising of suitable plant species on mine spoils.

Conclusion

Increasing human and livestock populations, as well as mismanagement of land resources have become a major cause of desertification in the drylands of India. The problem gets accentuated with periodic droughts in arid regions. To counter the problems, the country runs a number of programs aimed at providing relief to ensuring the livelihood of the affected people. For example, a Drought Prone Area Program (DPAP) has been started from the mid-1990s to cover 180 districts and 16 states under the semi-arid and dry sub-humid regions, where rainfed agriculture is dominant. Similarly, a Desert Development Program (DDP) has been launched in 40 districts of 7 states having hot and cold arid areas. Arid western part of Rajasthan is the most vulnerable to drought and desertification. A number of employment and 'food for work' programs are run especially during the drought periods, while several other programs to boost the dryland agricultural economy, develop the infrastructures and sustain livelihood are also continued. A number of research institutes and universities are involved in developing technologies to combat desertification and for the improvement of agriculture.

Despite these efforts, the problems still persist, especially due to high growth rates of human and livestock populations, mismanagement of the resources, and lack of a consortium approach to the problems. Adoption of most technologies is very slow in the arid areas due to inadequate finances, poverty, illiteracy, slow land reforms and gender inequity, lack of trained personnel, lack of market facilities, and lack of appropriate national policy frameworks, especially for land and water use.

The country is, however, learning from the mistakes. For example, after spending millions of rupees on drought relief it has been found that government interventions through relief measures, including supply of drinking water, subsidies on food and fodder resources, organizing cattle camps, wage employment to needy people, food for work program, nutrition and health improvement program, etc., do not necessarily lead to any long-term strategies for coping with future droughts, although these short-term measures help people to withstand the current drought (Narain and Kar, 2005). This problem is now being addressed by linking a number of welfare programs for asset creation and capacity building that can help people to be less dependent on relief.

Unregulated use of groundwater for irrigation of high-value crops has exhausted the reserve in many areas, but diversification of rainfed cropping system that depends on less water but can provide long-term sustainability to the rural economy, including livestock farming, dairy development, horticultural development with product processing and marketing, etc. have received attention very recently. Such sustainable land management needs to be boosted at watershed level in the semi-arid and dry sub-humid areas, as well as in the fringe areas of the arid lands, but the unit for development in larger part of the arid lands, having no/ ill-formed surface drainage, should be village clusters. Livestock-based farming system has proved its superiority over crop-based farming in the arid region, and it needs to be encouraged, especially through appropriate linkages between livestock development - silvi-pasture – agri-horticulture – fodder bank development - infrastructure development (including markets) – dairy development, and co-operative formation, especially by women groups.

Proper implementation of the development plans may be difficult if the country does not have an appropriate national land use policy, as well as a drought mitigation policy, at least for the more vulnerable arid regions. At the same time land reform and gender empowerment need to be carried out through enactment of relevant laws. It is also necessary to develop policies on management of grazing lands and other common property resources, as well as on water resources. Apart from executing sustainable development programs, it is necessary to establish a robust monitoring mechanism on desertification and an early warning system (Kar and Takeuchi, 2003), so that the impact of different programs and schemes could be regularly monitored and evaluated, and corrective steps could be taken.

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Scientific bases of increasing efficiency of rainfed lands of Kyrgyzstan

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Abstract

The rainfed areas make 40% of all arable land, i.e. about 0.5 million hectares, in Kyrgyzstan. The main factor limiting stability in crop yields is the annual precipitation. The basis of increasing the land-use efficiency of a rainfed areas should be the adoption of a cereal-fallow rotation, in which the fallow area would account for 20 percent of the cropping intensity. Keeping the field fallow increases moisture conservation in the ground as also the accumulation of nitrate nitrogen. For enhancing the beneficial effect of fallow, control of weeds is essential. The productivity of winter wheat grown after fallow is increased by 0.5-1.0 ton per hectare depending on the rainfall in the year. Appropriate conservation tillage is important in rainfed agriculture. The productivity of crops in cereal-fallow rotation also depends on the place of the crop in the rotation. Winter wheat and spring barley are the best cereals for realizing full yield potential in a cereal-fallow rotation system. In Kyrgyz Agriculture Research Institute a major emphasis is placed on developing drought-tolerant cereal varieties for rainfed areas. Research has shown the possibility of replacing fallow by crops such as safflower, peas, chickpea, chickling (*Lathyrus sativus*) and vetches (*Vicia* spp.) to increase the intensity and diversity of cropping and for enhancing land-use efficiency of rainfed agriculture. Use of legumes not only increases rotational efficiency but also enriches soil with available nitrogen.

Introduction

Rainfed agriculture in Kyrgyz Republic occupies some 0.5 million ha, which accounts for nearly 40% of the total arable area in the country. Based on the amount of precipitation received, the rainfed area can be divided as arid (annual precipitation around 250 mm), semiarid (300-350 mm), and sub-humid (450 mm). Some 57% of these lands are allocated to grain crops, 20% to perennial forages and 20% of the area is left fallow.

During the agricultural reforms period there was a tendency to reduce the cultivation of crops on the rainfed areas and leaving them to become grasslands or weedy fallow lands. This resulted in the reduced efficiency of land use of the rainfed areas.

Increasing the land-use efficiency of rainfed areas

Research at the Kyrgyz Agricultural Research Institute has shown that the efficiency of rainfed agriculture can be substantially improved by adopting a grain-fallow rotation strategy in which the fallow occupies 20% of the cropped land each year. There is accumulation of more moisture and nitrate nitrogen during the fallow period which benefits the grain crop. Depending on moisture availability in the soil, winter wheat yields could increase by 0.5 to 1.0 ton ha^{-1} as compared to wheat grown on stubble land.

Soil conservation tillage is important in rainfed agriculture for soil and moisture conservation and improving land productivity. Deep tillage with v-type sweeps increases moisture infiltration and enhances soil moisture content in the top 100 cm of soil layer by 25-40 mm. A carry-over effect of such tillage can be clearly noticed on the succeeding crops of the rotation. In the dry years, positive effect was observed when discs were used for tillage as this system ensured better moisture conservation in the crop-root zone.

For adequate soil moisture management it is advantageous to adopt deep tillage during the fallow phase with a sweep cultivator, shallow tillage for winter wheat using discs and doing plowing with moldboard plough for barley, which is the last crop in the rotation. Better moisture storage in the root zone ensures higher crop yields.

The overall crop productivity of wheat in the grain-fallow rotation depends firstly on the amount and distribution of precipitation and secondly on the place of this crop in the rotation. In the years of favorable weather conditions, the winter wheat crop has yielded up to 5 tons ha^{-1} on lands that were under summer fallow and were tilled with deep sweeps in the fallow period.

Crop improvement

Among the grain crops grown under rainfed conditions the most important are winter wheat and barley as they are well adapted to fully mobilize the potential of the grain-fallow rotation. The Kyrgyz Agricultural Research Institute is devoting considerable efforts on developing drought tolerant grain crop varieties for rainfed agriculture.

The bread wheat variety 'Eritrospermum 760', 'Adyr', and 'Kayrak' were developed with the purpose of meeting the adaptation needs of the rainfed areas. These varieties are rather early maturing and hence are able to complete their heading before the onset of the drought spell. The grain yields at the experimental station have ranged from 2.7 to 5 tons ha^{-1} depending on the amount of precipitation. These wheat varieties contain 14-15% protein and 28-29% gluten in the grains.

Main variety of spring barley grown in the rainfed areas in 'Naryn 27'. It is characterized by high drought tolerance and improved water use efficiency. Its grain contain 15-16% protein content. In contrast to other varieties, 'Naryn 27' has more vigorous early growth during the vegetative phase and it completes heading 8-12 days earlier, which helps to escape the driest period. The potential productivity of this variety under rainfed conditions is 3.0 to 3.2 tons ha^{-1}. New varieties of barley have been now developed by the Research Institute for increasing the choice for the rainfed farming. These include 'Taaly', 'Bestan', and 'Kylym'. These are all early maturing and drought tolerant. The protein content in their grain is in the range of 14-15%. Potential productivity under rainfed condition is 4.5 tons ha^{-1}. All these varieties are well adapted to local soil and climatic conditions of their recommendation domain in the Kyrgyz Republic.

Crop diversification and intensification

Recent research at the Kyrgyz Agricultural Research Institute has shown that the fallow in the rotation could efficiently be replaced by introduction of crops under rainfed farming system. In the current practice of keeping 25% land under fallow in the grain-fallow rotation there was an annual loss of 8.5 tons ha^{-1} of organic matter in contrast to only 3.7 tons ha^{-1} loss when fallow was replaced by a suitable crop. When fallow was replaced by crops, the whole arable land was used more intensively and additional crop produce was obtained. At the same time, the soil fertility was improved because of the return of more crop residues to the soil.

As a fallow replacement, several crops have shown promise. These include safflower, dry pea (*Pisum sativum*), chickpea (*Cicer arietinum),* chickling *(Lathyrus* spp.*)* and vetches (*Vicia* spp.). Introduction of leguminous crops for increasing cropping intensity also results in soil enrichment with available nitrogen to stabilize nitrogen balance in the rainfed areas.

B. Concurrent Sessions

Theme: Soil and Water Conservation and Degradation

Water management using drainage water and its impact on irrigated rice in the Delta region of Egypt

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Abstract

This study aims to analyze the effects of reusing drainage water (DW) in rice irrigation system in the northern Nile Delta, Egypt. Amount of applied water, quality of water, water use efficiency, and grain yield were measured. Six treatments of irrigation with fresh water (FW) only (I), irrigation with FW mixed with DW at 1:1 ratio (I1D1), irrigation with FW mixed with DW at 1: 2 ratio (I1D2), irrigation with FW mixed with DW at 2:1 ratio (I2D1), irrigation with FW mixed with DW at 1:3 ratio (I1D3), and irrigation with DW only (D), were set up. Electrical conductivity (EC) of FW and DW were 0.35 and 2.86 dS m^{-1}, while the values of sodium adsorption ratio (SAR) were 2.81 and 3.94, respectively. In all irrigation treatments three rice varieties (Sakha 102, Giza 178 and Sakha 101) were grown. The interactions between irrigation treatments and rice varieties were not significant in terms of amount of applied water. As to the irrigation efficiency, I2D1 showed water saving (3550 m^3 ha^{-1}) while grain yield from the different irrigation treatments were in the following order: I (9476 kg ha^{-1}) > I2D1 (8929 kg ha^{-1}) >I1D1 (8918 kg ha^{-1}) > I1D2 (8730 kg ha^{-1}) > I1D3 (7992 kg ha^{-1}) > D (7619 kg ha^{-1}) averaged over the three rice varieties. Thus, an increase in the amount of DW led to a decrease in rice grain yield. Besides, field water use efficiency also decreased in all treatments with DW as compared to FW. Highest crop water use efficiency of 1.182kg m^{-3} was obtained in treatment I, whereas lowest value of 0.949 kg m^{-3} was obtained in treatment D. The levels of soil EC1:5 decreased after irrigation season under all irrigation treatments except the treatment D.

Introduction

Working on the water policy for Egypt, the Planning Sector (1996) of the Egyptian Ministry of Water Resources and Irrigation has predicted a shortage in the national water supply after the year 2000. Thus, irrigated agriculture would face the challenge of using less water, in many cases of poorer quality, to provide food and fiber for an expanding population. Using the available water supplies more efficiently is essential, but in many cases it will be necessary to make increased use of municipal wastewaters and drained irrigation water (Oster, 1994). The collection and reuse of drainage water by blending it with irrigation water of better quality to irrigate salt-tolerant crops is a common practice in the Nile Delta region of Egypt (DRI, 1995).

Provision of irrigation water for rice in summer is made through irrigation canals on the basis of a rotation, which consists of 4 days “on” and 6 days “off” (4/6 rotation). The normal duration for rice irrigation is from May 1 to October 15. The schedule for non–rice cultivated areas (winter crops) is 5 days “on” and 10 days “off” (5/10 rotation), from October 16 to April 30 (Oad and Azim, 2002). In the gravity irrigation system, Zulu et al. (1996) concluded that water reuse is better done at the tail end where the irrigation water supply is lower and there is more water in the drainage channels than at the head. Blending the drainage water is done to reduce the total salt concentration.

An alternate strategy of using drainage water was studied in the San Joaquin Valley, California, where irrigation with fresh water was alternated with irrigation using drainage water. In that study, waters with salt content of 0.3 and 6 g L^{-1} were applied to irrigate wheat and cotton, respectively. This strategy requires a farming system that includes crops tolerant and sensitive to soil salinity and an irrigation program with the use of fresh water especially during the germination and seedling stages, when the crops are more sensitive to soil salinity (Rhoades, 1989; Grattan and Rhoades, 1990).

Rice crop and agricultural drainage water reuse in Egypt

The rice area has increased from 420×10^3 ha in 1987 to 633.4×10^3 ha in 2003 (about 1.5 times; with an average annual increase of 2.6 %). The increment is because of the importance of rice for Egyptian farmers and increased population. The grain yield increased from 5714 kg ha^{-1} in 1987 to 9738 kg ha^{-1} in 2003 (RRTC, 2003). The Egyptian farmers prefer to keep deep standing water in the rice plots and drainage water is reused in the Nile Delta to increase the amount of water available for irrigation. The drainage flow comes from three sources: (a) tail end and seepage losses from canals; (b) surface runoff from irrigated fields, and (c) deep percolation from irrigated fields that is required for leaching of salt. The first two sources of drainage water are considered to be fresh water with relatively good quality. The agriculture drainage of the upper and middle Egypt is discharged directly in the Nile River, which can be used for different purposes downstream. The total amount of such direct reuse is estimated to be about 2.3 BCM/year (Kotb et al., 2000). In addition, it is estimated that 12.3 BCM/year of drainage water, mainly produced by irrigated agriculture (including the freshwater released during winter closing), is disposed annually into the Mediterranean Sea (DRI, 1994).

Fig. 1 shows the amounts of drainage water reused in the Delta and its average salinity during the period 1984/85 to 1999/2000 (MWRI, 2002). A significant increase was observed in 1990/91, 1996/97 and 1998/99. Drainage water in the Delta region is ultimately emptied to the Sea and the northern lakes via drainage pump stations.

Egypt started implementing reuse of drainage water by expanding agricultural in the new lands, using Nile water mixed with drain agricultural water. It is important to take into account the balance between

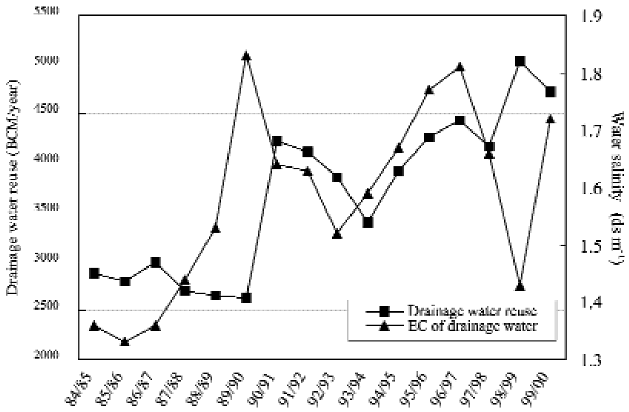

Fig. 1. Reuse of drainage water and water salinity from 1984 to 2000 in Egypt (MWRI, 2002).

official and unofficial reuse. The unofficial practice adopted by individual farmers does not always match with the concept of integrated irrigation management in which the total supply required by a farmer is planned and assured. If individuals do not comply, then the calculations of water distribution and water availability will be affected if unofficial reuse remains significant (FAO, 2005).

Kotb et al. (2000) mentioned that some irrigation water mixing stations in Egypt were completely shut down due to severe contamination by municipal and industrial pollutants. Some of these stations recorded a salinity level of 3000 mg L^{-1}, as in the case of Mariout mixing station in the western Nile Delta; however it is still in operation. At micro-level, farmers intensively pump drain water for their irrigation whenever a shortage occurs in tertiary canal water. However, the information on the benefits of reuse of drainage water for paddy rice irrigation in the Nile Delta region is scanty and not well documented. The objectives of this study were to clarify the effects of the reuse of drainage water from branch drains by farmers on the rice water use efficiency and to recommend the optimum blending ratios of fresh water (FW) and drainage water (DW) for rice irrigation.

Materials and methods

The field experiment was conducted in 2002 at the Motobus Center, located in the lower Nile Delta, Kafr El-Sheikh Governorate, Egypt (31° 34´ N latitude and 30° 52´ E longitude), where there is shortage of fresh water. The soil at the experimental site is clay. The physico-chemical properties of the soil and meteorological data of the studied location during the rice growing season are presented in Tables 1 and 2.

The experiment was conducted in a split-plot design with four replicates. There were six main treatments (management of fresh and drainage water): (1) I - irrigation with fresh water (FW) only, (2) I1D1 - irrigation with FW and drainage water (DW) at 1:1 ratio, (3) I2D1 - irrigation with FW and DW at 2:1 ratio, (4) I1D2 - irrigation with FW and DW at 1:2 ratio, (5) I1D3 - irrigation with FW and DW at 1:3 ratio, and (6) D - irrigation with DW only. Three rice varieties, V1 - 'Sakha 102' (125 days), V2- 'Giza 178' (135 days) and V3 - 'Sakha 101' (135 days) were selected as sub-plot treatments. All agricultural operations and conditions such as land preparation, fertilizer application and planting date were the same for all treatments. Nitrogen was applied in splits at the rate of 150 kg ha^{-1} as urea. Calcium mono-phosphate was applied at the rate of 36 kg ha^{-1} and zinc sulphate at the rate of 50 kg Zn ha^{-1} before transplanting. One-month old rice plants were transplanted at 20 X 20 cm spacing in each experimental plot. The cultivar Sakha 102 matured two weeks earlier than Giza 178 and Sakha 101. The obtained data were statistically analyzed using the StatView software (SAS, 2002).

The following parameters were studied:

(a) Amount of water (FW and DW) applied for irrigation (mm ha^{-1}) was measured by parshall flume (20×90 cm) according to USBR (1997). After measuring the water discharge and the required time, the amount of water applied per unit area was calculated. The electrical conductivity (EC) of FW and DW was 0.35 and 2.86 dS m^{-1}, and the sodium adsorption ratio (SAR) was 2.81 and 3.94, respectively, as shown in Table 3.

(b) Rice grain yield was determined from a 10 m^2 area in each plot, after harvesting. The plants were air-dried for about 3 days, threshed and the weight of grains was recorded at 14 % moisture content basis.

(c) Soil samples were taken from 0-20, 20-40 and 40-60 cm layers and analyzed for soluble cations and anions. EC was determined in the

Table 1. Physico-chemical properties of the soil before planting at the study area.

Physical properties

Depth (cm)	Particle size distribution (%) Clay	Silt	Sand	Bulk density gm cm^{-3}	Texture class
0-20	61.5	21.5	17.0	1.21	Clayey
20-40	57.4	23.0	19.6	1.27	Clayey
40-60	55.0	23.6	21.4	1.31	Clayey

Chemical properties

Depth (cm)	pH 1:2.5	$EC_{1:5}$ (dS m^{-1})	Cation (meq L^{-1}) Na^+	K^+	Ca^{2+}	Mg^{2+}	Anion (meq L^{-1}) HCO_3^-	Cl^-	SO_4^{2-}	SAR $_{1:5}$
0-20	8.1	3.21	14.4	0.38	6.4	5.1	5.9	10.3	10.08	6.01
20-40	8.2	4.15	17.2	0.36	6.3	4.1	7.9	11.9	8.16	7.45
40-60	8.3	4.65	19.5	0.35	5.0	5.9	10.3	12.2	8.25	8.35

** Extraction for ions was carried out in a soil-water ratio of 1:5*

Table 2. Metrological data and potential evapotranspiration (ETp) at the study area

Season	2002						
Month	Air temperature (^oC) Max	Min	Mean	Humidity (%)	Wind velocity (km d^{-1})	Sunshine hours	ETp (mm d^{-1})
June	29.6	23.8	26.7	54.3	66.0	12.2	5.71
July	31.1	23.4	27.3	58.1	61.0	12.0	5.64
Aug.	33.6	25.0	29.3	52.0	57.0	11.7	5.48
Sept.	30.8	20.4	25.6	59.2	75.0	11.2	4.56

field using a portable EC-meter. The methods employed for chemical analyses were as follows: pH using pH-meter in soil water suspension (1:2.5) (Jackson, 1967); calcium plus magnesium as well as calcium by titration method (Jackson, 1967); sodium and potassium by flame photometer (USSL, 1954); carbonate and bicarbonate by titration (Nelson, 1982); chlorides by titration (Rhoades, 1982), and sulphate calculated by difference.

(d) Sodium adsorption ratio (SAR) was computed to get an indicator of potential soil sodification using the following equation:

$$SAR = [Na^{+}]/\sqrt{([Ca^{2+}]+[Mg^{2+}])/2}$$

where Na^+, Ca^{2+} and Mg^{2+} are expressed in meq L^{-1} in the soil solution.

(e) The consumptive use of water for rice crop was determined by using tanks (60 cm diameter and 110 cm height) placed in the center of the experimental field and surrounded by a buffer area of paddy, representing the actual microclimate. Three kinds of tanks were used for the measurement of consumptive use of water for each treatment. The first tank had a closed bottom, and rice plants were grown in this tank to measure evapotranspiration. The second tank also had a closed bottom but no plants were grown so as to measure evaporation from water surface. The third one had open bottom and rice plants were grown in it to measure both evapotranspiration and percolation. At the beginning, the water level in each tank was set at 10 cm above the soil surface. It was then measured daily to determine water loss, which was compensated to maintain the desired level. Rice plants were transplanted in the two tanks on the same day as the transplanting in the field.

(f) Potential evapotranspiration (ETp) was calculated using Modified Penman method according to Doorenbos and Pruitt (1977), a reliable method for prediction of potential evapotranspiration of rice under north Nile Delta conditions (Abou El Hassan et al., 2005), as given below:

$$ETp = C\left[W \times Rn + (1 - W) \times f(u) \times (ea - ed)\right]$$

(g) Crop coefficient (Kc) was calculated as the ratio between actual crop evapotranspiration (ETa) and potential evapotranspiration (ETp) when both are in a large field under optimum growing conditions (Doorenbos and Pruitt, 1977):

$$Kc = \left[ETa / ETp \right]$$

(h) Field water use efficiency (FWUE) was estimated as the weight of marketable crop produced (kg) per unit volume of applied water (m^3) (Michael, 1978). Crop water use efficiency (CWUE) (kg m^{-3}) was estimated as the weight of marketable crops produced (kg) per consumptive use of water (m^3) (Michael, 1978).

Results and discussion

Water relations

The total amount of water and drainage water used in different irrigation treatments is shown in Figs. 2 and 3, respectively. As an average of the three cultivars (V1, V2 and V3), the highest amount of water (11417 m^3 ha^{-1}) was used in the treatment D (irrigation with drainage water), but this did not differ significantly with other irrigation treatments (Fig. 2). Cultivar Sakha 101 (V3) received the highest mean volume of water (11,460 m^3 ha^{-1}), but there was no significant difference between this cultivar and Giza 178 (V2). This difference in the varieties was because of the difference in their growth duration. The interaction between irrigation treatments and rice varieties was also not significant.

The amount of drainage water applied (m^3 ha^{-1}) during the growing season was 5787 for V1, 6035 for V2 and 5973 for V3. As shown in Fig. 3, the highest total amount of fresh water that can be saved by irrigation with only drainage water (treatment D) was 11417 (m^3 ha^{-1}). The amount of fresh

Table 3. Chemical properties of the irrigation and drainage water at the study area during the growing season.

Water type	SAR	EC	Cation (meq L^{-1})				Anion (meq L^{-1})		
		(dS m^{-1})	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
Fresh Water (FW)	2.807	0.35	2.28	0.21	1.2	0.12	0.8	1.08	1.93
Drainage Water (DW)	3.941	2.86	11.2	0.93	9.73	6.42	9.9	15.73	2.65

water saved decreased to 8281 m^3 ha^{-1} with I1D3 treatment, to 5255 m^3 ha^{-1} with I2D1 treatment and to 3550 m^3 ha^{-1} with I2D1 treatment.

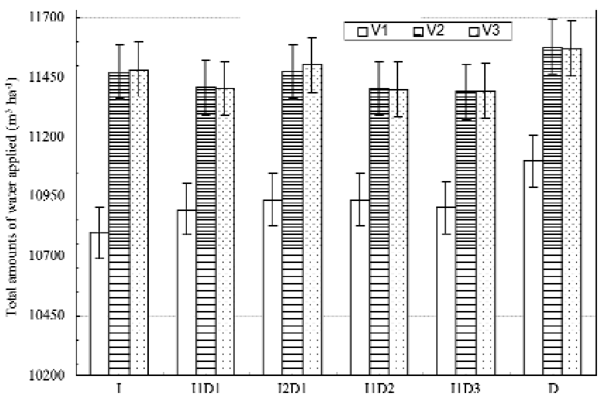

Fig. 2. Total amounts of water applied (m^3 ha^{-1}) for different irrigation treatments and rice varieties.
LSD I= 188.5, nonsignificant; V=133.3, highly significant (0.01 probability); I×V, nonsignificant.

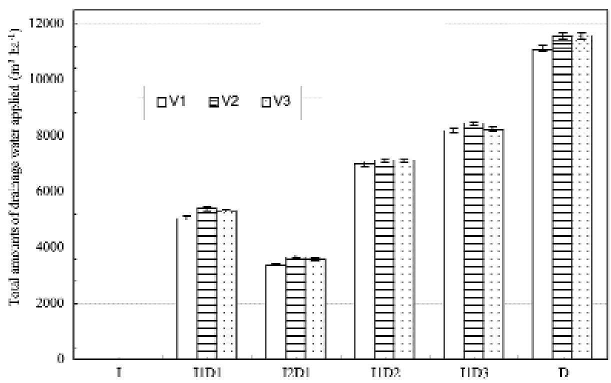

Fig. 3. Total amounts of drainage water applied (m^3 ha^{-1}) for different irrigation treatments and rice crop.
LSD I= 255 (significant at 0.01); V=180 (significant at 0.01 probability).

The potential evapotranspiration (ETp) was calculated using the modified Penman method as it is most suitable to predict the crop water requirement of rice plant under North Delta condition, having the highest correlation coefficient (R^2 = 0.914) between ETa and ETp among the major methods to estimate ETp (Abou El Hassan et al., 2005). Crop coefficient (Kc) is presented to account for the effect of crop characteristics on crop water requirement. The average monthly values of Kc were 1.16, 1.32, 1.18 and 1.07, for June, July, August and September, respectively (Table 4). The maximum value was in July, which corresponded to the maximum tillering stage. The respective average monthly values of ETp were 5.71, 5.64, 5.48 and 4.56 mm d^{-1} (Table 2). Daily ETa showed that the consumptive use of water was 6.65 mm d^{-1} at the first growth stage and it increased to the maximum at maximum tillering stage; it then decreased during the maturity stage. There was no significant difference among irrigation treatments for ETa and Kc. The maximum values of ETa were recoded under I2D1 treatment.

Rice grain yield and field and crop water use efficiency

Rice grain yield (Fig. 4) was significantly affected by irrigation treatments. The highest mean grain yield was under I treatment, which was followed by the treatments in following order: I2D1 > I1D1 > I1D2 > I1D3 > D, averaged over all the varieties. An increase in the volume of drainage water applied thus led to a decrease in rice grain yield. FAO (2003) and Bernstein and Francois (1973) reported that the total concentration of salts in drainage effluent is of major concern in irrigated agriculture. Salinity in the root zone increases the osmotic pressure in the soil solution, which causes plants to exert more energy to take up soil water

Table 4. Monthly actual evapotranspiration (ETa) and crop coefficient (Kc) during the studied growing season.

Irrigation	June		July		August		September	
Treatments	ETa (mm d^{-1})	Kc	ETa (mm d^{-1})	Kc	ETa (mm d^{-1})	Kc	ETa (mm d^{-1})	Kc
I	6.65	1.165	7.42	1.316	6.46	1.179	4.86	1.066
I1D1	6.66	1.166	7.42	1.316	6.48	1.182	4.86	1.066
I2D1	6.68	1.170	7.43	1.317	6.48	1.182	4.87	1.068
I1D2	6.63	1.161	7.42	1.316	6.45	1.177	4.85	1.064
I1D3	6.63	1.161	7.41	1.314	6.45	1.177	4.85	1.064
D	6.62	1.159	7.4	1.312	6.45	1.177	4.85	1.064
Average	6.65	1.16	7.42	1.32	6.46	1.18	4.86	1.07

to meet their evapotranspiration requirement. At a certain salt concentration, plant roots fail to generate enough force to extract water from the soil profile and the resulting water stress leads to yield reductions. The grain yield was significantly affected by varieties; V3 gave the highest mean grain yield. This may partly be due to the difference in the salt tolerance among the varieties.

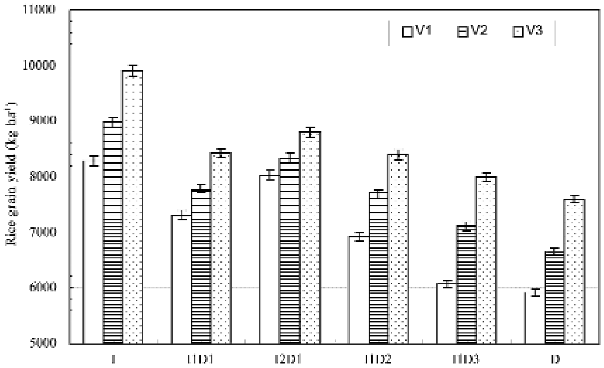

Fig. 4. Rice grain yield (kg ha^{-1}) for different irrigation treatments and rice.

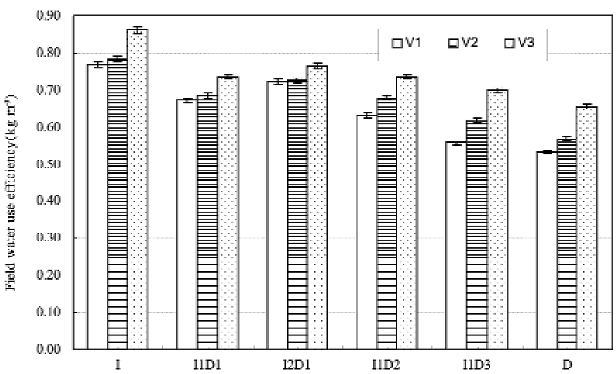

Fig. 5. Field water use efficiency (kg m^{-3}) for different irrigation treatments and rice varieties. LSD I= 0.013, V=0.009.

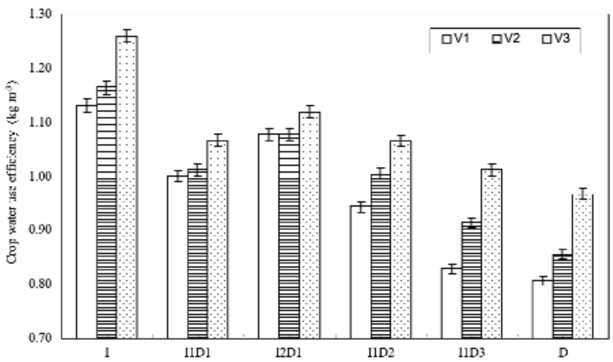

Fig. 6. Crop water use efficiency (kg m-3) for different irrigation treatments and rice varieties. LSD I= 0.013, V=0.010.

Irrigation treatments significantly affected the field water use efficiency (FWUE) (Fig. 5). All treatments using drainage water decreased the FWUE, compared with irrigation with fresh water. The FWUE varied markedly in the order I > I2D1 > I1D1 > I1D2 > I1D3 > D. Sakha 101 (V3) had the highest FWUE due to its longer maturation time and its agronomic characteristics.

The crop water use efficiency (CWUE) was directly related to the grain yield and inversely related to the consumptive use of water of the crop. CWUE also differed significantly by irrigation treatments and rice varieties (Fig. 6). The highest CWUE was obtained in the I treatment whereas the lowest was in the D treatment. The highest value of CWUE was 1.259 kg m^{-3}, recorded for the treatment combination I × V3.
The FWUE and CWUE values were high for the treatments which gave high grain yield. Thus, grain yield is the main factor affecting FWUE and CWUE and the amounts of water used and water applied were rather secondary factors.

Chemical properties related to soil salinity

The Electrical Conductivity (EC) of fresh irrigation water was 0.35 dS m^{-1}. According to the United States Salinity Laboratory (USSL, 1954), water with EC ranging between 0.75 to 2.25 dS m^{-1} is considered highly saline and can not be used in soils with restricted drainage. The EC of the drainage water was 2.86 dS m^{-1} (Table 3). Thus, the use of this drainage water on the long run could create severe salinity problem.

Data in Fig. 7 showed that soil $EC_{1:5}$ levels at the end of the crop season decreased in all irrigation treatments except treatment D. Applying only drainage water (D) resulted in the maximum EC values in all the soil layers because of salt input with the water. In all irrigation treatments, the $EC_{1:5}$ of the soil increased with soil depth because of the movement of salts with irrigation water. The exchangeable cation and anion composition of the soil at the end of the experiment is given in Table 5. The exchangeable Na+ content in the soil increased as increasing amount of drainage water was used for irrigation. The effect on the other cations was rather small.

The soil $SAR_{1:5}$ levels increased, from the level before the start of the experiment, for all irrigation

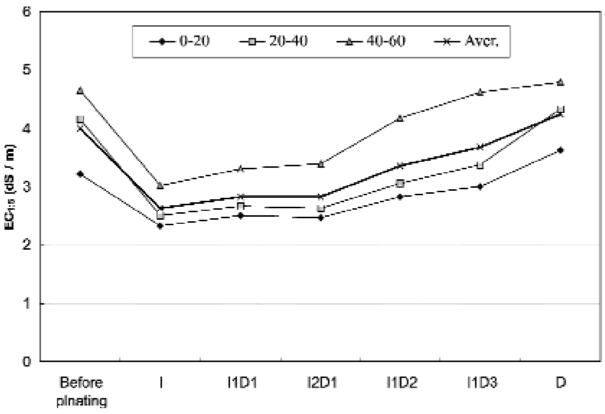

Fig. 7. Soil $EC_{1:5}$ of the experimental site as affected by the studied water reuse treatments at different soil depths.

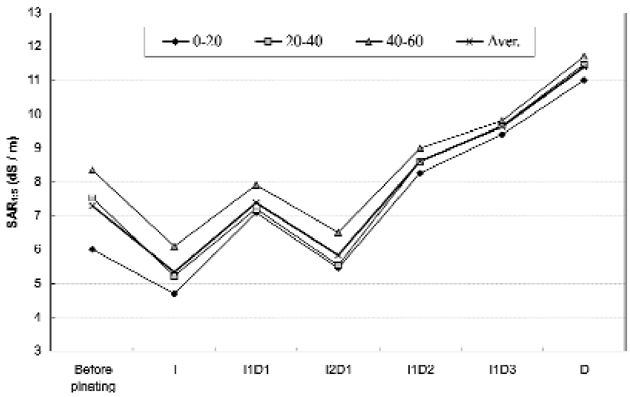

Fig. 8. Soil $SAR_{1:5}$ of the experimental site as affected by the studied water reuse treatments at different soil depths.

treatments except I and I2D1 (Fig. 8). The $SAR_{1:5}$ of the soil increased with soil depth. It was clear that using high quality water in sufficient amount (I and I2D1 treatments) for irrigating the rice crop on saline soil improved soil chemical characteristics related to soil salinity.

Conclusions

A large volume of drainage water is discharged into drainage canals in the Nile Delta region of Egypt during the summer season when rice is generally grown. There is at the same time a great demand for water to irrigate the rice crop. As shown in this study, the use of the drainage water, which otherwise poses a big disposal problem could save about 30 % of fresh water commonly used for irrigation. Where farmers can lift water from drains close to their fields, it's recommended that they grow Sakha 101 rice variety using irrigation water that has FW mixed with DW in a 2:1 ratio. This will save 3595 m^3 ha^{-1} of fresh water and support a grain yield of 8798 kg ha^{-1} with 0.765 kg m^{-3} field water use efficiency and 1.113

Table 5. Chemical properties of the soil at the study area after harvesting.

Irrigation treatments	Depth (cm)	Soil chemical properties: Cations (meq L^{-1})				Anions (meq L^{-1})		
		Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
I	0 – 20	9.1	0.74	3.8	3.7	7.8	4.43	5.13
	20 - 40	10.1	0.63	3.5	4.12	5.23	4.32	8.79
	40 – 60	12.5	0.53	4.8	3.65	5.48	5.70	10.3
I_1D_1	0 – 20	11.3	0.64	2.4	2.7	7.1	4.24	5.7
	20 - 40	12.6	0.60	3.6	2.5	8.4	4.10	6.8
	40 – 60	15.7	0.68	3.8	4.1	7.8	5.75	10.73
I_2D_1	0 – 20	9.4	0.60	2.8	3.1	6.7	3.9	5.3
	20 - 40	10.3	0.53	3.5	3.4	7.7	5.3	4.73
	40 - 60	12.8	0.72	3.7	4.0	6.92	4.2	10.1
I_1D_2	0 – 20	13.4	0.63	3.1	2.15	9.34	3.87	6.07
	20 - 40	14.3	0.68	3.3	2.2	8.94	4.53	7.01
	40 - 60	18.4	0.71	3.7	4.7	8.43	5.73	13.35
I_1D_3	0 – 20	14.7	0.94	2.5	2.4	9.22	5.21	6.11
	20 - 40	16.9	0.81	2.9	3.2	8.95	5.48	9.38
	40 - 60	19.5	0.63	3.8	4.1	10.4	6.33	11.3
D	0 – 20	16.9	0.98	2.2	2.5	8.35	5.12	9.11
	20 – 40	20.4	0.89	3.4	2.9	9.64	6.36	11.59
	40 – 60	23.4	0.70	4.8	3.2	12.4	6.50	13.2

** Extraction for ions was carried out in a soil-water ratio of 1:5* kg m^{-3} crop water use efficiency. This practice, when applied on the total area cultivated with rice crop (based on 1999 data), would save 2352.6 million m3 of fresh water per year in the irrigation network during the period from June to September, which could be released for new irrigation commitments. Based on the results of this study and other related experiments, it is recommended that on saline soils of the Delta region only rice crop should be grown and in the case of shortage of fresh water, it can be mixed in 2:1 proportion with drainage water to irrigate rice crop without deteriorating the soil chemical properties.

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Rainfall time series in arid environment of Mauritania

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Abstract

Mauritania extends in western Africa from the western part of the Sahara Desert to the coastal area facing the Atlantic Ocean. The development of water resources has been the major challenge facing the policy makers in the arid environments of Mauritania. Agricultural activity in oasis areas depends only on a limited rainfall during the rainy season from June to September. In addition to apparent difference between the rainy and dry season, there is a big annual fluctuation of the rainfall over time. Oases areas on the edge of the Sahara are suffering from the water scarcity, salinity and desertification. Therefore, the sedentary peoples live in a very difficult situation because of their dependence on an irregular rainfall for water for domestic use and irrigation. Sometimes, sudden storm brings large amount of water in short period. On the other hand, a year, or even several years, may pass without any rain in some locations. As the rainfall is crucial for any developmental activity in arid zones, a quantitative evaluation of rainfall pattern is essential for the water resources management. In this study, daily rainfall data at three stations in the arid region of Mauritania (Atar, Chinguetti, and Akjoujt) were used for the analysis. Rainfall time series from 1931 to 1999 of three stations were analyzed. Frequencies corresponding to periodical fluctuations of the rainfall time series were obtained by the power spectrum analysis. Then, the Fourier series was applied for reconstruction of the original time series. Rainfall time series of the stations follow the same tendency with the rainy period in 1950's and the dry one in 1970's. The Fourier series showed the trend of fluctuations of those time series.

Introduction

Mauritania, located in Western Africa, comprises mainly of Sahara (arid zone) in the northern part and the Sahel and Sudano zones (semi arid) in the southern part, under the influence of monsoonal rain. Sahara extends over a large area and is characterized by the absence of vegetation cover, water scarcity and irregularity of rainfall. Sahel zone, in contrast, receives more rainfall; but in the last decades its rainfall regime has undergone a big change, which has affected the vegetation cover as well as the agricultural and pastoral activities. The rain in the Sahel and Sahara areas mostly comes from humid air masses carried by the Atlantic Ocean wind. Sea surface temperature (SST), which controls the humidity of the air mass, has an important influence on the rainfall.

Several studies have demonstrated that relatively warm conditions over global oceans, especially the Atlantic and Indian Oceans, tend to promote drier conditions over the continent as a whole (Nicholson, 2001). Biasutti et al. (2004) reported that the role of SST in the annual cycle of air temperature and precipitation to be large over the Atlantic Ocean, the Guinea coast of Africa, and northeast of Brazil. Giannini et al. (2005) also mentioned that modeling studies confirmed statistical association between observed Sahel rainfall variability and tropical Atlantic SST, in the mid 1980s.

The impact of SST anomalies in the eastern tropical Atlantic Ocean on the boreal summer rainfall over sub-Sahara in West Africa is confined to approximately 10°N. The rainfall north of this latitude is linked via changes in the large-scale atmospheric circulation to the changes of Indian Ocean SST. Importantly, Nicholson and Kim (1997) have shown that there is indirect influence of El Nino

South Oscillation (ENSO) on Sahelian rainfall, from ENSO event exciting SST anomalies in the Atlantic and Indian Oceans (Hunt, 1999). Therefore, in several studies, different oceanic regions were identified to have influence on Sahel and more generally African rainfall regimes. In the study presented here we aim to specify the regions that influence the rainfall in Adrar and Inchiri areas in north Mauritania during the last decades.

The pole-ward movement of the Inter-Tropical Convergence Zone (ITCZ) controls monsoonal rain over continent. The ITCZ is resulting from meeting of north-easterly (Harmattan) flow coming from the Sahel and Sahara desert and the south-easterly (monsoon) flow. These two flows determine the monsoonal characteristics of the African continent. The Sahel's demographical, agricultural and pastoral importance and the drastic changes occurring there in the last few decades have been of concern to researchers. However, more attention is needed to be given to study the arid environment and its climatic variability for better understanding of its characteristic and behaviour to mitigate drought and desertification and to conserve the Oasis. The rainfall decadal and seasonal trends of the study area have apparent similarity with Sahelian rain. We aim in this work to study the general trend of rainfall and its relations with SST for rainfall prediction purpose. We focus on monthly rainfall of August and September, as they are the months of highest rain in this region.

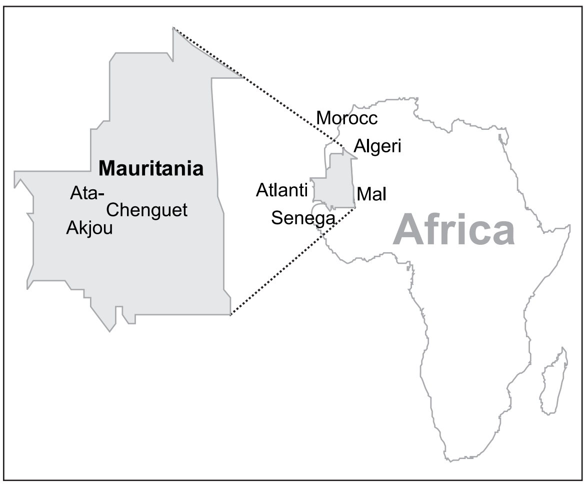

Fig. 1. Location map of the study area.

Methods and material

Study area

The rainfall stations used in this study are Atar and Chenguetti (Adrar district) and Akjoujt (Inchiri district) bounded between 19°-20.5°N and 12°-14°S. Adrar and Inchiri are located in northern Mauritania (Fig. 1) receiving an average annual rainfall of less than 100 mm (from 1930 to 1990s). They cover a part of the Sahara, Sahilo-Sahara, bordering the West African semi arid zone (Sahel) in the northern limit. In this region a total of fifty three oases and around one million palm trees exist, which are 24.3% and 47.2%, respectively, of the national total number.

Agricultural activities have been the main source of revenue for the sedentary people since several centuries. These activities are mainly in oasis areas, which are located usually in the bed of *Wadis* where soil is suitable and water is available most of the season. The availability of water is much related to the rainfall occurrence as this is the unique source of recharge. Recurrent drought, sand dune movement, and introduction of motor pumps have compounded the problems of livelihoods in the oasis area.

Rainfall and SST

Daily and monthly rainfall data set was collected from the Atar, Akjoujt and Chenguetti stations and analyzed. Time series from 1930 to 1990s were used in this analysis and a span of 1930 to 1980 was used for rain-SST cross-correlation. Time series set of monthly SST one degree all over the world, obtained from the British Atmospheric Data Center (BADC), was also used. Monthly and annually time series was normalized to remove the seasonal fluctuation. For the purpose of normalization of the original time series monthly mean and standard deviation was used (e.g., Yasuda et al., 2005) as follows:

$$R = \frac{r - \mu_m}{\sigma_m} \tag{1}$$

where R is normalized rainfall, r is original rainfall (mm), μ_m is monthly mean and σ_m is monthly standard deviation.

Results

Rainfall

Monthly average rainfall:
From the monthly average rainfall and the coefficient of variation of the three stations we can observe a dry period; with an average below 5 mm, extended from November to June and a rainy one from July to October with a maximum in August and September. The rainfall occurrence in these two months (August and September) is more reliable as the coefficients of variations indicate.

Annual rainfall:
Variation of the annual rainfall time series at the three stations (Fig. 2) shows similar tendency. For two decades (1970s to 1980s) the rainfall was below the standard deviation. On the other hand in 1950s rainfall was up to the standard deviation. In general the tendency of same rainfall fluctuation behavior of the three stations is also clear around the standard normalized. The average annual of Atar, Akjoujt and Chenguetti were respectively 89.55 mm (from 1931 to 92), 83.64 mm (from 1931 to 1994) and 58.74 mm (from 1931 to 1980).

Continuous drought days and monthly rainfall event

The top ten and twenty continuous drought days and rainfall event values were selected from observed rainfall at each station. The maximum rainfall event in Atar, Akjoujt and Chenguetti was 94 mm (from 1964 to 80), 64 mm (from 1950 to 1991) and 29 mm (from 1964 to 1980) respectively. The maximum continuous drought days were 335, 328 and 303 in Akjoujt, Atar and Chenguetti

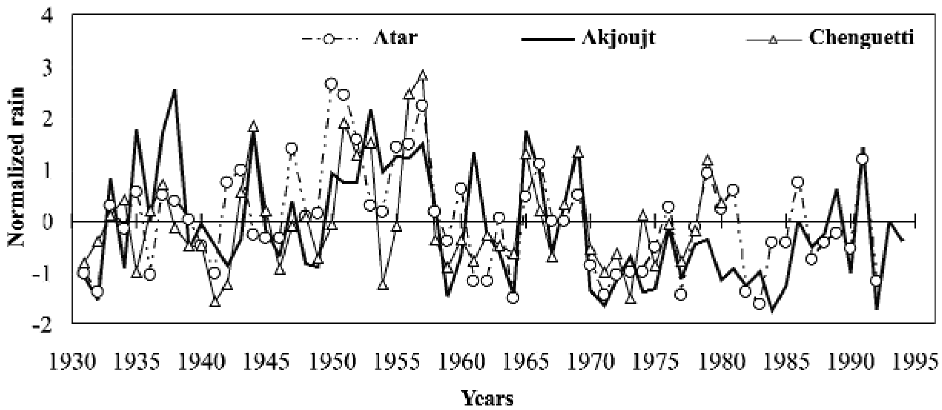

Fig. 2. Annual rainfall time series of Atar, Akjoujt and Chenguetti stations.

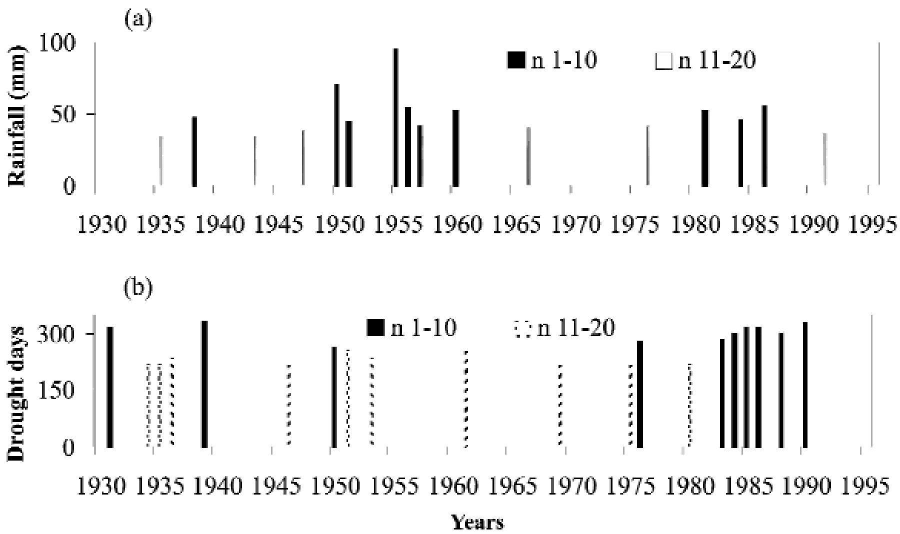

Fig. 3. (a) Rainfall event of Atar station; (b) Continuous drought days of Atar station.

Table1. Frequencies obtained by spectral analysis in Atar, Akjoujt and Chenguett.

Atar			Akjoujt			Chenguetti		
f*	T (month)	T (year)	f*	T (month)	T (year)	f*	T (month)	T (year)
0.082	12.24	1.0	0.034	29.15	2.4	0.198	5.04	0.4
0.034	29.33	2.4	0.178	5.61	0.5	0.163	6.13	0.5
0.195	5.13	0.4	0.082	12.22	1.0	0.035	28.49	2.4
0.055	18.05	1.5	0.139	7.17	0.6	0.086	11.64	1.0
0.041	24.27	2.0	0.007	135.14	11.3	0.151	6.63	0.6
0.102	9.78	0.8	0.050	20.04	1.7	0.044	22.73	1.9
0.129	7.76	0.6	0.105	9.53	0.8	0.007	138.89	11.6
0.018	55.56	4.6	0.023	42.74	3.6	0.129	7.78	0.6
0.008	126.58	10.5	0.018	56.50	4.7	0.018	54.35	4.5

respectively (Fig. 3). Drought was continuous in the period of 1970s and 1980s. On the other hand rainfall event occurrence was more important in 1950s as well in Akjoujt.

Periodical fluctuation

Spectral analysis and fit by the Fourier series:
The frequencies determination is important to provide historical "risk" interpretation for future conditions and to evaluate the periodical fluctuation of the rainfall time series, the spectral analysis was carried out and frequencies were obtained as shown in the Table 1. The Fourier series follows the tendency of the original time series of the three stations as shown in Figure 4 (Atar station). The periodical fluctuation of the rainfall time series is controlled by the frequencies in Table 1. Cycle contained in the rainfall time series corresponding to long periods was around 11 years which represent the cycle of Sunspot number. Therefore, the Sunspot number has an influence on rainfall of northern Mauritania. Other remarkable short periods are around 4.5, 2.4, 2.0, 1.0 and 0.5 years. Those frequencies were applied to the Fourier series:

$$r(t) = a_0 + \sum_{i=1}^{i=M} \left(a_i \sin 2\pi f_i t + b_i \cos 2\pi f_i t \right)$$

Where r(t) is rainfall, M is number of terms, a_i and b_i are the Fourier coefficients. Figure 4 shows Fourier series obtained by those frequencies. Fourier series follows tendency of the original time series. Those frequencies control the rainfall time series.

Link between rainfall time series and SST
To find out links between the rainfall time series and sea surface temperature (SST), cross-correlations of SST all over the world with the rainfall time series were calculated. The cross-correlations between August and September rainfall and SST were obtained using rainfall span from 1931 to 1980 and SST span of 1930 to 1979 for all over the world to check the areas which have significant correlations. Cross-correlation more than 0.28 and that more than 0.48 corresponded to the significance level of 95 % and 99 %, respectively. The rainfall of August and September of stations showed significant correlations except that of September in Chenguetti and Atar. The regions of high correlations of all stations have a very good

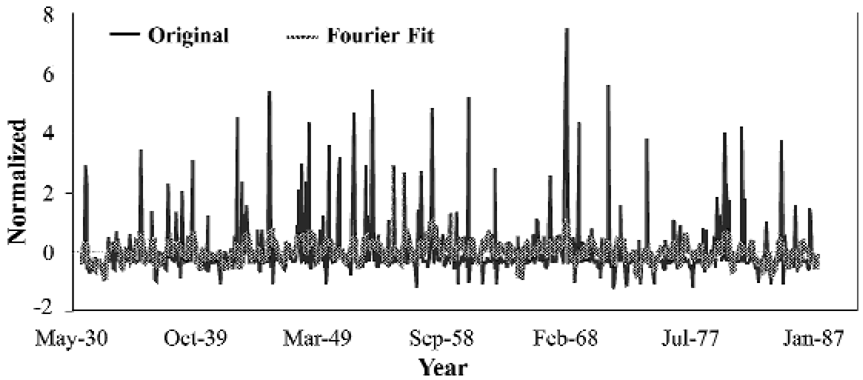

Fig. 4. Fourier fit of rainfall time series in Atar.

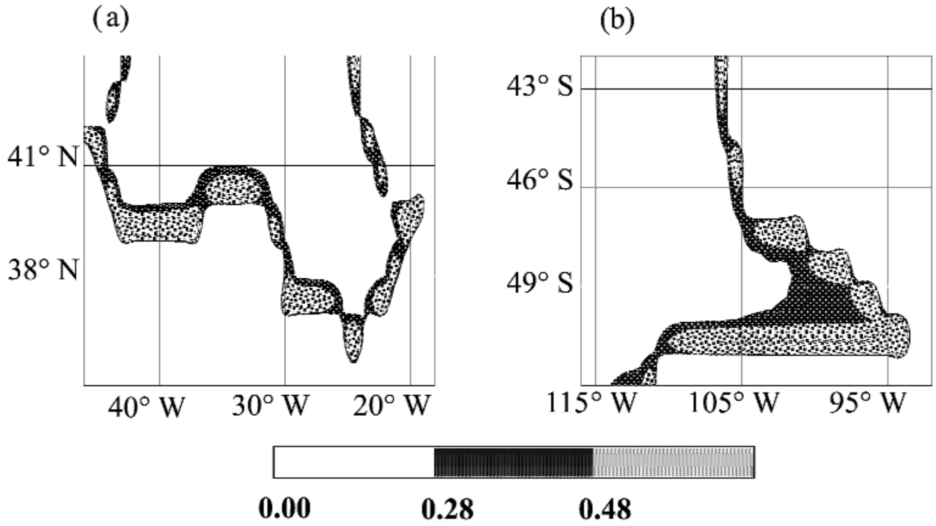

Fig. 5. Area of significant correlation between SST in March and Atar rainfall in August: (a) North Atlantic and (b) South Pacific Oceans.

similarity for all lags and there is a significant correlation between rainfall and SST for all over the word. We have detected areas in North Atlantic Ocean (in March and April) and South Pacific (in February, March and April) as areas of significant correlations with rainfall of the study area (Fig. 5).

Conclusion

The rainfall time series of Atar, Akjoujt and Chenguetti stations show a similarity in their general trends. The periods of drought appeared in the late 1960s and extended until the end 1980s. The 1950s had the longest rainy period in the region. This is similar to Sahel zone as Nicholson (1986) has found. The cycles contained in the rainfall time series corresponding to long periods observed at different stations are around 11 years, which represent the cycle of Sunspot number. Therefore, the Sunspot number has an influence on rainfall of northern Mauritania. Other remarkable short periods are around 4.5, 2.4, 2.0, 1.0 and 0.5 years. The SST of North Atlantic Ocean in March and April and South Pacific Ocean in February and March have influence on the rainfall in the studied area

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Desertification controlled by fluvial, aeolian and playa interactions: a case study from Abarkoh Basin, Central Iran

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Abstract

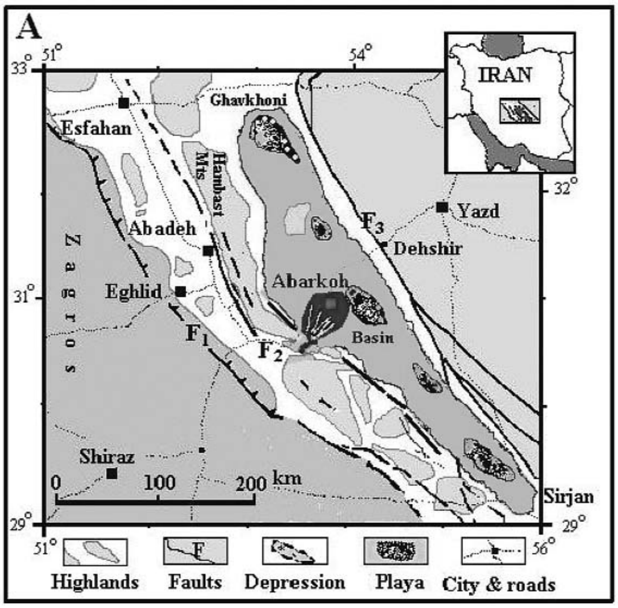
The implementation of the convention for combating desertification can not be achieved without a multidisciplinary method of study, among which, understanding the geology as well as geography of the area receives enough attentions. This study highlights the desertification controlled by fluvial, aeolian and playa interaction and represents a case study from an arid land in distal part of an alluvial/fluvial mega fan in Abarkoh Basin, Central Iran. The periodic flash floods through the ephemeral fluvial systems of this mega fan recharge the playa lake, which is located in the center of this basin. The late quaternary evolution of the playa fringe area represents the relative dominance of wind vs. water transport and deposition as a function of fluctuation in the discharge of ephemeral fluvial systems and changes in water table/playa lake level. The combination of climatic change, human impact and to a lesser extent, tectonics resulted in a recent fall in water table/playa lake level and associated periods of extensive erosion and dune shifts. Recent deflation of the dune fields either exposed the playa-fringe, lacustrine travertine-marl deposits with exhumed plant roots or eroded part of the vegetated sand dunes. The interaction between fluvial, aeolian and playa environments is distinctive by fluctuation in water table/playa-lake level and associated aeolian landscape, which was reshaped by the major ephemeral streams that flooded the inter-dune deposits. This interaction has controlled the general geomorphologic and sedimentologic patterns of the Abarkoh Desert. This may highlight the extent of environmental factors in controlling the sensitive media of a desert sedimentary system.

Introduction

Deserts cover a considerable area in Central Iran and are closed drainage basins mostly located within the fault-bounded depressions (Berberian & King, 1981; Arzani, 2006). Playas (salt lakes) develop in the central parts of these arid to semi-arid enclosed drainage basins, where the water table is close to the surface and evaporation exceeds ephemeral rivers and/or groundwater recharge. Desert sedimentary and geomorphologic systems comprise a variety of sub-environments including ephemeral fluvial rivers of the distal parts of the alluvial fans, aeolian dunes/inter-dunes, sand sheets, salt/mud flats and playa lakes. They are highly sensitive to internal and externally imposed environmental changes (e.g. Sweet, 1999; Alonso-Zarza, 2003; Mountney, 2004). The sub-environments of a desert system have a close interaction and undergo sedimentary and morphological adjustments in response to environmental modification, such as change in climatic and tectonic regimes (e.g. Nanson & Tooth, 1999; Tooth, 2000; Mûller et al., 2004). The net result of this interaction should be considered for any proposed project to control the desert transgression.

In the arid desert regions the climatic factors control mainly the rate of precipitation as well as evaporation. The related externally-forced changes, such as dust-storm intensities/periodicity and the magnitude of flash floods, as well as intrinsic sedimentary behaviors, such as dune migration, mud and salt flats areas (associated with the variability of the playa lake level/underground water table) modify the geomorphology of the desert areas. Tectonic uplift and basin tilting, because of fault activities, change the drainage net. They also control the accommodation space for the sediment to be trapped and especially the place and extent of the playa lake and fringe. This study highlights the influence of playa-lake level fluctuations on recent lacustrine/aeolian and ephemeral fluvial sediments and their importance in desertification. It represents a case study from distal part of the Abarkoh mega fan in the Gavkhoni-Sirjan Depression in Central Iran (Fig. 1).

The width of this basin is about 100 km in the studied area and is bounded by the Dehshir high-lands and fault in the east and the Hambast Mountains and faults in the west (Fig. 2). The Abarkoh alluvial/fluvial mega fan originates from the apex in a valley in Hambast Mountains in the west of the Abarkoh Basin and covers an area >940 km^2 (Arzani, 2006). It terminates in the playa-lake in the middle of this basin. The old city of Abarkoh, with ~40000 populations and ~80 km^2 in area, is located in the medial parts of this mega fan (Fig. 2). In this city, >850 shallow (<100 m) to deep (up to 400 m) irrigation water wells and 103 *Qanat* systems (>270 km of underground tunnels) extract more water from the ground than its recharge. As a result, the groundwater table has dropped during the last 10 years (10-35 m in the city and up to 1 m in the playa fringe) and dried some of the *Qanat (Kareze*) systems (Arzani, 2003). The Abarkoh Basin has an arid climate with an average annual rainfall of about 90 mm, minimum annual 29 mm, and maximum ~132 mm. The average annual evaporation has been 3632 mm during an investigated period of 15 years (Bagheri, 1995). The dominant wind sys-tems today across the Abarkoh Basin are those



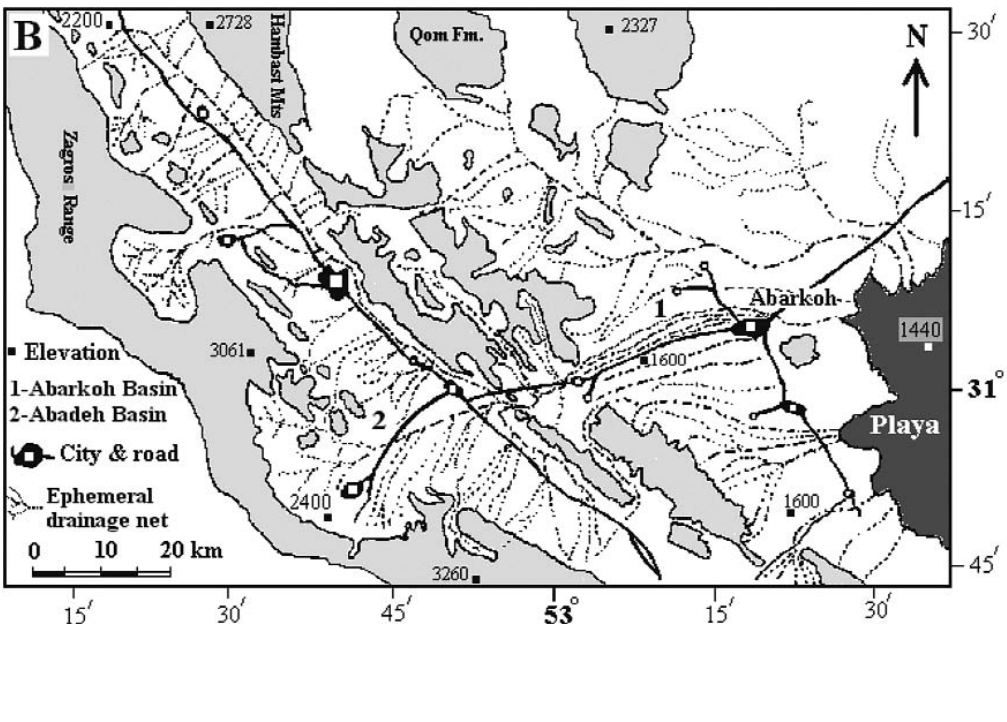


Fig. 1. Location, structural and drainage maps of the Abarkoh Basin. A. Abarkoh Basin as a part of Gavkhoni-Abarkoh-Sirjan depres-sion in Central Iran (F1, F2 & F3 are Zagros, Abadeh and Dehshir faults respectively); B. Drainage net of the Abarkoh and Abadeh Basins (drawn based on geological map of Abadeh, 1/250000 sheet, Geological Survey of Iran, Amidi et al., 1983, topographic maps of Abadeh & Abarkoh, 1/25000-1/250000, Iranian Cartographic Center and satellite images, TM, Landsat 4, & ETM Landsat 7, sheet numbers 162R38 & 162R39, see Arzani, 2006 for details).

which blow from northeast and southwest and nearly all divert in the center of basin toward the south, where the sand dunes are shifting downwind and toward the playa lake center.

The different sub-environments of the Abarkoh desert system are affected by the natural and anthropological factors such as recent climatic changes and the drop in ground water/lake level as a result of excessive water pumping in the higher-level plains (Abarkoh City) and desert borders (Arzani, 2003). It is important to understand the interplay between the processes active in the deserts and to predict the response of their sub-environments to these modifications.

Methods

General geology and geomorphology of the studied area have been studied based on available geological maps (Amidi et al., 1983), Landsat (TM & ETM, Landsat 7) image data (imagery calibrated by ground survey) and field observation during

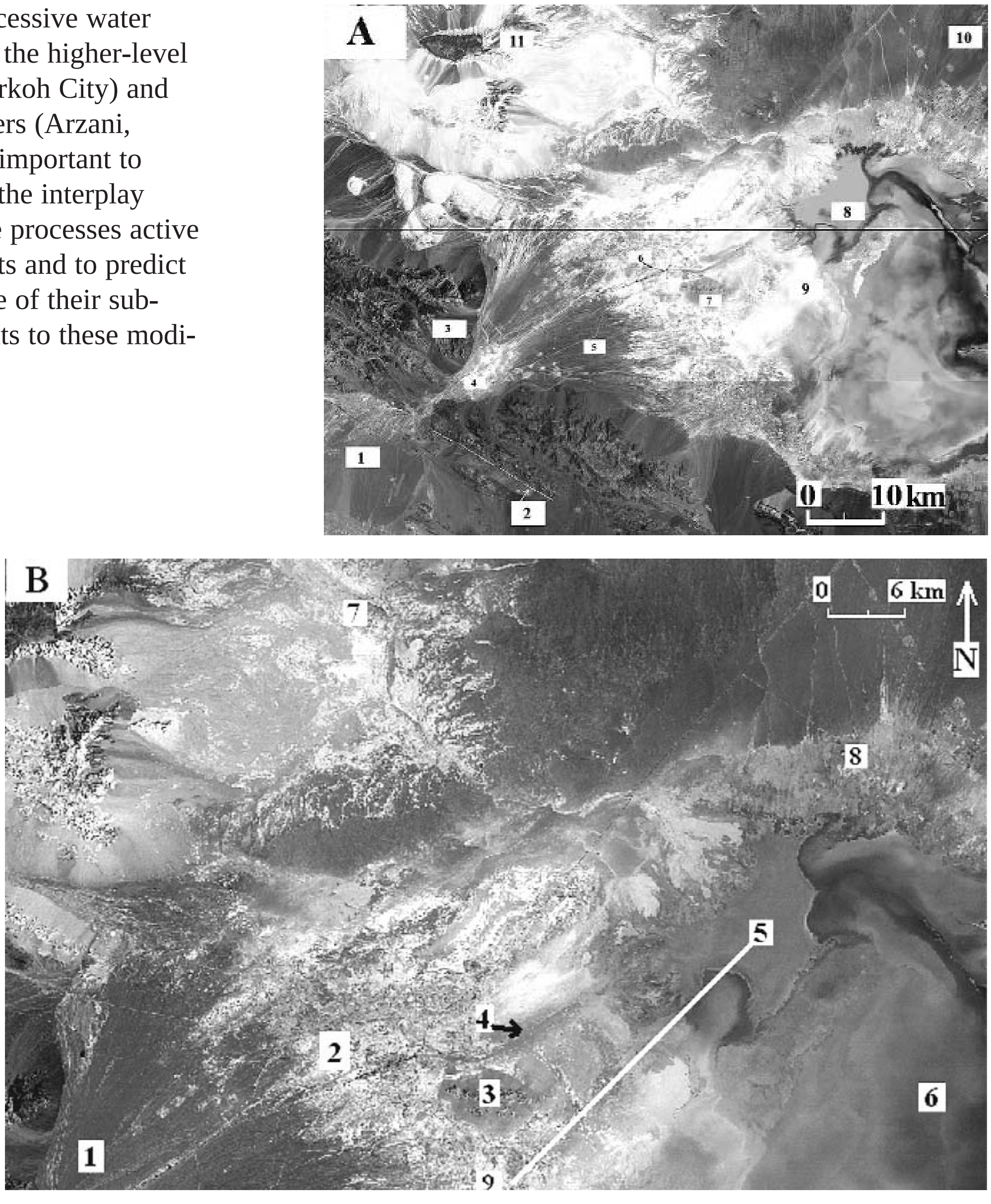


Fig. 2. Satellite images (TM, Landsat 4, 16th Jan., 1988) of the Abarkoh Basin. A. The general view of the west of this basin, showing: (1) part of the Abadeh Basin (catchment of the Abarkoh mega fan), (2) Abadeh fault, (3) Hambast Mountains, (4) proximal and lower feeder channel areas of the Abarkoh mega fan (5) lower proximal fan areas, (6) Abarkoh City (midfan areas), (7) Oligocene-Miocene outcrops, (8) playa, (9) mud-salt flats in playa fringe, (10) Dehshir highlands, and (11) Oligocene-Miocene outcrops; B. Center of the Abarkoh Basin showing: (1) Abarkoh mega fan, (2) Abarkoh City, (3) Oligocene-Miocene (limestone) hills, (4) gravely meander belts and channels of the distal fan areas, (5) playa lake, wet surface in January, 1988 and dry in summer 2004, (6) playa lake partly wet in winters, (7) Oligocene-Miocene red beds and evaporitic exposures, (8) Chah Begi Village and (9) Nosrat Abad Village, where the traverse started toward the playa.

several separate weeks of ground survey (1998-2004). This has been combined with the field observation in certain stations and along a west-east traverse of >28 km, from the distal parts of the fluvial system of the Abarkoh mega fan toward the playa fringe. In each station, trenches up to 3 m (at the beginning of the traverse) and 1.5 m (in the playa fringe) were dug and representative samples were studied.

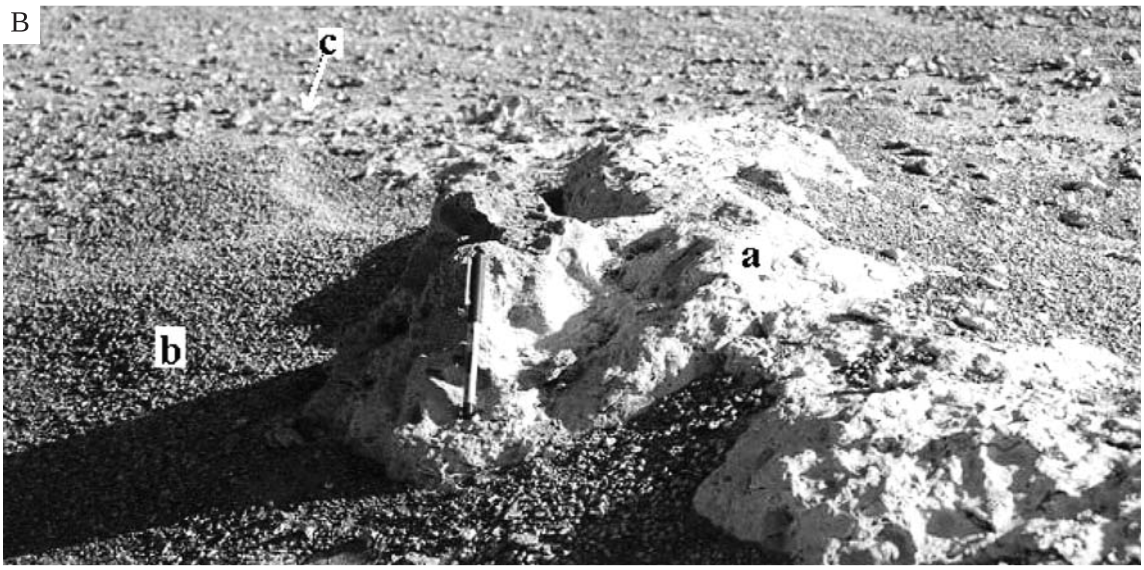
Abarkoh desert

The desert system of the Abarkoh Basin covers an area of ~1750 km^2 and comprises a variety of sub-environments, including the playa-lake, salt and mud flats, aeolian dunes and inter-dunes, sand sheets, gravel pavements and the ephemeral fluvial rivers and flood plains of the distal parts of the Abarkoh mega fan (Fig. 1 & 2). The playa-lake and its periphery (consisting mainly of salt-flats, mud-flat and sand dunes) cover an area of ~600 km^2 (~15 km wide and 40 km long) and with a general NW-SE trend of the basin are the main sedimentary environments of this desert system. The remaining areas of this desert are the deflation surfaces at the toe of the alluvial fans along the north and eastern sides of this basin. Ephemeral rivers carry the periodic flash floods and enter the playa from its sides. The major fluvial systems are those from north and west, which carry floods from north and west of Abarkoh Basin.

The representative sedimentary environments of the studied desert system and along a 28 km traverse (Fig. 2), from SE of Abarkoh City (Nosrat Abad Village) to the playa-lake margins include the following:

1- The flood plains of the Abarkoh mega fan, where the calcareous marls and soils represent the typical surface sediments. They grade downward into travertine nodules and beds. The surface sediments laterally change into gravel/sand sheets with locally exposed travertine deposits (Fig. 3). The gravel/sand sediments form elongated ripples (up to 10 cm high and 15 m long) showing wind direction toward NE and playa center. The travertine deposits are

Fig. 3. Gravel/sand sheets and locally exposed travertine deposits of the start of the traverse and 7 km SE of Nosrat Abad Village. A. The gravel/sand sediments of these stations form elongated ripples showing wind direction toward NE (upper left); B. exposed travertine sediments (a), between rippled gravel/sand (b), and travertine-cemented sand pebbles (c), which are scattered on the surface. See text, for interpretation.



interpreted as lacustrine and pond margin biochemical deposits contaminated with aeolian/fluvial terrigenous sediments. Carbonate as tufas or travertines are the common biochemical deposits formed as a lacustrine and an outer belt deposits around the playa lakes, which are well documented in the literature (e.g. Ford & Pedley, 1996; Evan, 1999; Andrews et al., 2000; Alonso-Zarza, 2003).

2- Along the studied traverse and about 7 km east of Nosrat Abad village, the gravel/sand sheets and travertines grade into sand dune fields (Fig. 4). Stabilized (by small bushes or plants), isolated to joined aeolian sand dunes are oriented NW-SE and show a predominant flow from southwest. The isolated dunes have a length from 5 to 32 m and a width from 2 to 20 m. The maximum height is 1.5 m above the ground. The inter-dune is covered with dark-grey gravely (granule)/ sand sediments and underlying large desiccated mud flakes break through the surface. The surface sediments grade downward into alternation of desiccated mud and sand lamina and then greenish calcareous marls and travertine nodules to whitish-cream travertine (Fig. 4 & 5). The calcareous marls and travertine deposits are exposed in very wide inter-dune areas, where the plant roots are standing up to 50 cm above the ground and the surface is also partly covered with rippled granules to sand deposits (Fig. 6). The surface sediments are interpreted as aeolian sand dune fields and inter-dune area covered with alternating slack water deposits of the distal ephemeral flood rivers (inter-dune channels) and wind-blown gravely (granule)/sandy sediments. The exposed travertine deposits and plant roots represent the deflation areas where the transverse sand dunes are recently deflating toward southeast (playa center). The deflation and dune migration in this area is interpreted as the result of the drop in playa-lake level.

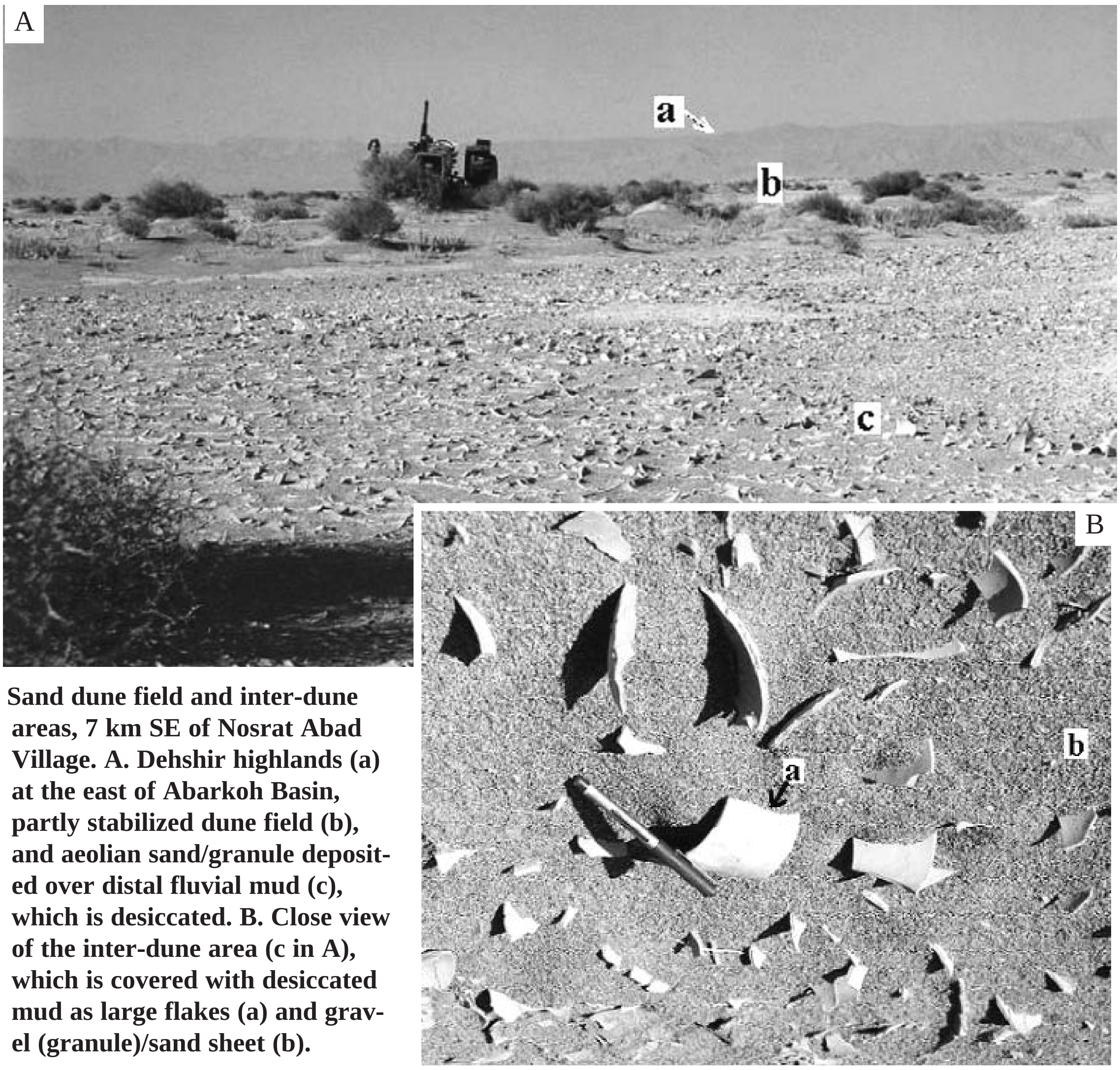
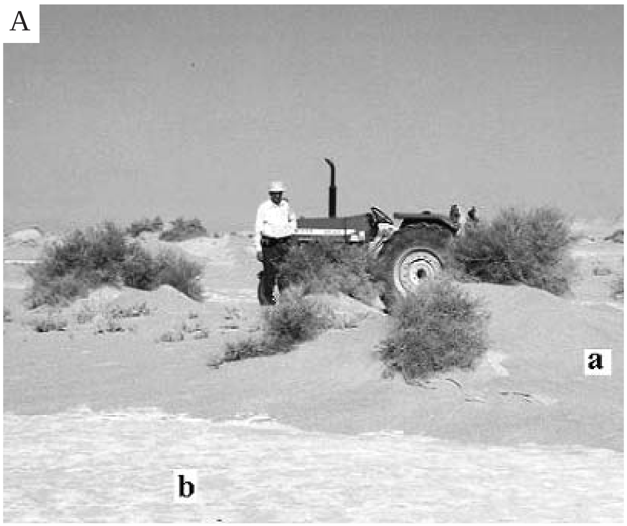


Fig. 4. Sand dune field and inter-dune areas, 7 km SE of Nosrat Abad Village. A. Dehshir highlands (a) at the east of Abarkoh Basin, partly stabilized dune field (b), and aeolian sand/granule deposited over distal fluvial mud (c), which is desiccated. B. Close view of the inter-dune area (c in A), which is covered with desiccated mud as large flakes (a) and gravel (granule)/sand sheet (b).

Fig. 5. Sand dune (partly stabilized) field and inter-dune areas, 10 km NE of Nosrat Abad Village. A. Linear sand dunes (a) and inter-dune areas of station 5. The latter is covered with marls and travertine deposits. B. Dehshir highlands (a), and stabilized sand dune field (b), and inter-dune areas (c & d) of station 8. Rippled coarse sands (c), and exposed travertine-marls (d) represent the general deflation nature of the very wide inter-dune areas.



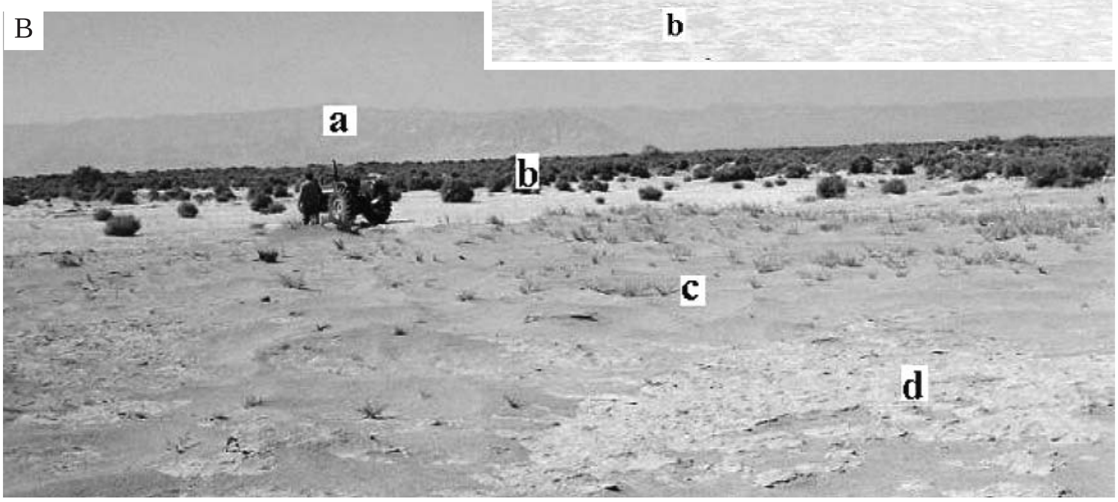
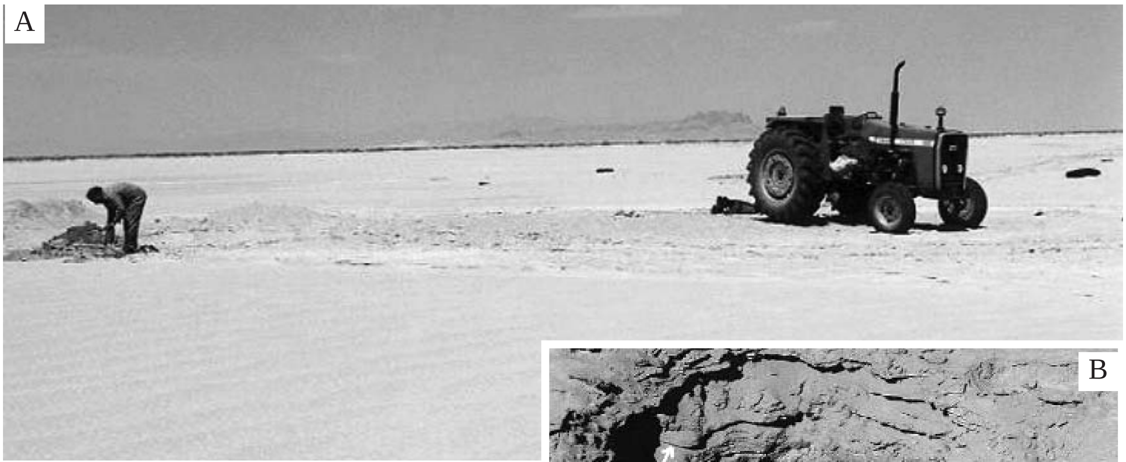


Fig. 6. Deflation areas changing to salt flats 12-15 km NE of Nosrat Abad Village (along the traverse). A. Dehshir highlands (a) at the east of Abarkoh Basin, very wide sandsheet to travertine/marl covered area (b), with exposed plant roots (c), and rippled coarse sand to granule and finer sediments (d). B. Efflorescent, partly salt-cemented and desiccated aeolian sand deposits.

Aeolian sediments in the surface grade downward into very calcareous marls with gypsum nodules and travertine of the playa-lake fringe environment. The sand/mud layers in subsurface represent deposition of aeolian sediments on a damp surface.

3- Toward the SE and 18-28 km from Nosrat Abad village, very wide, brown sand-salt flats with desiccated, efflorescence and partly whitish salt crusts characterize the sediments of the playa lake fringe (Figs. 6, 7 & 8). They grade downward into inter-layered sand (rippled sand and wavy laminated sand-silt deposits) and white hard salt crusts. The salt crusts are characterized by either elongated halite crystals (*chevron halite crystals*) or isolated halite cubes (*cumulate halite crystals*) associated gypsum crystals. Cumulate halite crystals are common down the trenches and below the water table (> 100 cm subsurface in summer 2004) and are mixed with the aeolian sands (Fig. 7 & 8). The aeolian sedi-



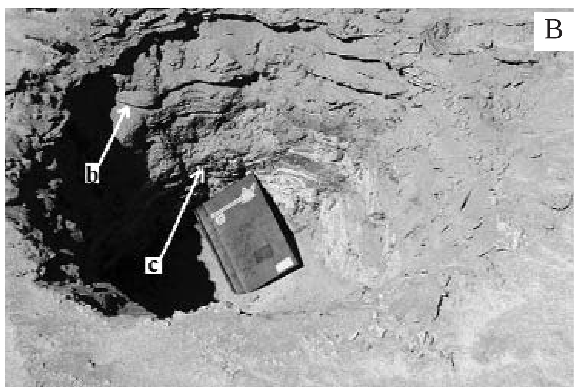


Fig. 7. Sand/salt flat and a shallow trench, 28 km NE of Nosrat Abad Village (along the traverse). A. Very wide, flat surface rippled sandsheets and efflorescent, partly salt-cemented and desiccated aeolian sand deposits. B. The surface (a) and subsurface aeolian sand deposits (b) and the salt (halite and gypsum) layer (c). The salt crust shows chevron halite crystals.

Fig. 8. Playa-lake borders and 28.5 km NE of Nosrat Abad Village (end of the traverse). A. Surface sandsheets and whitish, partly salt-cemented efflorescent crusts changing downward into salt crusts. B. The close view of the salt crust down the trench, showing the chevron halite crystals.

ments are also cemented with salts and form large irregular nodules occurring near the surface (Fig. 8). According to the local residence of the villages of around the playa and the remnants of the salt exploration plant of a company, the lake level had been at the surface in this station in 1996. The laterally extensive sand sheets and efflorescence salt crusts have replaced the salt crusts at the surface.

Recent desert geomorphology controlled by playa-lake level fluctuation

The present position of the Abarkoh Playa Lake is evident in the satellite images and also in the field (35 km SE of Nosrat Abad Village) as wet surfaces and extensive salt flats (Fig. 3). The lake level is 1445 m (above sea level). This lake has been in higher level (1485m) in the quaternary and its lateral extends >30 km (horizontal distance) to the east of its present lake level margin in this basin. This is inferred by the geographic position of the marls and travertines in the starting points of the traverse and 7 km SE of Nosrat Abad village. The drop of playa-lake level during the recent years was associated with the depositional (salt crusts and aeolian sediments) and diagenetic (dissolution voids in salt crusts and salt-cemented aeolian nodules) structures. Lake-level reduction and associated intensive evaporation has led to the development of brine pools and precipitation of evaporites in salt crusts. They were covered, from time to time, with wind blown deposits and gradually shifted toward the lower level, basin center, beyond which mudflats and palaeo-lake shoreline carbonate deposits developed.

The general recent drop of the studied playa-lake level, which occurred in the last 100 years, can be because of: (1) fluctuation in rate of precipitation, (2) dramatic change in groundwater pumping, (3) construction of local dams along the main rivers in the medial fan regions, and (4) reactivation of the faults in this basin. There is no long-term rainfall data for this basin, but the rate of groundwater pumping has increased from 1960s, when the water wells replaced Qanat system (Bagheri, 1995**;** Arzani, 2003). The flash floods moving toward the playa are restrained by the local dams constructed in the Abadeh and Abarkoh Basins. As a result, only very high magnitude floods were able to reach the playa center. Reactivation of the Dehshir fault in the east of the studied playa (where alluvial fans sediments have been recently dissected) shows that the Abarkoh Basin is slightly tilting toward east. This differential topographic elevation added to other factors controlled the western shoreline of this playa lake migrating toward the east.

Depositional processes acting within playa and saline lakes have been the focus of numerous studies (e.g., Turner & Smith, 1997; Schrieber &. Tabakh, 2000; Goodall et al., 2000; Yechiell & Wood, 2002). The solute composition of the brine in a closed saline system depends largely on the original composition of the input water. The level of the underground water of the studied basin has recently dropped to a considerably lower level and as a result, most of the *Qanats* of the medial areas of the Abarkoh fan have dried out (Arzani, 2003). However, the ephemeral floods are a major source of salinity for the Abarkoh Playa Lake. The contribution of Tertiary sediments, the Oligocene-Miocene Red Beds of the "Qom Formation", are very important source of evaporates contributed to the Quaternary alluvial fan sediments fringing the fault escarpments along the studied basin margins (Amidi et al., 1983, Berberian & King 1981;

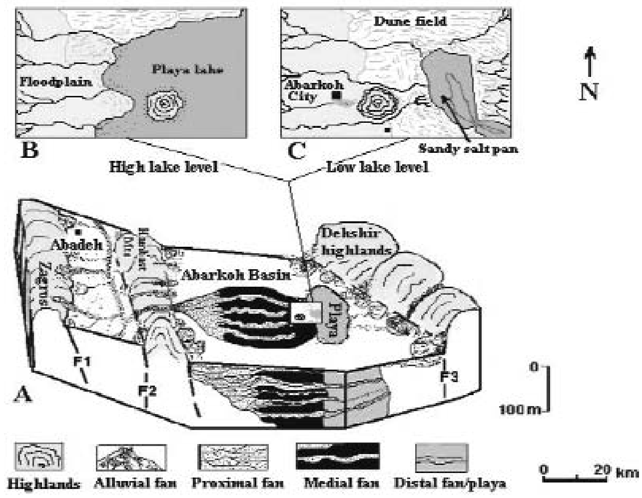


Fig. 9. Schematic model of geomorphology and face distribution in the Abarkoh Basin. A. Abarkoh mega fan and the playa lake. B. The distal parts of the mega fan/west of the playa fringe (rectangle in A) in high lake level condition. C. Low lake level condition. F1, F2 and F3 are Zagros, Abadeh and Dehshir faults respectively. See also figures 1 and 2 and the text for details (adapted and modified from Arzani, 2003; 2006).

Arzani, 2003). The gypsiferous/salty sediments of the Qom Formation are transported as aeolian and ephemeral fluvial sediments toward the basin centers and added to the mud flat/salt flat sediments of the playa fringe.

Playa lakes formed in closed topographic depressions may change from high water level and lacustrine condition to low water level, reduced into local brine pools, and or even complete desiccation (Fig. 9). The sedimentary system will be different in each of these stages.

High lake level: Rise in lake-water level and the lateral extent of shoreline occurs during the initial maximum flooding phase. At this stage the aeolian dune fields will be stabilized on damped wet surface of the playa fringe. In modern settings where surface run-off fills the lowest topographic elevation and changes into a lake, as water accumulates, depths increase and “lake expansion” takes place. Once a shallow lake is produced, a variety of vertical faces associations develop in response to changes in hydraulic regime and infilling of the saline pan. Carbonate formations, such as travertine and calcareous tufa deposits, are typical deposits of the margins of playa lakes during high lake level (e.g. Ford & Pedley, 1996; Alonso-Zarza, 2003).

Low lake level: During low lake level, as a result of net moisture loss through evaporation and lake level reduction in the desert arid climate, brine pools and salt crusts will develop and aeolian dunes will migrate along the lake fringe. At this stage typical evaporite minerals (gypsum and halite crystals) will precipitate. Halite crystals will precipitate mostly either as cumulate/chevron crystals and/or efflorescent crusts (Smoot & Castens-Seidall, 1994; Sweet, 1999; Schreiber & El Tabakh, 2000). Cumulate halite crystals, which are of millimeter-scale with a random orientation, will precipitate at the air-water interface and as floating crystals and then settle through the water column at the bottom. Chevron crystals are of centimeter-scale, vertically oriented, elongated crystals. They will precipitate once at the bottom, crystal overgrowth forms vertically elongated crystals. During the higher salinity phase in an evaporative system, the elongated halite crystals will grow with hollow depressed faces and pronounced raised corners and edges. Desiccation of halite crusts results in repeated dissolution (creating dissolution cavities) and precipitation and extensive early re-crystallization (see, Schreiber & El Tabakh, 2000). Efflorescent crusts develop by direct crystallization onto sediment grains as a result of the evaporation of the brine drawn up by capillary forces. Gypsum is associated with halite and usually precipitates as tiny prismatic needles in hyper-saline water bodies. In general, evaporite crusts form and dissolve during seasonal to inter-annual fluctuations.

Conclusions

The desert sedimentary sub-environments are very sensitive areas and their geomorphology depends on various environmental factors. The playa-lake level fluctuation is one of these factors in desert systems, which controls the desertification by interaction between fluvial, aeolian and playa lake environments. As an example, in the Abarkoh Basin, the geographic position of the marls and travertine deposits of the lacustrine origin represent a higher lake level and the considerable lateral extent of the palaeo-shoreline. Fluctuation in the groundwater/playa-lake level resulted in a change in aeolian landscape and development of a sandy saline pan. Salt-encrusted sand flats covered the major areas of the playa and the aeolian sediments inter-layered with halite and gypsum crusts. Cumulate halite crystals are forming in present day water table (>1 m subsurface), where the playa lake level was at the surface in 1996. Sand dunes have shifted and partly stabilized toward the north-west where the ephemeral streams drain into the playa fringe. It has also resulted in a general negative sediment budget and the generation of a deflationary surface at most parts of the studied area.

Acknowledgements

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Floodwater effect on infiltration rate of a floodwater spreading system in Moosian, Iran

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Abstract

Uneven rainfall distribution in time and space as well as the low amount of rainfall has made the farmers to overuse the ground water in order to manage more reliable farming in the southwestern plain of Ilam province in Iran. In this scenario, ground water recharge has an important role in secure farming. One way to increase ground water quality and quantity is a floodwater recharging system. However in practice, like many other natural resource projects, this system has some real difficulties. Among the main difficulties is clogging phenomenon, which occurs through sedimentation by fine particles over the surface of water spreading systems. In this study a floodwater-spreading system was selected to measure and monitor the variation of the infiltration and clogging phenomenon. The vertical variation as well as flow direction variation of the infiltration was studied. The study showed that the sedimentation significantly decreased the surface infiltration of the desilting basin when compared with the data obtained from the control points. The control points were selected on the intact area where the soil and geomorphic surface were similar to the selected sites. Removal of the top 10 cm of the natural surface beneath the sediment showed that the infiltration rates were significantly increased. Therefore, in order to decrease the adverse effects of sedimentation on the infiltration rate in the desilting basin, the recent sediment of the basin should be removed and the top 10cm of the natural surface, below the removed sediment, should be plowed.

Introduction

In the arid region with uneven distribution and inadequate rainfall it is possible to increase underground water availability by floodwater spreading. In Iran, there are about 30 billion cubic meters of runoff flowing in the intermittent dry waterways, which can not be economically controlled by constructing expensive structures. Floodwater spreading system is not expensive and it does not take much time to be constructed. The system however has the problem of sedimentation that most of the big- and medium-size dams are facing. The sedimentation not only reduces capacity of the system but also its infiltration rate.

In 1997, a floodwater spreading system was constructed in southwest of Dehloran plain in Ilam province of Iran with a total area of about 5000 hectares. It has been in operation since then with an area of 3000 hectares. In this part of the plain, 157 deep and semi deep water wells were in use with a total of 73.5 million cubic meters per year. After five years of the construction of the floodwater spreading system, the water table monitoring showed a balanced water table in this part of the plain.

Several studies have been done with respect to the clogging and sedimentation effects on the floodwater spreading systems in Iran in recent years. Rezai and Mossavi (1998) studied the effects of sediment removal from some basin surfaces of the floodwater-spreading basins in Esfahan. The infiltration rate was measured by using double ring method in this study. The results showed significant difference in the rate from the control basin without any manipulation to that when 15 cm of the natural underlying material was removed in addition to the removal of the recent sediment. This study demonstrated the effect of clogging because of the sediment. In general, the clogging reduced the infiltration when the sedimentation ranged from 10 to 40 cm depth. The degree to which the infiltration was reduced depended on the particle-size distribution of the suspended materials of the floodwater, total sediment load, and the pore geometry of the underlying materials. Basirpour (1995) measured the infiltration rate in Remsheh floodwater system and showed that after a certain depth of sediment, there was no effect of further increase in sedimentation on the infiltration rate of the spreading basins. He noted that the infiltration rate was reduced in the first month of sedimentation and then remained relatively constant. Kamali (1998) measured the infiltration rate of several floodwater- spreading systems in Khorasan province, which received sediment from different lithological materials, and found that infiltration rates were reduced by nearly 2.5 times due to sedimentation as compared to the control. Shariati (1999) studied the system in Damghan province and showed that the infiltration rates in floodwater-spreading basin were nearly10 times lower than in the control.

Hossieni (1998) studied the effect of formation of petrogypsic and petrocalcic horizons in desert soils of Damaghan on the infiltration rates and found that soils with these horizons had four times lower rate of infiltration than the soils without these horizons. Therefore, the nature of the soil profile should be studied before any comparison of the infiltration rates is done. The purpose of this study was to monitor the infiltration changes in the runoff direction as well as in the soil profiles as affected by sedimentation in the floodwater-spreading system in the Dehloran plain in Ilan province of Iran.

Characteristic of the region

The Moosian alluvial plain is located in the Dehloran County in Ilam province of Iran. It is located between 32º 27’ and 32º 35’ N latitudes and 47º25’ and 47º42’ E longitudes. This plain is formed from alluvium in a syncline, in northwest to southeast direction. The elevation of the plain is about 104 m from the sea level. The flood spreading system is located on a piedmon plain, which is generally formed from the coarse gravely materials, derived from Bakhtiyari formation. Sediments in the floodwater are generally derived from Lahbari member of Aghajari formation (Aj). This member of Aghajari consists of light brown marls and sandstones, which would explain why the texture of the sediments of floodwater ranges from light to medium. The mean annual temperature is 31.4º C and the mean annual relative humidity is 39.9%. The mean annual rainfall is 264.4 mm with a range of 422 to 174 mm. The mean annual evaporation rate is 3553 mm.

Methods

To measure the infiltration rates, 12 points were selected as shown in Figure 1. Of these points, three points were in the north of the system where no floodwater spreading is done and served as control (T0), three were on the sedimentation basin (T1), three in the levelled spreading channels (T2), and finally three in the spreading basins (T3) to the south of the system.

Five different kinds of surfaces were used for studying the infiltration rate at each location. They are designated as Ds (recent sediment surface), D0 (natural surface, the recent sediment was removed), D1 (10 cm below the natural surface), D2 (20 cm below the natural surface), and finally D3 (30 cm below the natural surface). Thus, there were 20 different treatment combinations of four

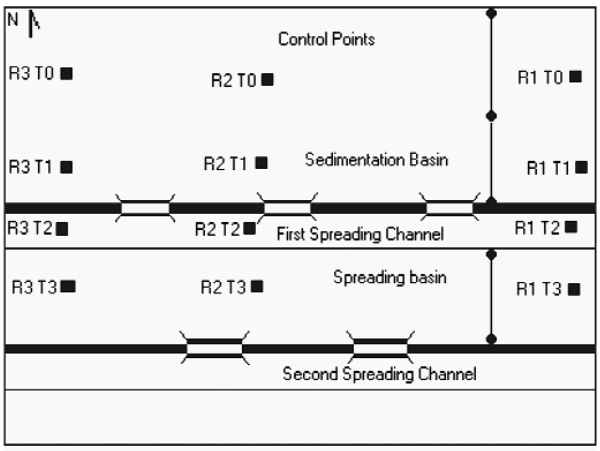

Fig. 1. Layout of the test area. To, T1, T2 and T3 are the locations for control, sediment basin, spreading channel and spreading basin, respectively. R1 to R3 refer to the replications.

locations and five kinds of surfaces at each location. The treatment combination T1Ds for example denotes the location where no flood spreading is done (control) and the surface is the recent sediment since the system was constructed.

The infiltration measurements were done in triplicates with double ring method (Hais et al., 1956). The approximate distance between the measurement points in the east to west direction was 500m. Due to the gravely texture of the natural surface it was difficult to push the rings in the soil. Therefore, only bottom 10 cm of the rings was pushed into the surface and then covered by fine earth to prevent leakage. Samples were taken for the topsoil and/or subsoil, where they were present, for the determination of particle size distribution. These samples were taken where the measurements of infiltration were done. For statistical analysis of the data the SPSS statistical package was used.

Results and discussion

The results of particle size distribution analysis for the soil samples collected from different locations (control as well as different parts of flood water spreading system) are shown in Table 1. The clay percentage in the top and subsoil was less than 12 percent. The average clay percentage in the top soil was 5 percent. This indicates a light textured topsoil and subsoil at the selected locations. Low clay content in the top soil is a positive factor for a floodwater spreading system in this region. As the samples tested also included locations where flood spreading had been occurring, a lack of high clay content would also mean that the sediment load of floodwater did not have high clay content. Considering the characteristics of the natural surface and the sediment in the spreading system, one would expect a high infiltration rate and therefore good recharging of the water table.

The results of 54 of infiltration determinations are shown in Table 2. For each of the surface treatment and location combinations, three determinations were made and the average of the three determinations is given in Table 2. The average values for the locations are given in the last column of the table.

The difference in the average infiltration rate of control point (T0), floodwater spreading (T1), levelled spreading channels (T2), and spreading basin (T3) was not significant ($P < 0.05$). The results also revealed that removing the recent sediments (D0) increased the infiltration rate in the sedimentation basin (T1).

The average effects of surface treatments on infiltration rates are shown in Table 3. The variations

Table 1: Particle size distribution (%) in the soil samples from different depths at various locations.

Location No.	Depth (cm) mm	Clay <.002 mm	Silt .002 - .075 mm	Fine Sand 0.075-2.000 mm	Coarse Sand 2.000–70.000
4	0-15	12	86	2	0
5	0-20	12	86	2	0
6	0-10	12	81	4	3
10	0-15	3	57	14	26
3	0-12	6	51	27	16
2	0-20	7	46	25	22
12	0-15	4	45	16	35
1	0-10	6	44	24	26
8	0-17	10	42	30	18
9	0-10	4	25	20	51
Average		5	35	24	36
7	0-5	4	20	18	58
1	10-40	2	18	36	44
3	12-30	0	0	17	83
4	15 -100	0	0	40	60
7	5 - 100	0	0	44	56
9	10 - 100	0	0	40	60
11	15 - 100	0	0	47	53

Table 2: Replication wise and average infiltration rate for different treatment combinations (surface treatment x location) and average for locations.

	Infiltration rates (cm/h)				
Treatment combinations	**R1**	**R2**	**R3**	**Average**	**Location average**
T0D0	6.2	2.1	6.2	4.8	Control (T0)
T0D1	9.1	9.5	8.7	9.1	=31.6
T0D2	27.4	71.5	45.8	48.2	
T0D3	32.1	62.1	99.3	64.5	
T1Ds	1.2	1.0	1.1	1.1	Sedimentation
T1D0	44.7	20.0	16.2	27.0	basin (T1)
T1D1	66.7	10.02	84.2	50.3	=43.2
T1D2	73.5	15.2	77.1	55.3	
T1D3	178.5	24.8	44.5	82.6	
T2Ds	1.7	2.2	1.2	1.7	Levelled
T2D0	4.7	2.9	6.6	4.7	spreading
T2D1	28.2	13.2	74.7	38.7	channels (T2)
T2D2	25.7	11.0	86.5	41.1	=27.0
T2D3	46.8	35.5	64.5	48.9	
T3D0	10.8	3.0	6.8	6.9	Spreading
T3D1	47.1	38.4	47.0	44.2	basin (T3)
T3D2	48.9	40.2	60.8	49.9	=37.9
T3D3	55.9	55.2	41.8	50.9	

Table 3. Average basic infiltration rate as affected by surface treatments

Surface treatment	**Average infiltration rate (cm/h)**
Recent sediment surface intact (Ds)	1.37
Natural surface (D0)	10.8
10 cm below the natural surface (D1)	36.3
20 cm below the natural surface (D2)	48.1
30 cm below the natural surface (D3)	61.7

in the infiltration rates indicated that the permeability increased with increasing depth of removal of natural surface. The LSD test indicated that the difference between the D0 and D1, D2, and D3 was not significant. However, the difference between Ds and D1, D2, and D3 was significant at 1 percent level of probability.

Conclusion

The study revealed that sedimentation had great impact on surface permeability of sedimentation basin and spreading channel in comparison with the control point and had no significant impact on spreading area. With the scraping of sediments that got deposited during the last five years of the project, and plowing to the depth of more than ten centimeters can cause an increase in permeability of basin and this will lead to effective ground water recharge.

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Analysis of wind erosion on the Columbia Plateau in the United States

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Abstract

There are about 3,348,600 hectares of agricultural drylands in the inland Pacific Northwest; at least half of the dryland is kept fallow for as long as 14 months to conserve soil moisture. Top 10-20 cm fine soil mulch is formed in several fallow fields. The fallow period coincides with the windy season, making the surface more susceptible to wind erosion. Conventional fallow field is often blamed as one of the major sources for dust and PM10 emission in this region. Detailed analysis and documentation of soil loss from agricultural drylands during significant wind event were rarely conducted in this region. Therefore, a significant soil wind erosion event that occurred on 28 October 2003 was carefully analyzed and assessed in this study. A 9-ha conventional fallow field was selected in the eastern Washington state of the USA. Soil and PM10 loss along with meteorological parameters were monitored over various heights above surface at three positions in the field using creep and airborne soil sediment collectors Big Spring Number Eight (BSNE), high-volume air sampler and tapered element oscillating microbalances. Aggregate size distribution for both parent soil and sediment in BSNE was characterized by rotary and sonic sieve. Silt loam is the dominant soil in the region. The erodible fraction of the silt loam at the experiment site comprised of 62% suspension-size and 38% saltation-size aggregate; however, only 7% of the total soil discharge was of saltation-size. Particles less than 45 µm, which could contribute to long-range sediment transport, constituted 46% to 70% of the BSNE sediment. It indicated that suspension not saltation is the dominant erosion process in the region. Control practices should be focused on minimizing suspension component. Soil and PM10 loss from the dryland fallow field during the significant storm were 2317 and 212 kg ha^{-1}. Horizontal flux increased with distance with flux about 15 times greater at the midfield position and 25 times greater at the leeward position than at the nonerodible boundary. PM10 discharge at the midfield position was 61% of that at the leeward position. Soil discharge did not reach transport capacity, indicating that field layout could contribute to wind erosion control. The threshold velocity of PM10 emission at 2 m and 5 m were 6.6 and 9.8 m s^{-1}, respectively.

Introduction

Wind erosion is of particular concern for agricultural production, air quality, visibility and human health in arid and semiarid regions all over the world. Wind removes the fertile surface soil, which degrades soil quality and therefore reduces agricultural sustainability. Off-site transport of wind blown soil can severely affect crop emergence and damage young plants, which often requires reseeding of fields. Dust, such as PM10 or 2.5 (particulates less than or equal to10 or 2.5 microns), emitted from dry lands significantly influences the quality of air at local and regional scales. Blowing fine dust also affects various aspects of human health such as the respiratory system. In addition, wind erosion can greatly reduce visibility, which often severely affects the transportation industry.

There are 3,348,600 hectares of agricultural lands in the inland Pacific Northwest where average annual precipitation is 600 mm or less and no irrigation is used (Schillinger et al., 2003). In this dryland region, most rainfall occurs in the winter and outside of windy season; peak gusts of wind exceed 20 m s^{-1} every two years or 30 m s^{-1} every

10 years (Wantz and Sinclair, 1981). Summer fallow is widely practiced on at least half of the dryland area to conserve soil moisture. Soils in this region are dominated by fine particles. These characteristics render the soil particularly susceptible to wind erosion. In fact, wind erosion has long been a severe problem in the Pacific Northwest. Saxton (1995) reported that wind erosion was a major cause of non compliance of the US Environmental Protection Agency (US EPA) PM10 National Ambient Air Quality standard (150 µg m^{-3}). Drylands were blamed as one of the major sources for dust emission. Therefore, the objective of this study was to monitor and assess soil loss and PM10 emission from conventional 'winter wheat-summer fallow' fields within the Columbia Plateau region of the Pacific Northwest.

Materials and methods

The Columbia Plateau is a 75,000 km^2 region, located in north-central Oregon and south-central Washington. Large areas of the plateau are relatively flat and about half of this region receives less than 300 mm annual precipitation. Near surface soil water content can vary from 0.01 to 0.05 m^3 m^{-3} in the autumn wind season (Schillinger and Bolton, 1996; Schillinger et al., 1998). The predominant soil type is silt loam and the depth of loess deposits ranges from a few centimeters to 76 m (Busacca, 1989). The organic matter content in top 10 cm surface soil is less than 1% (Schillinger et al., 2003). The highest wind velocities occur either in spring or autumn. The most common dryland cropping system on the Columbia Plateau is a 'wheat-fallow' system with a 13-month fallow period that begins after harvest in August. Keeping fields fallow for an extended period exposes the surface soil to high winds in spring and autumn.

A 9 ha experimental plot was selected 18 km northwest of Washtucna, Adams County, Washington, USA (46°50'N, 118°30'W, elevation=510 m) (Fig. 1). The plot was flat with a 1.9% slope and located in the north-east corner of a 300 ha field. Winter wheat stubble was maintained on the south and west boundaries of the plot; this provided a non erodible boundary when winds were from the south or west. The east and north sides of the plot were in Conservation Reserve Program (CRP) and wheat, respectively. The soil type was Ritzville silt loam (Andic Aridic Haplustoll) with 30% sand (0.02-2.0mm), 20% very fine sand (0.05-0.1mm), 63% silt and 7% clay in the top 5cm of the soil profile. Details of topsoil chemical, physical and hydrologic properties are given in Table 1. The plot was maintained in fallow; the plot was disked on 10 April and rod-weeded on 6 May, 18 June, 4 September, 18 September, and 21 October 2003 to control weed infestations as well as to maintain an erodible surface.

The experimental plot was instrumented to continuously monitor meteorological conditions, total soil movement, and PM10 emissions across the plot during 2003 dust storm season (Fig. 2). Soil loss and PM10 emissions within the plot and across the boundaries of the plot were determined from instru-

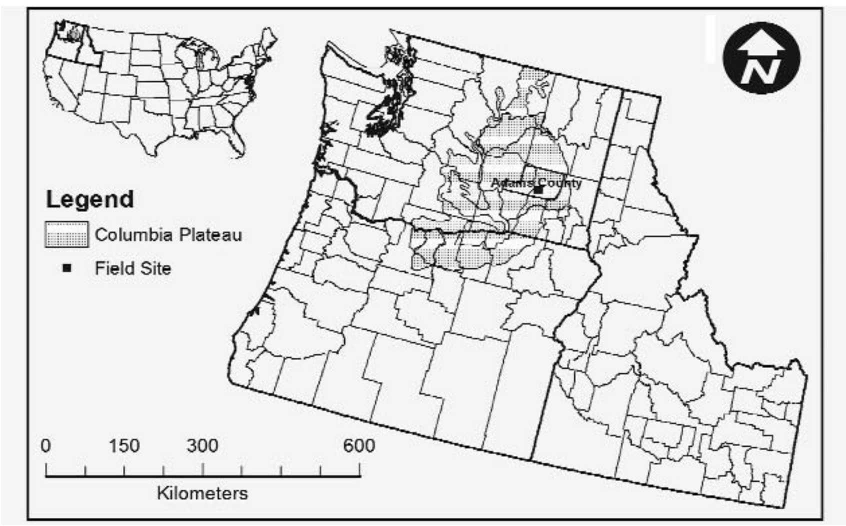

Fig. 1. Location of experimental site monitored in 2003.

mentation clusters located within the plot. Wind direction at the site is predominately from the south and west (Wantz and Sinclair, 1981). Therefore, an instrumentation cluster of PM10 and BSNE samplers was deployed at the southwest, middle, and northeast positions of the plot to assess soil moving into the plot from a non-erodible boundary and that leaving the plot (Fig. 2).

Time-integrated concentrations of PM10 were monitored with two opposing-jet, constant flow high-volume air samplers (HiVols) (Model PM 10; Graseby Andersen Division; Smyrna, Georgia). The samplers are US EPA approved and have an approximate lower operating limit of 5 µg m^{-3} and an upper operating limit of about 1000 µg m^{-3} (Lodge, 1989). The units were mounted at 3 and 5 m above the soil surface at each position in the plot and were activated to sample the air stream when winds were over 6.4 m s^{-1} at a 3m height for 10 minutes. Conversely, the HiVols were deactivated when the wind speed was less than 5 m s^{-1} for 15 consecutive minutes. High volume sampler filters were removed after each high wind event; the filters were equilibrated to standard laboratory conditions prior to weighing.

Tapered element oscillating microbalances (TEOM: Patashnick and Rupprecht, 1991) were installed at the leeward position in the plot. The TEOM is an active sampling technique and an accepted method for measuring PM10 concentrations at urban sites. PM concentrations were monitored continuously with TEOM units (Model 1400ab, Rupprecht & Patashnick Co., Inc.; Albany, New York) fitted

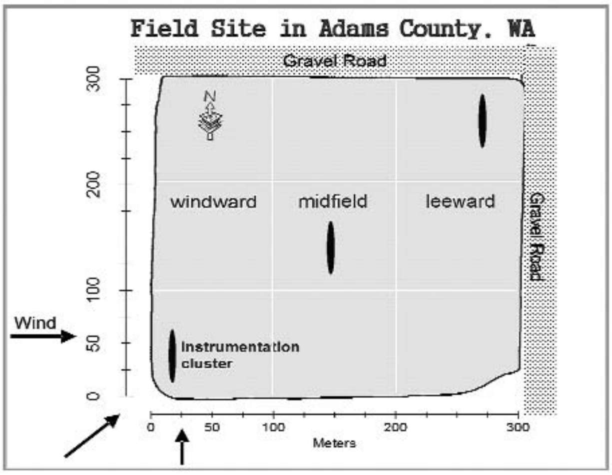

Fig. 2. Layout of experimental plot and instrumentation in 2003.

with PM10 cut-off inlets. Inlets were placed at 3 m and 5 m heights. A microprocessor recorded concentrations continuously at 10-minute intervals. The TEOM's provide additional capabilities in characterizing real-time PM10 emissions.
Saltation and suspension were measured using 6 sets of BSNE (Fryear, 1986) airborne soil collectors arranged on a 3 x 3 m grid at the middle and leeward positions in the plot. Three sets of BSNE were installed along the west and south boundary of the plot. A cluster consisted of 5 BSNEs mounted to a pole at heights of 0.1, 0.2, 0.5, 1, and 1.5 m. Creep was measured using two creep samplers (USDA/ARS; Big Springs, Texas) that were placed at ground-level. Sample collections were periodic depending on the occurrence and magnitude of high wind events. Samples were air-dried only if the BSNE samplers had collected water during the sampling period. A mean sample mass was calculated at each collection height for each field position.

An automated meteorological station was deployed at the leeward position in the plot to continuously measure wind speed and direction, precipitation, solar radiation, and atmospheric temperature, humidity, and pressure. The meteorological station utilized a data logger (Model 23X, Campbell Scientific Inc., Logan, Utah) to record and control operations. Three-cup anemometers (Model 14A, Met One; Grants Pass, Oregon) and air temperature sensors were placed at heights of 0.1 m, 0.5 m, 1 m, 2 m, 3 m and 5 m. Wind direction (Model 024A, Met One; Grants Pass, Oregon) was monitored at 3 m.

For each position in the plot, sediment catch from BSNE samplers was averaged at the same height and fitted to:

$$q = az^{-b} \tag{1}$$

where q is sampler mass (kg m^{-2}), z is height of the BSNE sampler opening above the soil surface (m), and a and b are fitting parameters (Zobeck and Fryrear, 1986). Sediment discharge was determined by integrating equation 1 from 0 to 1.5 m. Net soil loss from the plot was calculated using a box model by subtracting sediment discharge at the upwind position from that at the downwind position in the plot. Net soil loss was assessed only for high wind events characterized by southerly or westerly winds.

Results and discussion

On the fields maintained in conventional fallow in the Columbia Plateau region, at least 10 cm of topsoil is mulched to prevent evaporation loss. Soil moisture in the top 10 cm of the profile was below 4% (Fig. 3) during the season, thus effectively conserving water in the deeper layers as evidenced by higher water content below the depth of 10 cm. In the course of this experiment, near surface soil water content was stable over time. Bulk density of the top 5 cm layer remained constant over time and averaged 1.05 kg cm^{-3}; bulk density increased slightly with depth down to 25 cm (Fig. 4). Organic matter content was 0.016 kg kg^{-1} in the top 5 cm of the soil profile (Table 1). The soil thus lacks the physio-chemical properties to form large and stable aggregates that might otherwise prevent wind erosion in the region. Wind velocity appeared to be the major driving force of soil erosion in the region.

Four dust storms were observed during 2003 with winds predominately from the south and west. Total soil loss ranged from 43 to 2317 kg ha^{-1} and PM10 emissions ranged from 5 to 212 kg ha^{-1} over these four storms (Fig.5). The largest dust storm occurred on 28 October 2003, and due to the magnitude of this storm, measurements taken during this event were analyzed in detail and reported in the paper.

The dynamic TEOM PM10 concentration versus wind speed at 5 m during the October 28 dust storm is plotted in Figure 6. The relationship is well described as CTEOM=Cu(u-ut), where CTEOM is TEOM PM10 concentration measured at 5m, u is wind speed at 5 m, ut is threshold velocity at 5 m, and C is the empirical dust content. The threshold velocity is defined as the wind speed when emission of PM10 is initiated. As illustrated, the threshold velocity was 9.8 m s^{-1} at 5 m during this dust storm. Concentrations of PM10 increased rapidly when wind velocity was above the threshold velocity. Based on a logarithmic wind profile and an aerodynamic roughness length of 3 mm (Kjelgaard et al., 2004b), the threshold velocity at 2 m was 6.6 m s^{-1}. The magnitude of ut depends upon wind

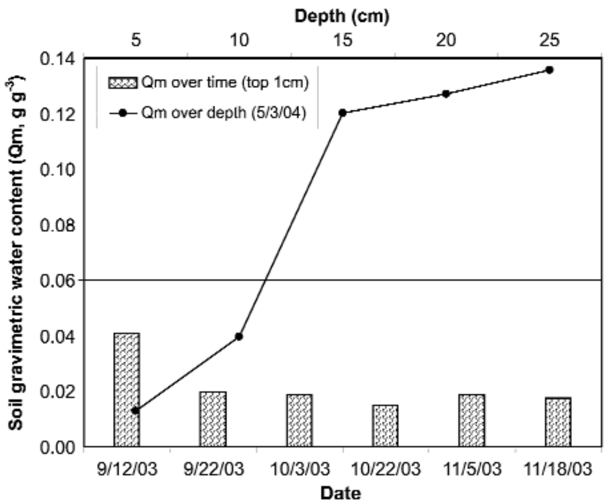

Fig. 3. Soil gravimetric water content versus time and depth in the experimental plot.

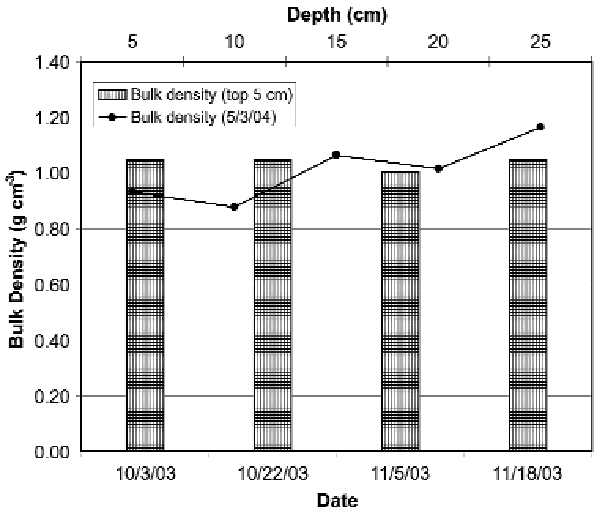

Fig. 4. Soil bulk density over time and depth in the experimental plot.

Table 1. Soil organic matter, calcium carbonate ($CaCO_3$), pH, cation exchange capacity (CEC), saturated water content (θ_s), water content at field capacity (θ_{fc}), residue water content(θ_r), saturated hydraulic conductivity (K_s), air entry matric potential (ψ_e), exponent from the equation relating matric potential to water content (*b*) as developed by Campbell (1974) in the top 5cm layer at the field site in 2003.

Organic matter (kg/kg)	$CaCO_3$ %	pH	CEC (meq/100g)	θ_s (kg kg^{-1})	θ_{fc} (kg kg^{-1})	θ_r (kg kg^{-1})	K_s (10^{-5} m s^{-1})	*Campbell's Eq.ye* (J kg^{-1})	*Campbell's Eq.* *b*
0.0161	<2	5.40	12	0.33	0.19	0.074	0.755	-0.293	4.407

speed, soil type, and surface conditions such as roughness. Kjelgaard et al. (2004a) observed at the same experimental plot a threshold velocity of 8 m s^{-1} and 6 m s^{-1} at 2 m for undisturbed and mechanically disturbed soils, respectively, in 2001 and 2002. The field was rod-weeded on 21 October 2003, one week before the October 28 dust storm Therefore, our ut value was in good agreement with 6 m s^{-1} obtained by Kjelgaard et al. (2004a). This suggests that plot surface during 2003 had changed little compared with the surface in 2001 and 2002.

Horizontal soil flux, or the mass of soil moving across a vertical plane in the plot, was assessed using the BSNE samplers and integrating soil caught by the samplers to a height of 1.5 m above the soil surface. Flux of eroded soil diminished with height above the soil surface and also increased with distance from the leading edge of the field. The nonerodible or windward boundary appeared to be effective in minimizing soil transport into the field (Fig. 7). Horizontal flux increased with distance downwind with flux about 15 times greater at the midfield position and 25 times greater at the leeward position than at the nonerodible boundary (Fig.8). It appears that the discharge of saltation/creep or suspension did not reach transport capacity based upon limited monitoring instrumentation sites (Fig.8).

Analysis of aggregate size distribution for undispersed soil samples taken on 22 October 2003 indicated that the soil was comprised of 17% saltation-size, 28% suspension-size and 55% large immobile aggregates (Fig. 9, Table 2). The erodible fraction consisted of 38% saltation-size and 62% suspension-size. Although both size soil particles were present at the soil surface, the BSNE catch data showed that only 7-8% of the total soil discharge was of saltation-size (Table 2). Since saltation-size particles were readily available at the soil surface, surface roughness (10.8 mm) served as an effective trap and kept the saltation discharge low. Lack of saltators likely suppressed

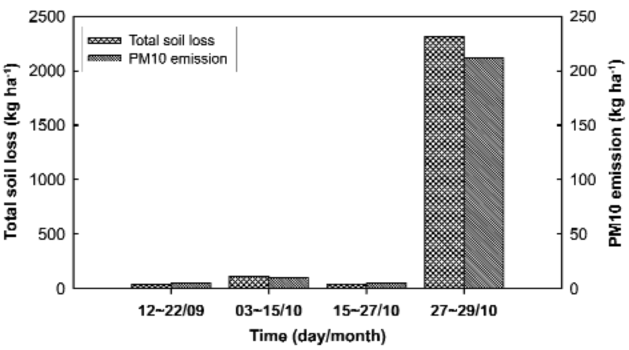

Fig. 5. Soil loss and PM10 emissions during four dust storms in 2003.

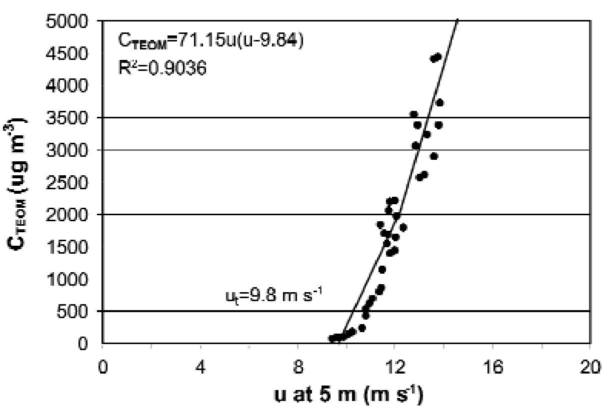

Fig. 6. PM10 concentration at 5 m height (measured using TEOM) versus wind speed at 5 m during the high event on 28 October 2003.

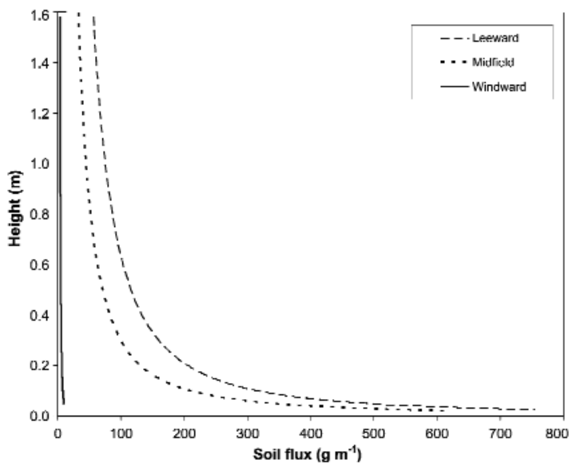

Fig. 7. Horizontal soil flux profile (versus height) at three different positions in the field.

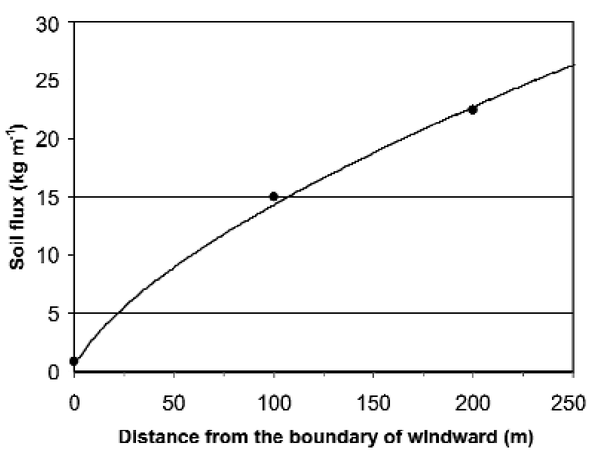

Fig. 8. Soil loss at three positions in the field.

abrasion and thus emissions were driven by direct suspension processes. Kjelgaard et al. (2004a) measured particle size distribution of dispersed samples taken from the same plot and found that 70-80% of the soil particles were suspension size and less than 20% of the particles were saltation-size. Although immobile aggregates were not considered in their analysis, our measured fraction of saltation-size particles was similar to their results. Their observed wind velocity profile indicated little evidence of saltation activity, even during high wind events (Kjelgaard et al., 2004a, b). They suggested that direct suspension is a predominant erosion process while saltation is not a major mechanism of eroding soil or generating dust emissions for loess on the Columbia Plateau. Our measurements provide evidence to support their conclusion as 93% of the sediment in the BSNE was suspension-size particles (Fig. 9, Table 2).

Although the total mass of sediment in the BSNEs at the midfield position was 60% of that at the leeward position (Table 2), the cumulative mass distribution of sediment in the BSNE catch was identical at the midfield and leeward positions (Fig. 9).

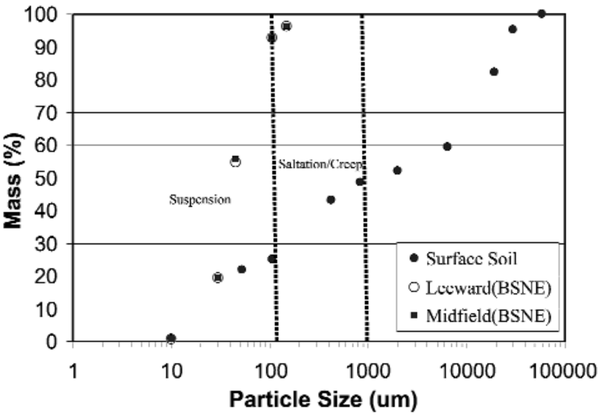

Fig. 9. Aggregate size distribution for Ritzville silt loam and BSNE sediment at midfield and leeward positions as determined by sonic and rotary sieving.

Sonic sieve analysis of the BSNE catch from the 28 October 2003 storm is shown in Figure 9. Since there was no difference in particle size distributions between the midfield and leeward positions in the plot (Fig. 9), mass fractions of various particle size ranges in the BSNE sediment at different heights were averaged as shown in Figure 10. Particles smaller than 45 µm in the BSNE sediment increased with height while the fraction of particles larger than 45 µm in the sediment decreased. Particles less than 45 µm are likely to contribute to long-range sediment transport and constituted 46% to 70% of the BSNE sediment. The US EPA considers total suspension particles (TSP) to be less than 30 µm; this fraction ranged from 16% at 0.1 m to 26% at 1.5 m height. PM10 accounted for only 0.5 to 0.8% of the total sediment in the BSNEs; this small fraction can be attributed to inefficiencies of the BSNE to trap small particles (Shao et al., 1993; Goosens and Offer, 2000; Kjelgaard et al., 2004b). Few particles larger than 100 um were trapped in the BSNEs; about 12,5 and 3% of the sediment at 0.1, 0.2, and 0.5 m heights, respectively, were particles less than 100 µm.

Figure 10b shows the total mass of different particle sizes from eroded sediment at various heights at leeward position. The eroded sediment was largely composed of particles smaller than 45 µm particles. Mass distributions for all particle sizes can be fitted with a power law function. Identical mass-height distributions indicate that transport processes similarly influenced the various particle sizes.

The PM10 discharge was estimated from the BSNE catch and HiVol profiles. Sharratt et al. (2006) measured the PM10 catch efficiency of the BSNE collector for Ritzville silt loam by mass balance in a wind tunnel. Their results indicated that the BSNE catch efficiency for PM10 was 10%. The loss of PM10 was calculated using the method introduced by Sharratt et al. (2006); the method was based on

Table 2. Mass fraction of suspension-size and saltation-size aggregates of BSNE catch and surface soil at the midfield and leeward positions.

Site	Suspension (<106µm) (g)	Saltation (>106µm) (g)	Suspension (%)	Saltation (%)
Leeward	79.9	6.4	92.6	7.4
Midward	48.6	3.8	92.7	7.3
Mid/Lee (%)	61	59		
Surface Soil (%)	28	17	62	38

the catch efficiency, measured wind speed, and PM10 concentration during a dust storm. As illustrated in Figure 11, a pattern of PM10 emission similar to soil loss (Fig. 7) was found. PM10 concentration diminished with height from the surface to 5 m and increased with distance from the windward position. Loss of PM10 between the windward and leeward positions in the field was equivalent to 210 kg ha^{-1} for the October 28 event.

The PM10 discharge was about 0.44 % of total discharge at the leeward position. At the midfield position, PM10 was 0.38 % of total discharge. However, the ratio of PM10 to <840 µm for the surface parent soil was 2.3%, which is far above the ratio of PM10 to total discharge at the both positions. The ratio of PM10 to <840 µm of the parent soil should equal that of the eroded sediment when efficient samplers are used in trapping suspended sediment and abrasion of immobile clods and breakage of saltators is insignificant. The discrepancy in the ratio of PM10 to <840 µm fraction between BSNE sediment and parent soil suggests that process of direct emission might be important in wind erosion on the Columbia Plateau. PM10 discharge increased with distance downwind from the nonerodible plot boundary as was observed for horizontal soil flux. PM10 discharge at the midfield position was 61% of that at the downwind position.

Conclusions

A significant wind event occurred within the Columbia Plateau of the United States on 28 October 2003. This storm resulted in 2317 kg ha^{-1} soil loss and 212 kg ha^{-1} PM10 emission from a silt loam on a fallow field. Horizontal flux increased with distance with flux about 15 times greater at the midfield position and 25 times greater at the leeward position than at the nonerodible boundary. PM10 discharge at the midfield position was 61% of that at the leeward position. Soil discharge did not reach transport capacity, which suggests that field layout could contribute to wind erosion control. The threshold velocity of PM10 emission at 2 m and 5 m were 6.6 and 9.8 m s^{-1}, respectively. The erodible fraction of surface parent soil consisted of 38% saltation-size and 62% suspension-size aggregates, however, as high as 93% suspension-size was measured in the BSNE catch sample. It indicated that suspension rather than saltation is the dominant erosion process in this region. Strategies to control wind erosion should be focused on minimizing suspension component.

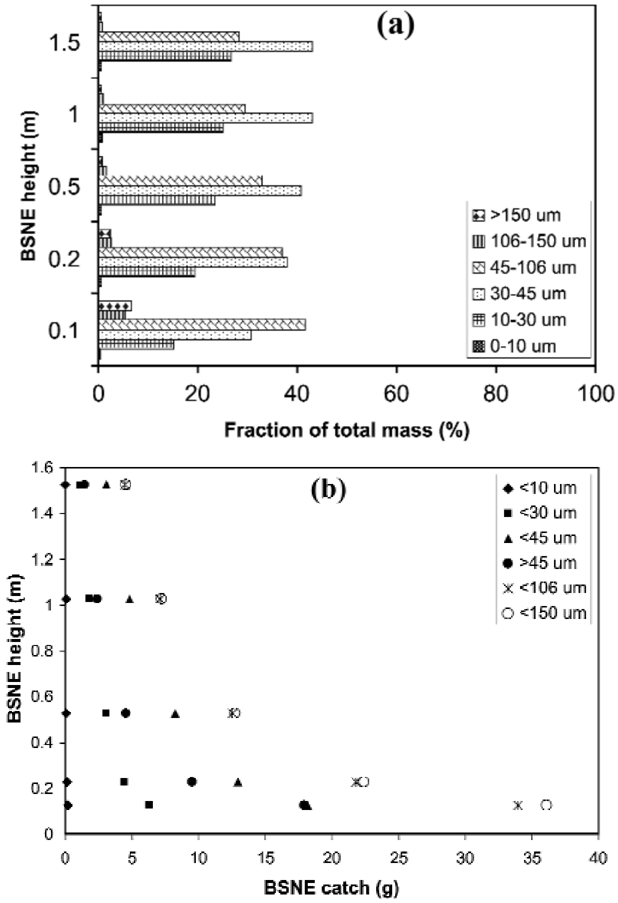

Fig. 10. (a) Particles mass fraction of BSNE catch at various heights for the 28 October 2003 wind event; and (b) BSNE mass distribution with height for all particles.

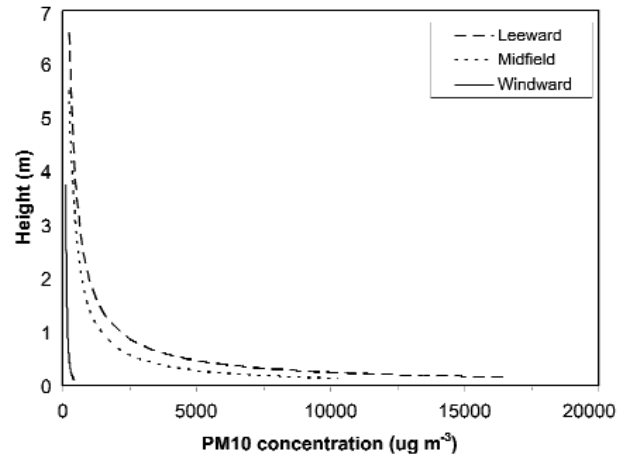

Fig. 11. PM10 concentration profile (versus height) at three different positions in the experimental plot.

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The combined impacts of soil cultivation and crop residue on C and N kinetics in a semi-arid soil

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Abstract

Soil C and N mineralization plays the primary role in supplying nutrients essential to plant growth, especially in dry lands. Soil cultivation and crop residue may affect C and N turnover and hence nutrient availability and ultimately soil conservation in semi-arid soils. This study was conducted to evaluate the combined impacts of soil cultivation and crop residue on C and N turnover in a calcareous soil in Central Iran. Soil samples were collected from 0-15 cm depth in cultivated and uncultivated plots and analyzed for major soil attributes. Wheat (*Triticum aestivum* L.) and alfalfa (*Medicago sativa* L.) residues were collected and analyzed for the chemical composition. Carbon and N mineralization rates were measured using laboratory incubations for 60 days. Results show that in this calcareous soil, cultivation decreases soil organic carbon and total N contents, while C/N ratio, bulk density, pH, and P and K contents remain unaffected. Cultivation resulted in a significant increase in soil C and N mineralization, and therefore high losses of soil organic matter. Data on crop residues indicates that wheat residue has a lower quality than alfalfa residue, and therefore decomposes more slowly. Consequently, plant residue has a significant impact on decomposition rate and nutrient cycling in soils with low carbon levels. It may be concluded that soil cultivation and residue quality have a striking influence on C and N cycling and nutrient contents.

Introduction

Carbon and N mineralization processes are of great importance in maintaining soil quality and fertility, and hence agricultural sustainability. Mineralization processes, particularly in wetlands, are significantly affected by the long-term cultivation and different cropping practices (Qualls and Richardson, 2000; Mendelssohn et al., 1999). Soil management and cropping practices are known to modify factors that affect most biological processes in the soil. Previous studies have indicated that soil tillage and crop residue management affected microbial population, activity, and biomass (Simard et al., 1994; Chander et al., 1997; Islam and Weil, 2000), and soil moisture content, bulk density, porosity, nutrient distribution, and structure stability (Zhang et al., 1988; Unger, 1991; Bouma, 1994; Islam and Weil, 2000; Mikhailova et al., 2000; Lobe et al., 2001). These changes may alter C and N dynamics and have an influence on nutrient uptake by plants. Soil disturbance by plowing disrupts soil aggregates temporarily increasing soil porosity and enhancing mineralization of soil organic matter that weakens soil structure stability (Elliott, 1986; Cambardella and Elliott, 1993; Solomon et al., 2000). Upon cultivating the soil, application of chemical fertilizers, especially N, for improving nutrient availability may also have an effect on biologically-mediated processes (Mahmood et al., 1997; Liang et al., 1998; Kanchikerimath and Singh, 2001; Raiesi, 2004).

The chemical composition and input rates of plant residues are found to affect C decomposition and N mineralization rates. Plant residues with a higher quality (high N contents; low lignin, cellulose and polyphenol contents; and low ratios of C/N and lignin/N) often show high decomposition and N mineralization rates (Coûteaux et al., 1995; Vanlauwe et al., 1996; Lupwayi and Haque, 1998; Raiesi, 1998). Although, residue quality is recognized as a factor affecting C and N mineralization rates, crop residue management practices appear to also influence the processes (El-Harris et al., 1983; Smith and Sharpley, 1990; Graham et al., 2002). Residue management influences soil nutrient cycling by altering the rate of organic matter addition and soil physical / chemical properties which all affect C and N dynamics in the soil (Lupwayi and Haque, 1998; Graham et al., 2002).

Decomposition of plant residue is often limited in wetland soils (Quall and Richardson, 2000, Mendelssohn et al., 1999), and reduced residue decomposition may induce a decrease in N mineralization, and hence reduced N availability for plant growth. Plant residue management is, therefore, crucial in wetland soils. Besides, soil and residue management may interactively influence soil nutrient concentrations that would further affect mineralization of C and N in the soil (Salinas-García et al., 2002).

To provide insight in the role of cultivation and crop residue in soil C and N mineralization, it is necessary to understand the residue decomposability in relation to its chemical composition and more importantly the interaction between soil cultivation and plant residue. Further research is therefore needed to realize the combined effects of cultivation and plant residue quality on C and N mineralization rates. The main objective of this study was to determine the effect of soil cultivation on C and N turnover associated with residue quality and decomposability, and to understand C and N dynamics in soils amended with wheat (*Triticum aestivum* L.) and alfalfa (*Medicago sativa* L.) residues in a calcareous wetland soil in Central Iran.

Materials and methods

Experimental site and treatments

The study was conducted in a recently dried-wetland ecosystem, approximately 80-km southeast of Shahrekord, Central Iran (31° 57´ N latitude, 50° 49´ E longitude, around 2570 m above sea level). The climate of the area is semi-arid, with a mean annual rainfall of 450 mm, most of the rain falling between October and January, and a mean annual air temperature of 10°C with a minimum of -8°C in winter and a maximum of 24°C in summer. About 40 % of the precipitation occurs as snow. As a result of recurrent drought events over the last 50 years, a large area of this wetland site has dried out. The dry part of the wetland has thus been cropped for a several years. Winter wheat (*Triticum aestivum* L.) and alfalfa (*Medicago sativa* L.) are common crops in the area and currently irrigated wheat - alfalfa rotation, with high inputs of chemical fertilizers (mainly N and P), is the dominant cropping system in arable lands. As a result of water scarcity, some areas have not been cultivated and the soil there has remained covered with reeds, which have been affected by die-back. A large area of the wetland site consists of an open shallow lagoon containing live reeds. So, this wetland site served as a suitable area to test the combined impact of cultivation and crop residue on soil properties and residue decomposability.

The experiment was conducted in two fields, one cultivated (CU) for more than 50 years and the other uncultivated (UC). In each field three plots of 0.5 ha each were used for the experiment. All soil forming factors except management were similar for the two fields. Tillage depth in the cultivated soils was about 20 cm, depending on crop type. The cultivated plots had been fertilized (150 kg N ha^{-1} and 50 kg P ha^{-1}, without K), plowed and disked regularly prior to winter wheat and alfalfa planting in fall (mid-October). About 35 % of plant residues including above and belowground parts were returned into the soil annually

Soil sampling was carried out in May. Ten soil samples were collected from the top 0-15 cm of soils in three plots in each of the cultivated and uncultivated fields. Soil samples were mixed thoroughly to obtain a composite sample for each plot. This resulted in triplicate soil samples for each of the two fields. The samples were air-dried at room temperature for 2 weeks, and passed through a 2-mm sieve prior to laboratory analysis. Sand, silt, and clay contents were determined by particle-size analysis using the pipette method (Gee and Bauder, 1986). Soils of the area are calcareous, silty clay, derived from calcite and marl (Luvic Calcisol). Soil pH (H_2O in 1:2.5 ratio) and bulk density, total calcium carbonate, total organic carbon, total nitrogen, extractable P and available K were determined following procedures described by Baruah and Barthakur (1997) and Page (1991). Total porosity was calculated assuming a particle density of 2.65 g cm^{-3}. Soil aggregate stability was determined by the mean weight diameter (MWD) using the wet sieving method described in Kemper (1965).

Residue sampling and analysis

Four replicated samples of wheat straw (W) and alfalfa (A) residues were collected immediately after harvesting from plots cultivated with winter wheat and alfalfa crops in May 2001. The residues consisted of whole aboveground plant material without seed. The samples were air-dried for three weeks at room temperature and mixed carefully, and their moisture content determined upon drying at 70°C. They were then analysed to determine total C, N, and P concentration using methods described by Baruah and Barthakur (1997). The lignin and cellulose contents were determined using the acid detergent fiber (ADF) method using the 1 mm sized materials (Rowland and Roberts, 1994). The moisture content of sieved material was determined by oven drying at 105°C overnight. All concentrations were expressed on an oven-dried weight basis. As there was no significant differences in chemical composition among the four replicates of each of the crop residues, the material from the four replicates were pooled to obtain large composite samples for C and N mineralization experiments.

Carbon and N incubation experiments

The potential C mineralization was studied in a laboratory incubation experiment at constant humidity and temperature for 60 days. A soil sample of 50 g from the cultivated and uncultivated treatments was evenly mixed with a 100-mg sub sample of 1 mm-sized, air-dried residues (equivalent to 4.8 t ha^{-1}) to obtain a homogenous mixture. The mixture was placed in 0.750 L plastic jars, and moistened by adding 5 mL of distilled water to a soil moisture content of about 60% of water holding capacity. Three jars with soil, but without plant residue, were used as controls. Additionally, five containers without soil and plant residue were considered as blanks. All jars were kept overnight in the dark at 25°C prior to incubation. A plastic vial containing 10 mL 0.5 *M* NaOH was placed in the jars for CO_2 absorption, and the NaOH solution was replaced at four-day intervals. Upon replenishing the NaOH solution, the jars were opened and samples were re-aerated to supply adequate oxygen. The evolved CO_2 was trapped in NaOH and the excess alkali was titrated with 0.5 *M* HCl after precipitating the carbonate with 15% $BaCl_2$ solution. The cumulative C mineralization was calculated as the difference between CO_2 evolved from the soil containing residue and CO_2 evolved from the soil without residue. Carbon mineralization was expressed as a fraction of total C initially present in the mixture. The measurements were carried out in triplicate and average C mineralization value determined.

The potential N mineralization was measured using a laboratory incubation procedure under controlled conditions. A 100-mg sub sample of air-dried, sieved residue was mixed thoroughly with 30 g of soil samples from the two cultivation treatments. The mixture was put in 0.750 L plastic containers, to which 5-mL of distilled water was added. Three containers with soil, but without plant residue, were used as controls. The containers were closed tightly and kept in the dark in a temperature-controlled chamber at 25°C. The samples were re-aerated weekly for adequate oxygen supply. Nitrogen mineralization was estimated from the increase in KCl-extractable inorganic N after incubating soil samples for 60 days. Initial inorganic N (NO_3-N and NH_4-N) was analyzed before incubation using the steam-distillation method (Bremner, 1965) after extraction with 1 *M* KCl for 2 hrs (soil: extractant ratio of 1:5). Final inorganic N (NO_3-N and NH_4-N) concentrations were measured at the end of 60 day incubation. The net N mineralization potential was calculated by subtracting initial mineral N from final mineral N for each sample. The cumulative mineralized N was expressed as a fraction of total added N in the residue. All measurements were carried out in five replicates.

Statistical analysis

Differences in soil pH, bulk density, and nutrient contents data between cultivated and uncultivated soils, and also litter quality parameters were analyzed using the t-test procedure. One-way analysis of variance (ANOVA) was then used to determine differences between C and N mineralization as a function of cultivation and plant residue. The original data were either arcsine or ln-transformed for normal distribution before analysis (Gomez and Gomez, 1984). Differences were considered significant only when p values were lower than 0.05, unless expressed otherwise. All statistical calculations were carried out using SigmaStat (Jandel Scientific, Germany). Carbon mineralization data were fitted exponentially, using a one-pool first-order kinetic equation:

$C_t = C_o(1\text{-exp}(-kt))$ (Eq 1)

where Ct is the cumulative C mineralized (mg C g^{-1} C) at time t, Co is the potentially mineralizable C, k is the decay rate (day^{-1}) and t is the time from the start of the incubation (days).

Results

Soil parameters and cultivation

Soil characteristics under the two treatments are shown in Table 1. The texture of the soil under the cultivation treatments was same. Soil cultivation also had no significant effect on soil bulk density, pH, and concentrations of calcium carbonate, extractable P and available K in the soil. However, the total organic carbon (TOC) and total nitrogen (TN) concentration in the soil were significantly decreased by cultivation. In contrast, both cultivated and uncultivated soils had similar TOC/TN ratios. The amount of TOC and TN per unit area was significantly greater in the uncultivated soil, whereas the amounts of extractable P and available K were similar for both soils. The mean weight diameter (MWD) in the uncultivated soils was numerically greater than that in the cultivated soil, but the difference was not statistically significant (p=0.054). Although, total soil porosity was numerically greater in the cultivated soil, but the difference was statistically non-significant.

Chemical composition of residues

The chemical composition and elemental ratios of wheat and alfalfa residues are given in Table 2. The concentrations of TOC were significantly higher in wheat than alfalfa residue. The lignin and cellulose contents in the wheat residue were higher than those in alfalfa residue. The TON concentration was significantly lower in the wheat than alfalfa residues. The values for total P (TP) and total K (TK) were also lower in wheat residue. As a consequence, TC/TON, TP/TON, lignin/TON, cellulose/TON, (lignin + cellulose)/TON ratios were significantly higher in wheat than alfalfa residues (Table 2). The lignin/cellulose ratio of wheat residue was numerically, but not significantly (p=0.08), higher than that of alfalfa residue.

Table 1. Physical and chemical properties and nutrient concentrations of cultivated (CU) and uncultivated (UC) soils (0-15 cm).

Soil Variable	Unit	Cultivated soil (CU)	Uncultivated soil (UC)	p
Clay	(g kg^{-1})	437 (36)	461 (43)	Ns
Silt	(g kg^{-1})	449 (39)	421 (31)	Ns
Sand	(g kg^{-1})	114 (5.0)	118 (8.0)	Ns
$CaCO_3$	(g kg^{-1})	353 (18)	371 (25)	Ns
Bulk density	(Mg m^{-3})	1.55 (0.03)	1.65 (0.04)	Ns
pH (H_2O)	-	7.75 (0.12)	7.87 (0.03)	Ns
Total Organic C (TOC)	(g kg^{-1})	5.80 (0.6)	8.60 (0.4)	*
Total N (TN)	(g kg^{-1})	0.84 (0.04)	1.10 (0.06)	*
Available K (AK)	(mg kg^{-1})	490 (20.1)	453 (19.4)	Ns
Extractable P (EP)	(mg kg^{-1})	34.5 (4.18)	38.8 (5.47)	Ns
TOC/TN	-	6.85 (0.57)	7.8 (0.26)	Ns
TOC/ EP	-	174 (33)	232 (41)	Ns
Total Organic C pool	(kg ha^{-1})	13466 (1430)	21191 (1365)	*
Total N pool	(kg ha^{-1})	1958 (72)	2718 (160)	**
Available K pool	(kg ha^{-1})	1139 (61)	1116 (25)	Ns
Extractable P pool	(kg ha^{-1})	81 (11)	95 (12)	Ns
MWD	(mm)	0.374 (0.01)	0.446 (0.03)	0.054
Total porosity	(cm^3 cm^{-3})	0.40 (0.03)	0.37 (0.04)	Ns

**p<0.05, **p<0.01, ***p<0.001, Ns= not significant, each value represents mean (n=3), standard error of means are included in parenthesis, MWD= Mean Weight Diameter.*

Carbon mineralization

The pattern of cumulative C mineralization over the period of incubation for soil from cultivated and uncultivated treatments is represented in Fig. 1 The cumulative C mineralization showed a linear increase with the incubation period, but the increase was higher during the first 40 days of incubation for soil without and with crop residues (Fig. 1) because of high C availability in the soil and residues, but it decreased afterwards. Generally, the control soil amended with plant residue had higher cumulative C mineralization than the soil not amended with plant residue over the entire incubation period, due to the large amounts of available resources for microbial activity. Alfalfa residue had significantly ($p>0.001$, Fig.1) higher C mineralization than wheat residue during the whole incubation experiment.

The final values of the cumulative C mineralization are presented in Table 3. The cumulative C mineralization in the cultivated soil was significantly higher than that in the uncultivated soil. When averaged across soil cultivation treatments, 6.9 % and 10% of the initial C present in the fresh residue was mineralized in wheat and alfalfa materials, respectively. A significant interaction between soil cultivation and plant residue for the cumulative C mineralization during 60 days incubation was detected. Carbon decomposition in both plant residues was faster in the cultivated than that in the uncultivated soil.

The Carbon mineralization data were fitted using a single-exponential model (Table 3). Uncultivated soils had higher *Co* (potentially mineralizable C) values than cultivated soils, probably because of higher C contents, but k (decay rate)

Table 2. Chemical composition and elemental ratios in wheat and alfalfa residues.

Variable	Unit	Wheat residue	Alfalfa residue	p
TC	g kg^{-1}	476 (11)	390 (7.0)	***
TON	g kg^{-1}	6.2 (0.1)	17.5 (0.5)	***
Lignin (Li)	g kg^{-1}	243 (11)	149 (6.1)	***
Cellulose (Ce)	g kg^{-1}	182 (2.1)	124 (2.0)	***
TK	mg kg^{-1}	48.4 (2.8)	73.3 (3.1)	***
TP	mg kg^{-1}	234 (5.1)	320 (7.5)	***
TC/TON	-	76.9 (2.7)	22.4 (0.7)	*
TP/TON	-	377 (9.6)	183 (6.0)	**
Li/TON	-	39.2 (1.3)	8.50 (0.4)	**
Ce/TON	-	29.3 (0.51)	7.20 (0.29)	*
(Li+Ce)/TON	-	68.5 (1.6)	15.6 (0.6)	**
Li/TC	-	1.34 (0.053)	1.20 (0.044)	Ns

**p<0.05, **p<0.01, ***p<0.001, Ns= not significant, each value represents mean (n=4), standard error of means are included in parenthesis.*

Table 3. Cumulative C and N mineralization in unamended soil and on soil amended with wheat and alfalfa residues. Estimated mean values of model parameters are also presented.

Soil treatment	Crop residue	C mineralization (mg C g^{-1} C)	N mineralization (mg N g^{-1} N)	Co (mg C g^{-1} C)	k (day^{-1})
Cultivated	Wheat	84.20 (0.73) b	10.1 (0.38) e	110	0.0241
	Alfalfa	122.8 (0.74) a	24.4 (0.80) a	276	0.0101
	Soil	62.60 (0.77) d	18.5 (1.50) b	112	0.0130
Uncultivated	Wheat	53.3 (0.70) e	8.5 (0.59) f	74	0.0208
	Alfalfa	77.4 (0.74) c	15.3 (0.50) c	148	0.0129
	Soil	41.7 (0.69) f	11.9 (0.38) d	326	0.0022
Source of variation		p			
Soil		***		***	
Residue		***		***	
Soil × Residue		**		**	

**p<0.05, **p<0.01, ***p<0.001; each value represents mean (n=3), Different letters within each column indicate significant difference at p<0.05, standard error of means are included in parenthesis; Co = potentially mineralizable C, k = decay rate.*

values were lower in uncultivated soils, suggesting that soil organic matter is more humified in cultivated than in uncultivated soils. *Co* values for alfalfa residue were greater than those for wheat residue, while *k* values showed the opposite trend.

Nitrogen mineralization

Table 3 also presents the cumulative N mineralization in cultivated and uncultivated soils with and without plant residues. In agreement with faster soil organic matter decomposition, the cumulative N mineralization in the cultivated soil was significantly higher ($p<0.01$) when in the uncultivated soil. The control soil without wheat residue had higher cumulative N mineralization than the soil with wheat residue at the end of incubation, suggesting wheat residue immobilized N because of relatively high TC/TN ratio of the added material. The soil amended with alfalfa material, however, had significantly higher N mineralization than the soil unamended because of relatively high quality of the added residue.

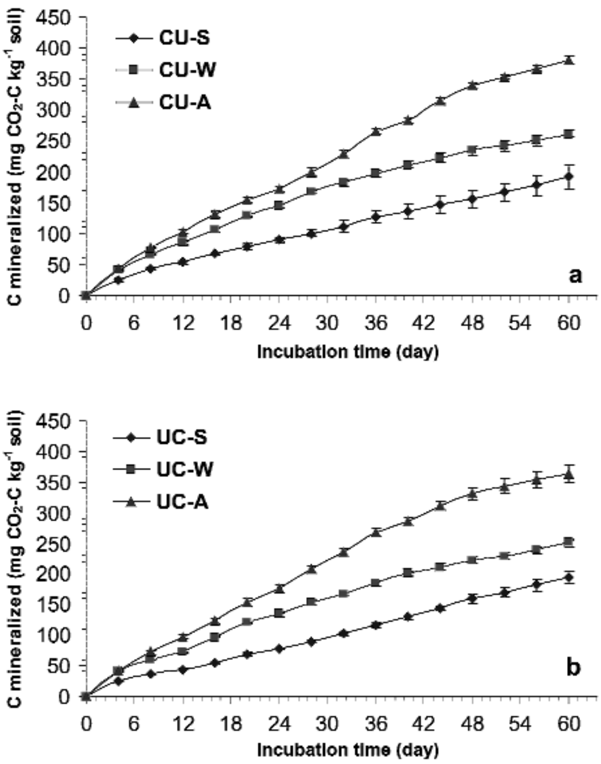

Fig. 1. Cumulative C mineralization in cultivated, (CU), (a) and uncultivated (UC), (b) soils, without crop residue (S) and with wheat (W) and alfalfa (A) residues during 60 days of laboratory incubation at 25°C. Each point represents mean (n=3), bars indicate standard deviations.

Alfalfa residue also resulted in significantly ($p<0.001$, Table 3) higher N mineralization than wheat residue. Averaged across soil cultivation treatments, 5.9% of the initial N present in soil-wheat residue mixture was immobilized, whereas in alfalfa residue 4.7% of the initial N was mineralized at the end of incubation. There was a highly significant interaction effect of soil cultivation and plant residue on the cumulative N mineralization during 60-day incubation. Nitrogen turnover rates in both plant residues were significantly faster in the cultivated than that in the uncultivated soil.

Discussion

Soil bulk density, pH, and concentrations of extractable P and available K (expressed on the basis of either mass per unit mass of soil or mass per unit area) and TOC/TN ratios of the soil appeared to be unaffected by cultivation. These results are in contrast to findings of a previous study by Zhang et al. (1988), which showed cultivation increased the bulk density of the surface soil, and decreased soil pH, exchangeable K and C/N ratio. Zhang et al. (1988), however, found no effect of soil cultivation on total P contents and they explained it on the basis that P was neither volatilized nor as readily leached as N. The non-significant effect of cultivation on extractable P and available K contents in our study are in contrast with results of Carter and Rennie (1982) who showed increased concentrations of extractable P and available K under zero tillage farming system. Soil cultivation in our study, however affected TOC and TN contents, with a significant decrease in soil TOC and TN contents in the surface 0-15 cm depth. Fifty years of continuous cropping and soil cultivation resulted in 47 % of soil organic C loss, which is probably due to the rapid decomposition of native soil organic matter (Fig. 1).

Cultivated soil had about 10 % less TN than the uncultivated soil, even though on average 150 kg N ha^{-1} has been repeatedly added during the period of cultivation. This suggests that cultivation enhanced the process of C and subsequently N mineralization by increasing microbial activity. Previous studies have similarly shown that cultivation of native soils results in a reduction in organic matter and total soil N (Stevenson, 1982, Zhang et al., 1988; Mikhailova et al., 2000; Lobe et al., 2001; Mrabet, 2002). However, Carter and Rennie (1982) reported opposite results. These authors observed no significant change in total organic C and total N between zero and conventional tillage systems of spring wheat in the Canadian prairies. Their uncultivated soil had a relatively low total organic carbon and total N contents for a wetland site, particularly with reed communities. This may reflect either that there was deposition of silt and clay or that there was higher rate of soil C and N mineralization. The higher clay and silt contents (Table 1) in our wetland site, may imply the former phenomena, due likely to preferential removal of silt and clay by accelerated water erosion from the surrounding slopes. Results of this study indicate greater, but insignificant, MWD values in uncultivated soils, showing more stable aggregates, which may be the result of greater amounts of organic C present in the soil. Obviously, high variation in the MWD contributed to lack of statistically significant differences. Other workers (e.g., Filho et al., 2002; Mrabet, 2002) have reported similar patterns and indicated that aggregate stability is greater for no-tillage than conventional tillage systems. Cultivated soils tended to have slightly higher total porosity.

Soil cultivation increased C and N mineralization, inducing lower concentrations of TOC and TN (Table 1). The small increase in soil porosity (Table 1) in the cultivated soils might be responsible for higher rates of C and N mineralization. Previous researchers (Elliott, 1986; Solomon et al., 2000) indicated that cultivation changes soil physical factors influencing microbial processes. Other studies (Mahmood et al., 1997; Liang et al., 1998; Raiesi, 2004) reported that addition of chemical fertilizers and crop remains increase microbial activities. The current results are in agreement with those reported by other workers who found that N additions and continuous disturbance of soil enhanced C and N mineralization (Dao, 1998). Mahmood et al. (1997), for instance, reported that aerobically mineralizable carbon increased under an irrigated wheat-maize cropping system receiving different fertilizer treatments. Also, the cumulative N mineralization over six weeks of incubation was higher for the tilled than for the native soils (González-Prieto et al., 1995). Cabrera and Kissel (1988) measured N mineralized in disturbed and undisturbed soil samples in fallow plots on three different soil types, and found that soil N mineralization was larger in disturbed samples. Thus, 50-years of cultivation had no consistent impact on soil physical properties; however, TOC and TN pool sizes decreased as a result of increased C and N mineralization (Table 3).

Microbial activity in wetland soils is often limited by the availability of substrate and nutrients. This study shows that addition of plant residue to wetland soils generally enhanced C mineralization because of high C and nutrient availability. This is in agreement with results obtained by Wright and Reddy (2001) who reported stimulated heterotrophic microbial activity after additions of substrates containing C, N, and P to Northern Everglades wetland soils. Residue quality has a major influence on the rate of C decomposition, and subsequently the N turnover (Upadhyay and Singh, 1989; Tian et al., 1992; Raiesi, 1998). The current results indicate that wheat and alfalfa residues showed significant differences in most litter quality parameters as well as in C and N turnover rates. Schomberg and Steiner (1997) have shown similar difference in the alfalfa and wheat residues. Alfalfa residue appeared to have a higher quality than wheat residue. Alfalfa residue had also higher cumulative C and N mineralization in laboratory incubation studies, correlating well with chemical compositions. Therefore, including alfalfa crop in farming systems may to some degree counteract the detrimental impact of cultivation on microbial activities in the studied wetland ecosystem. Finally, the results of this study suggest that including a legume species, with fast decomposing residue and the ability to fix atmospheric N_2, in the crop sequence can be used to amplify the synergy of both biologically and chemically fertilized farming systems, and including legume forage in the cropping system may therefore sustain nutrient availability and soil fertility. Crews and Peoples (2004) concluded that obtaining N from leguminous crops is potentially more sustainable than from chemical sources. Crop rotations may also have some effects on microbial activity and N release, although increased N availability may account for only a small portion of the increased production commonly associated with rotations that include legumes (Willson et al., 2001).

Conclusions

The results obtained in the study demonstrate that in this calcareous wetland soil cultivation decreases soil TOC and TN contents, while soil bulk density, pH, nutrient contents and TOC/TN ratio remained unaffected. Cultivation resulted in a significant increase in soil C and N mineralization. These differences may be generally attributed to the impacts of vegetation and soil cultivation (tillage) because other soil forming factors were relatively constant in the wetland site. Yet, it is difficult to make an absolute generalization since the initial soil characteristics might be different for the two treatments. Also, this study indicates that wheat residue decomposes more slowly than alfalfa residue, and therefore N availability may improve for plant growth in an alfalfa cropping system. So, the incorporation of alfalfa residue into the soil may, to some extent, lessen, the negative effects of cultivation on soil nutrient contents and, hence soil C and N mineralization rates. The results further show that plant residue has a significant impact on decomposition rate and nutrient cycling. Therefore, residue quality should be taken into account during soil management. There is however a need to study the combined effects of cultivation and chemical fertilizers on: 1) soil organisms and microbial activities, in particular the dynamics of microbial biomass, and 2) root exudation and the effects of root exudates on C turnover in these wetland sites.

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Characteristics and classification of degraded wind-deposited gypsiferous saline-alkali soils in eastern part of Isfahan, Iran

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Abstract

The degraded wind-deposited gypsiferous saline-alkali soils in the eastern part of Isfahan have developed on the old terraces of the Zayanderud river consisting of old river alluvium covered by eolian deposits. The gypsum is mostly transported by wind from the local eroded old gypsiferous upper terraces of the Zayaderud river. The thickness of the layers formed by eolian deposits is around 20 cm in north and around 80 cm in south. The deposits are loamy in texture, contain 8 to 30 percent gypsum, and are severely saline and alkali. The old river alluvial soils underneath the wind deposits are clayey, massive, dense and show redoximorphic features. In this part of the soil, gypsum and soluble salts are also present, but their amount is much less than those of the eolian deposits. Despite the presence of high amounts of gypsum, secondary gypsum cannot be observed in the studied soils. Therefore, according to the USDA soil taxonomic classification, the soils are classified as "Thapto-Sodic Haplocambidic Typic Haplosalids"at subgroup level. Presence of gypsum and sodium, which are two factors affecting physico-chemical properties of the soils, is not expressed in this name. Classification of the soils based on the World Reference Base for Soil Resources (WRB) is more approipriate, as the soil is classified as "Thapto-Hyposodic Calcaric Regosolic Gypsic Solonchaks (Hypersalic, Aridic, Sodic) as the presence of gypsum and sodium is also expressed. The wind deposits not only restrict the plant growth in the area due to gypsification and salinization of the soils, but also fill the local reservoirs of the sewage refining system, which is located in the study area.

Introduction

In many semiarid and arid areas, the presence of evaporitic basins with gypsiferous marls or gypsum outcrops suggests the origin of gypsum in the soil. Gypsum coming from these sources can be transported by wind (Porta, 1998). Some of the soils of the eastern parts of Isfahan, Iran were studied to know the soil characteristics that limit plant growth. By classifying the soils according to the USDA and WRB classification systems, it was possible to evaluate which classification system best reflects the conditions of the soils.

Materials and methods

The study area is located 30 km away from Isfahan city by the side of the Isfahan-Nain road. It covers an area of 600 ha. The climate of the area is cool desertic with a hot summer. Aridity of the climate, erodibility of the soils, erosive winds and flat topography make the soils susceptible to wind erosion. The maximum wind erosion coincides with the occurrence of erosive winds, from March till May. The period of minimum wind erosion and deposition is during the wet season when the soil surface is moist and at the end of the dry season when the wind speed is less than the threshold for erosion. The south-western and the western winds are considered to be the erosive winds (Karimzadeh, 2002). Old river alluvium covered by eolian deposits form the parent material of the soils.

Fifteen soil profiles were described in the study area based on Schoeneberger et al. (1998) and the physico-chemical soil properties which influence plant growth were determined in the laboratory using the standard laboratory methods. The soils were classified according to the USDA (Soil Survey Staff, 1999) and the World Reference Base for Soil Resources (WRB) (FAO, 2001) classification systems.

Results and discussion

Soil morphological and physico-chemical characteristics

Morphological and physico-chemical properties of the soils are shown in Tables 1 and 2, respectively. In the northern part of the area where eolian deposition is more severe, loess hummocks are 10 to 30 cm high and 1 to 2 m apart. In this part, the thickness of the soil surface layers formed by eolian deposits varies between 20 and 40 cm. Though in the southern part, the severity of the wind deposition at the present time is less, but the surface layers formed by eolian deposits are thicker (50 – 80 cm thick). Silt particles are mostly dominant in the wind deposits and they are in fact loess (Refahi, 1999; Karimzadeh, 2002). The deposits are loamy or silty loam in texture, very pale brown (10YR7/3, dry), slightly hard when dry, non-sticky and non-plastic when wet. They contain 8 to 30 % gypsum. The source of the gypsum is said to be the local eroded old gypsiferous upper terraces of the Zayaderud River located in the NNW-SSW sector (Karimzadeh, 2002).

Below the loess deposits, the soils are clayey, mostly massive, very hard to extremely hard when dry, very sticky and very plastic when wet. These soil properties indicate that the soil is very dense and compacted at this depth. Light olive brown color (2.5Y5/3, moist) of the soil matrix and presence of greenish gray (5GY6/1) and yellowish brown (10YR5/8) mottles reveal that water logging occurs in this part of the area. Here, gypsum is also present, but its amount is much less than the gypsum content of the eolian deposits. The soils are deep and moderately to very severely saline and alkali. Electrical conductivity and sodium adsorption ratio of the soil profiles decrease with increase in depth, ranging between 8 and 190 dS/m and 10 and 210, respectively.

Almost no plant can be grown in the natural soils

Table 1: Morphological characteristics of the soils (reference profile)

Depth (cm)	Matrix color (moist)	Texture[1] (by feel)	Structure[2]	Consistency[3] Dry	Moist Stickiness	Wet Plasticity		Redoximorphic features[4]
0-80	10YR6/4	SiL-L	Massive	SH	VFR	SO	PO	-
80-140	10YR5/4	SiC-C	1co-vcsbk	VH	VFI	VS	VP	-
140-200	2.5Y5/3	SiC	Massive	EH	SR	VS	VP	c,3,P, 10YR6/8; m,1+2, P,10YR4/1

[1] SiL = silty loam, L = loam, SiC = silty clay, C = clay

[2] 1 = weak, co = coarse, vc = very coarse, sbk = subangular blocky

[3] SH = slightly hard, VH = very hard, EH = extremely hard, VFR = very friable, VFI = very firm, SR = slightly rigid, SO = non- sticky, VS = very sticky, PO = non-plastic, VP = very plastic

[4] c = common = 2-20%, 3 = coarse = 5 – 20 mm, P = prominent, m = many = >20%, 1 = fine = <2 mm, 2 = medium = 2- <5 mm.

Table 2: Physico-chemical properties of the soils (reference profile)

Depth (cm)	Texture Sand	Silt %	Clay	O.C.[1] %	CEC cmol (+)/kg	Carbonates %	Gypsum %	pH	EC dS/m	SAR[2]
0-80	-	-	-	0.48	11.0	10.0	26.2	7.8	55.8	86.5
80-140	18.6	45.6	35.8	0.48	7.5	36.5	1.8	7.9	16.5	20.4
140-200	18.6	47.6	33.8	0.30	11.0	41.0	1.9	7.9	15.8	20.0

[1] O.C. = organic carbon

[2] SAR = sodium adsorption ratio.

of the area due to gypsification, salinization and alkalinization by loess deposition, soil compaction and lack of enough aeration in the subsurface soil. The wind deposits not only restrict the plant growth, but also fill the reservoirs of the sewage refining system located in the study area. Mulches and windbreaks are suggested to be used for prevention of eolian deposition.

Soil classification

Using the USDA Soil Taxonomy (Soil Survey Staff, 1999), the soil in the studied area is classified as ‘Thapto-Sodic Haplocambidic Typic Haplosalids’ in which ‘Sodic Haplocambids’ is the buried soil and the ‘Typic Haplosalids’ is the mantle (wind deposited materials). According to the WRB classification (FAO, 2001), the buried soil is classified as ‘Hyposodic Calcaric Regosols’ and the mantle is ‘Gypsic Solonchaks’ (Hypersalic, Aridic, Sodic). Therefore, the whole soil is named ‘Thapto- Hyposodic Calcaric Regosolic Gypsic Solonchaks’ (Hypersalic, Aridic, Sodic).

In the taxonomic name of the materials based on the system of Soil Taxonomy the presence of high amounts of gypsum and sodium in the wind deposited materials, which affects the physico-chemical properties of the soils, is not expressed. This is because of the lack of secondary visible gypsum, one of the requirements of the presence of gypsic horizon in the soils. This requirement for classification is not well suited for soils with wind deposited gypsum because here the origin of gypsum is lithogenic. Herrero (2004) believes that the definition of gypsic horizon by Soil Survey Staff (1999) as an "illuvial horizon in which secondary gypsum has accumulated …" lacks functional interest for soils in areas with ubiquitous gyprock or other gypsum sources because in these cases, the pedogenic or lithogenic origin of gypsum in soils cannot be distinguished.

By using the system of WRB (FAO, 2001) to taxonomically classify these soils the presence of gypsum in the wind deposited materials is reflected. This is because the diagnostic criteria in the definition of the gypsic horizon in this system do not include a reference to secondary accumulation of gypsum, although ISSS Working Group RB states "Primary gypsum such as gypsum rock and mobile gypsum sand are excluded from the definition of gypsic horizons" (Herrero, 2004).

When gypsum is the major component of a soil, the mechanical properties that affect rooting are impaired (Poch and Verplancke, 1997). There is change in consistency due to water content or to heating because of solar radiation (Herrero and Porta, 2000). There are strong differences in the water transmissivity of the horizon and in the soil moisture characteristic curve (Herrero, 2004). All of these properties control the capacity of gypseous soils to support life and their dynamics in relation to time, weathering, and land use. This is the reason why the definition of the gypsic horizon would have to evolve to reflect these properties (Herrero, 2004).

Based on the above mentioned reasoning, the taxonomic name of the reference soil is proposed to be ‘Thapto-Sodic Haplocambidic Gypsic Haplosalids’. Considering that the gypsic horizon is more stable than the silica horizon, one can question the inclusion of the Gypsic or Petrogypsic subgroups within Haplosalids. Thus, Saligypsids or Salidic subgroups in Haplogypsids or Petrogypsids are preferred (Florea and Al-Joumaa, 1998).

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Identification of indicators of salinization processes in Luohui irrigation scheme, China: Part of research to prevent salinization

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Abstract

Salinization is the main problem in Luohui irrigation scheme (52,000 ha) as is often the case in other arid and semi arid areas. In order to identify the indicators of salinization processes in the study area, electrical conductivity of groundwater (ECw), pore water salinity (ECp) and moisture content of surface soil (MC), groundwater depth, elevation, and geographic coordinates were measured at the sites of about 80 wells. Soil samples (from 0 to 10 cm depth) were subjected to laboratory analysis for measuring the salinity of soil saturation extract (ECe) and soil separates. All results were interrelated and analyzed. Accordingly, the indicators of silinization process were: 1) higher ECw (up to 21.1 dSm^{-1}) with in shallower depth (0 to 3 m); 2) relatively higher correlation coefficients between ECw and ECe and ECp for the cases with shallower depth (0 to 3 m); 3) dominance of loam textured soils (63%); 4) higher evaporation (1689 mm/annum) as compared to lesser rainfall (514 mm/annum) leading to salinization due to capillary water rise; 5) agreement between ECw and ECe for some irrigation wells indicating salinization process due to the use of saline irrigation water; 6) agreement between local information and measured higher ECp and MC at specific spots nearby the wells indicating salinization process due to dumping and compacting of dug soil during well sinking; and 7) an increasing trend of ECw in the downstream direction and higher ECw in poorly drained areas indicating the salinization process due to variation in topography and drainage status. To prevent further salinization, lowering the groundwater depth, controlling the dumping of saline soil and managing the use of saline irrigation water are recommended.

Introduction

Irrigation is an artificial application of water to plants to overcome deficiencies in rainfall for crop growth. It has been mainly practiced in arid and semiarid areas where natural rainfall is either inadequate or erratic to fulfil the water demand of the crops. It has significantly contributed to poverty alleviation, food security, and improving the quality of life of rural populations. However, the attention given to proper management of irrigation water in most places is poor, resulting in negative consequences to the environment and threatening the sustainability of irrigated agriculture. The lack or inadequate irrigation and drainage structures and excessive application of irrigation water have resulted in the groundwater table to rise and inevitably contribute to secondary (human-induced) salinization.

Salinization, the build up of salinity in the soil, is a worldwide problem, particularly in the arid and semi arid areas. The high rate of evaporation, little amount of annual rainfall, presence of soluble salts in groundwater and shallow groundwater table in arid and semiarid areas create favorable conditions for the transport of soluble salts from the groundwater to the surface through capillary water rise (Bohn et al.,1985; Levy, 1984). The resulting salinization negatively impacts plant growth directly because of salt effect as well as indirectly by destroying the soil structure. Ultimately, cultivable lands get abandoned leading to environmental degradation. Globally, out of the

230 million hectares of irrigated land, 45 million hectares (about 20%) are already salt-affected (FAO, 2000). Continued salinization would lead to further decline in arable land and accentuate food shortage unless proper remedial measures are taken in time.

Luohui irrigation scheme, the study area, was established 70 years ago as the cotton production center of Shaanxi province, China. This area has been facing salinization problem over the years. Remedial measures are needed to prevent further silinization and rehabilitating the area already salinized. Applying soil conditioners and leaching down the salt by applying additional water, installing surface or subsurface drainage structures, and cultivating salt tolerant crops are the typical measures to mitigate salinization problems. Moreover, the movement of salt through water can also be regulated by controlling the quality of irrigation water and keeping the level of groundwater table deep (Levy, 1984; FAO 1984). Before selecting and installing control measures, however, it is crucial to understand the salinization processes going on in an area.

The 'Core University Program' of Japan-China, which aims at combating desertification in inland China, has been investigating water management and salinization problems as a part of their research thrust. Within the framework of this large project, the main objectives of this specific study were to identify the indicators of salinization processes in the Louhui irrigation scheme area based on the relationship between groundwater salinity, groundwater depth, soil salinity, surface topography, and local practices. The study would allow the categorization of the potential salinization processes and help in recommending suitable preventive measures.

Methodology

Study area

The eastern block of Luohui irrigation scheme, having an area of about 52,000 hectares, is located in the left bank of the Luohui River near its confluence with Wei River (one of the tributaries of Yellow River) in the Shaanxi province of China. It is situated at the foot of the Loess plateau between 34° 45´ 23´´ to 34° 56´ 05´´ N and 109° 45´ 22´´ to 110° 10´ 23´´ E (Fig. 1). The altitude of the area ranges from 335 to 400 meters above sea level.

The climate of the area is semiarid; its average annual rainfall of 513.6 mm is inadequate for productive agriculture. The rainy season is from June to September. The average potential evaporation (1689.3 mm) is about threefold of the annual rain-

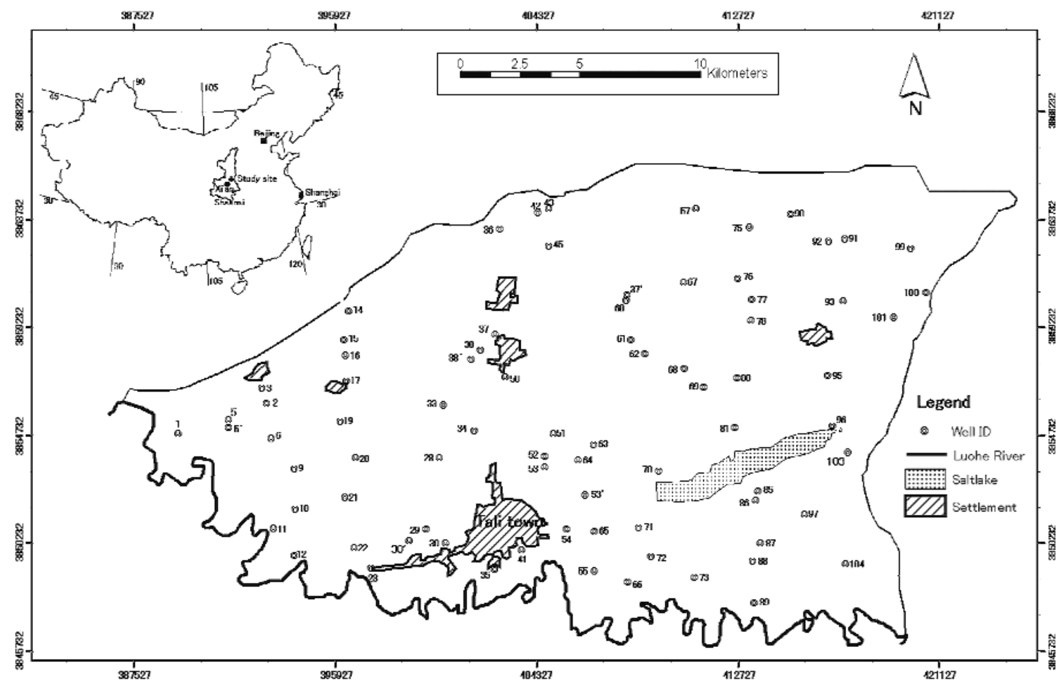

Fig. 1. The location of the eastern block of Luohui irrigation scheme, the study site.

fall (Li, 1995). The irrigated agriculture under such climatic condition is definitely exposed to salinization. Based on the analysis of the data from 1953 to 1966 and 1973 to 1990 provided by Li (1995), salt-affected areas expanded from 1140 hectares in 1953 to 4410 hectares in 1974. After the authorities identified the problem and installed drainage facilities, the salinized area decreased to 3000 hectares in 1980. However, it again increased to 3910 hectares in 1987 due to the aging of drainage structures and lack of effective maintenance. Recent enquiries with the local irrigation officials have revealed that the situation has not improved.

In the study area, there are about 80 groundwater wells serving as observation points and used for drinking water, and various agricultural (irrigation, and preparing insecticide sprays) and non-agricultural (pulp factory and concrete mixing) purposes. Each well has an identification number (Well ID) coded by the local officials. These wells and such features as salt lake (where the drainage from the study area mainly enters), town and villages (settlements) are shown in Fig. 1. The wells are grouped into north, central, southeast, southwest, northwest, and northeast based on their location in relation to the Tali town and their use is also indicated (Table 1).

Materials and methods

The geographic coordinates of the wells were measured using Global Positioning System (GPS). Elevation data were obtained from the management office of the scheme by direct enquiry. Electrical conductivity (ECw) and depth of groundwater were measured at each well from 2002 to 2004. Pore water salinity of surface soil (ECp) and moisture content (MC) were measured in 2004 at a minimum of three points along each of the four directions (north, east, south, and west) and at a distance of 5 to 10 m from each well using a '**w**ater content, **e**lectrical conductivity and **t**emperature' (WET) sensor (Delta-T), which had been calibrated to simultaneously provide data for ECp in mSm^{-1} and MC on % vol basis. Besides, soil sample from topsoil (depth of 0 to 10 cm) in the vicinity of each well were collected for further measurements in the laboratory. Pipette method was employed to work out the percentage of soil separates in each sample and texture classification was done using United States Department of Agriculture (USDA) soil texture triangle.

In summary, ECw, ECp, MC, groundwater depth, and elevation were directly collected from the field and ECe (EC of soil saturation extract) of the collected soil samples were analyzed in laboratory.

Results and discussion

After analyzing the results, the soil salinization was identified to be associated with capillary water rise, use of saline irrigation water, dumping saline soil excavated during well digging, and the variations in surface topography and drainage status. The identified indicators of each of these salinization processes are discussed and presented below.

Capillary water rise

Capillary water rise is the movement of water due to its adhesive and cohesive forces. It rises up through capillary pore until the weight of water counterbalance these two forces (Brady, 1990). During capillary water rise, salt is transported to the soil surface in the form of solution and then water evaporates to the atmosphere while salt remains and accumulates through time in the soil.

Relationship between groundwater salinity and groundwater depth

The groundwater quality depends on the quality of water entering from the surface to the groundwater aquifer as well as on the reaction of the groundwater with the minerals existing in the rock, where the chemical nature of the rock by itself varies laterally and vertically at depth and through time (Appelo and Postma, 1996). The dissolved minerals in the groundwater are controlled by the type of minerals the aquifer is composed of, the length of time that the water is in contact with the minerals (residence time), and the chemical state of the groundwater (Nelson, 2002). The chemical state of groundwater is affected by factors like pH, temperature, and fluctuation of groundwater level.

The temperature of the groundwater in the wells of the study area varied from minimum of 15°C to maximum of 23.6°C. In this temperature range minerals can easily dissolve and the difference of

Table 1 The list of groundwater wells in the eastern block of Luohui irrigation scheme

S.No	Well ID	Location	Purpose	S.No	Well ID	Location	Purpose
1	36	north	drinking	41	20	southwest	irrigation
2	42	north	insecticide mix.	42	21	southwest	irrigation
3	43	north	insecticide mix.	43	22	southwest	irrigation
4	45	north	measurement	44	23	southwest	irrigation
5	37	central	measurement	45	29	southwest	irrigation
6	38	central	irrigation	46	30	southwest	industry
7	38’	central	irrigation	47	30’	southwest	pulp industry
8	50	central	concrete mix.	48	35	southwest	irrigation
9	33	central	irrigation (rare)	49	37’	northeast	irrigation
10	34	central	irrigation	50	57	northeast	insecticide mix.
11	28	central	irrigation	51	60	northeast	irrigation
12	51	central	measurement	52	61	northeast	measurement
13	52	central	irrigation	53	62	northeast	irrigation
14	53	central	irrigation (rare)	54	67	northeast	irrigation
15	53’	central	irrigation	55	68	northeast	irrigation
16	63	central	irrigation	56	69	northeast	irrigation
17	64	central	irrigation	57	75	northeast	insecticide mix.
18	41	southeast	irrigation	58	76	northeast	insecticide mix.
19	54	southeast	irrigation	59	77	northeast	measurement
20	55	southeast	irrigation	60	78	northeast	drinking
21	65	southeast	irrigation	61	80	northeast	irrigation
22	66	southeast	irrigation	62	81	northeast	irrigation
23	70	southeast	measurement	63	90	northeast	irrigation
24	71	southeast	irrigation	64	91	northeast	drinking
25	72	southeast	irrigation	65	92	northeast	irrigation
26	73	southeast	irrigation	66	93	northeast	irrigation
27	85	southeast	irrigation	67	95	northeast	irrigation
28	86	southeast	irrigation	68	96	northeast	irrigation
29	87	southeast	irrigation	69	99	northeast	drinking
30	88	southeast	irrigation	70	100	northeast	irrigation
31	89	southeast	irrigation	71	101	northeast	irrigation
32	97	southeast	drinking	72	2	northwest	irrigation
33	103	southeast	irrigation	73	3	northwest	irrigation
34	104	southeast	irrigation	74	5	northwest	irrigation
35	1	southwest	irrigation	75	5’	northwest	irrigation
36	6	southwest	irrigation	76	14	northwest	irrigation
37	9	southwest	irrigation	77	15	northwest	irrigation
38	10	southwest	irrigation	78	16	northwest	irrigation
39	11	southwest	drinking	79	17	northwest	irrigation
40	12	southwest	irrigation	80	19	northwest	measurement

Note:
1. All wells are used for the mentioned specific purpose as well as for measurements;
2. Irrigation (rare) means that the use of the wells for irrigation is restricted to rare case;
3. Insecticide mix. & concrete mix. mean that the water from the wells is used for preparing insecticidal sprays and for making concrete.

5 to 10°C can cause change in total dissolved solids (TDS) of water. The pH influences the magnitude of TDS; lower the pH, higher the TDS content (Nelson, 2002). It ranged from 7.2 to 8.6 in the study area. Due to such variations, the ECw values in the study area ranged from 0.53 to 21 dSm-1 in August 2002, 0.97 to 20.7 dSm^{-1} in March 2004, 0.96 to 20.3 dSm^{-1} in June 2004, 1.02 to 21.1 dSm^{-1} in August 2004 and 0.98 to 21dSm^{-1} in October 2004. On the other hand, the ECw had inverse relationships with groundwater depth (Fig. 2); the ECw increased as depth decreased. Under this general trend, higher values were concentrated up to about 10 m groundwater

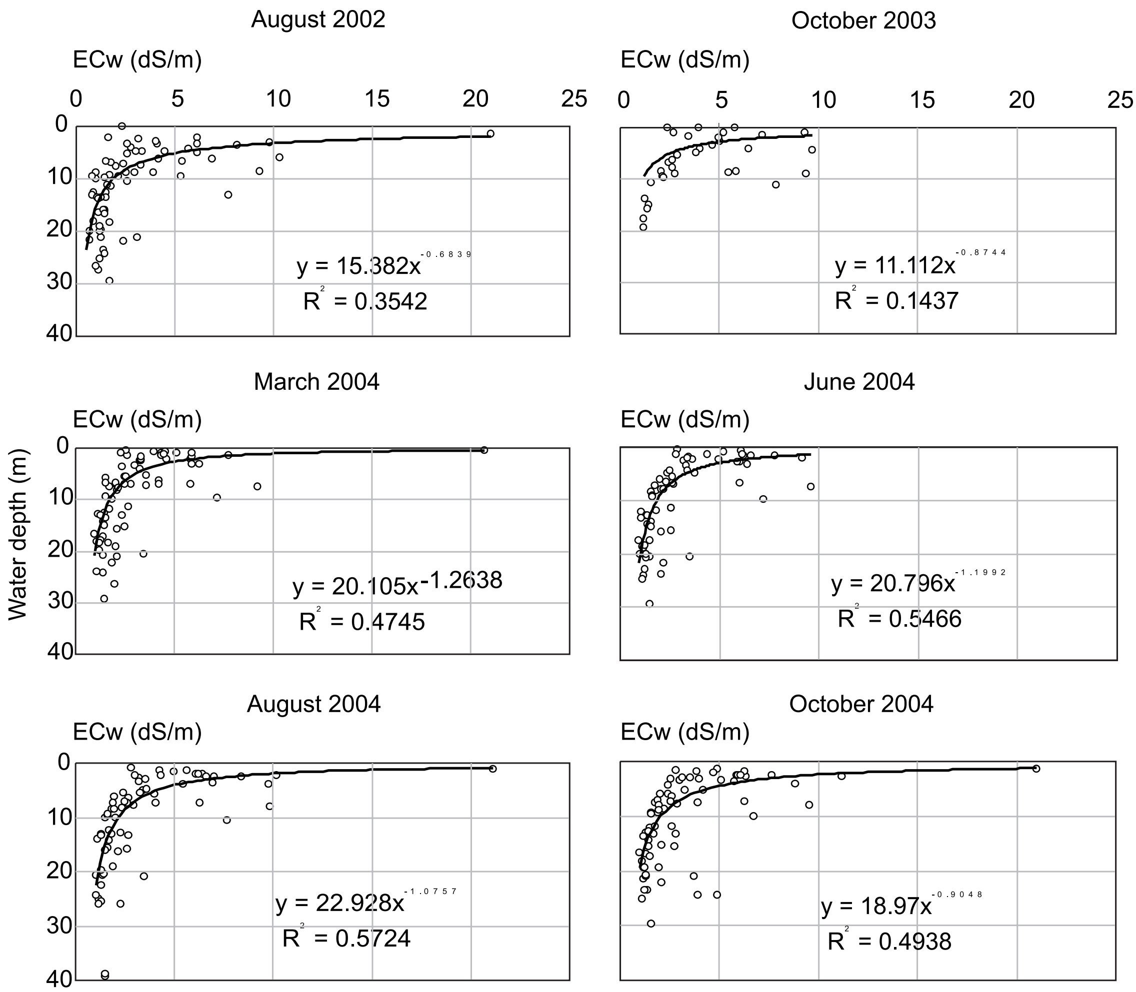

Fig. 2. The relationships between groundwater depth and ECw in the eastern block of Luohui irrigation scheme.

depth. Specifically, more than 3 dSm^{-1} values were concentrated within 1.5 to 9.4 m in August 2002, 0 to 8.9 m in October 2003, 0.5 to 9.6 m in March 2004, 0.8 to 9.9 m in June 2004, 1.1 to 9.9 m in August 2004, and 1.3 to 8.0 m in October 2004. Focusing on the shallower groundwater depth of 0 to 3 m, higher values of ECw (up to 21, 20.7, 21.1, and 21 dSm^{-1} in August 2002, March 2004, August 2004, and October 2004, respectively) were observed. Higher ECw within 0 to 3 m groundwater depth would favor salinization process due to capillary water rise (Muir, 2002).

Besides the increased salinity within the shallower groundwater depth, 90% of the wells showed water level rise from August 2002 to August 2004. The maximum and average rise was 6.7 and 1.6 m, respectively. With such a trend, the irrigated area throughout the scheme would be prone to salinization unless appropriate and timely remedial measures were taken.

Relationship between groundwater salinity and soil salinity

Based on Bohn et al. (1985) soil salinity classification, 30% of the analyzed soil samples in the study area are saline soils. Saline-sodic soil was also identified in one place. The saline soils were concentrated (48%) in the center and the north, followed (28%) by southwest and northwest, and the remaining (24%) were in southeast and northeast. The saline-sodic soil was located in northwest part only.

Soil texture is believed to be a factor contributing to soil salinization by influencing infiltration of water and soluble salt transport through capillary water rise. The investigated soil texture classes and their coverage in the study area were: loam (63%), clay loam (14%), loamy sand (11%), sandy loam (9%) and sandy clay loam (3%). The dominant loam soil texture would have higher capillary water rise through longer period of time (Brady, 1990), which would favor soil salinization.

Generally, soil salinity and groundwater salinity vary from place to place due to variation in groundwater, soils, irrigation method, plant cover, climatic conditions, topography and drainage conditions (FAO, 1984). The variations in groundwater depth, soil salinity and texture, surface topography and drainage conditions are pertinent to the study area. Soil salinity and groundwater salinity are supposed to have strong relationship in an area due to the influence of groundwater rise and soluble salt transport to the soil surface (Ali and Salama, 2003). In Fig. 3, the correlations between groundwater salinity and soil salinity of the study area are presented. Generally, as groundwater salinity increased the soil salinity also increased. Relatively higher correlations were obtained at shallower (less than 3 m) than deeper (more than 3 m) groundwater depths, which means that the shallower wells had relatively higher effect on surface soil salinization while the effects of the deeper wells were almost negligible.

In summary, the obtained results of higher concentration of groundwater salinity at shallower groundwater depth; the relatively higher correlation coefficients between soil salinity and water salinity at shallower groundwater depth; the dominance of loam soil texture; and the low rainfall and higher evaporation in the study area indicated salinization process due to capillary water rise in the study area.

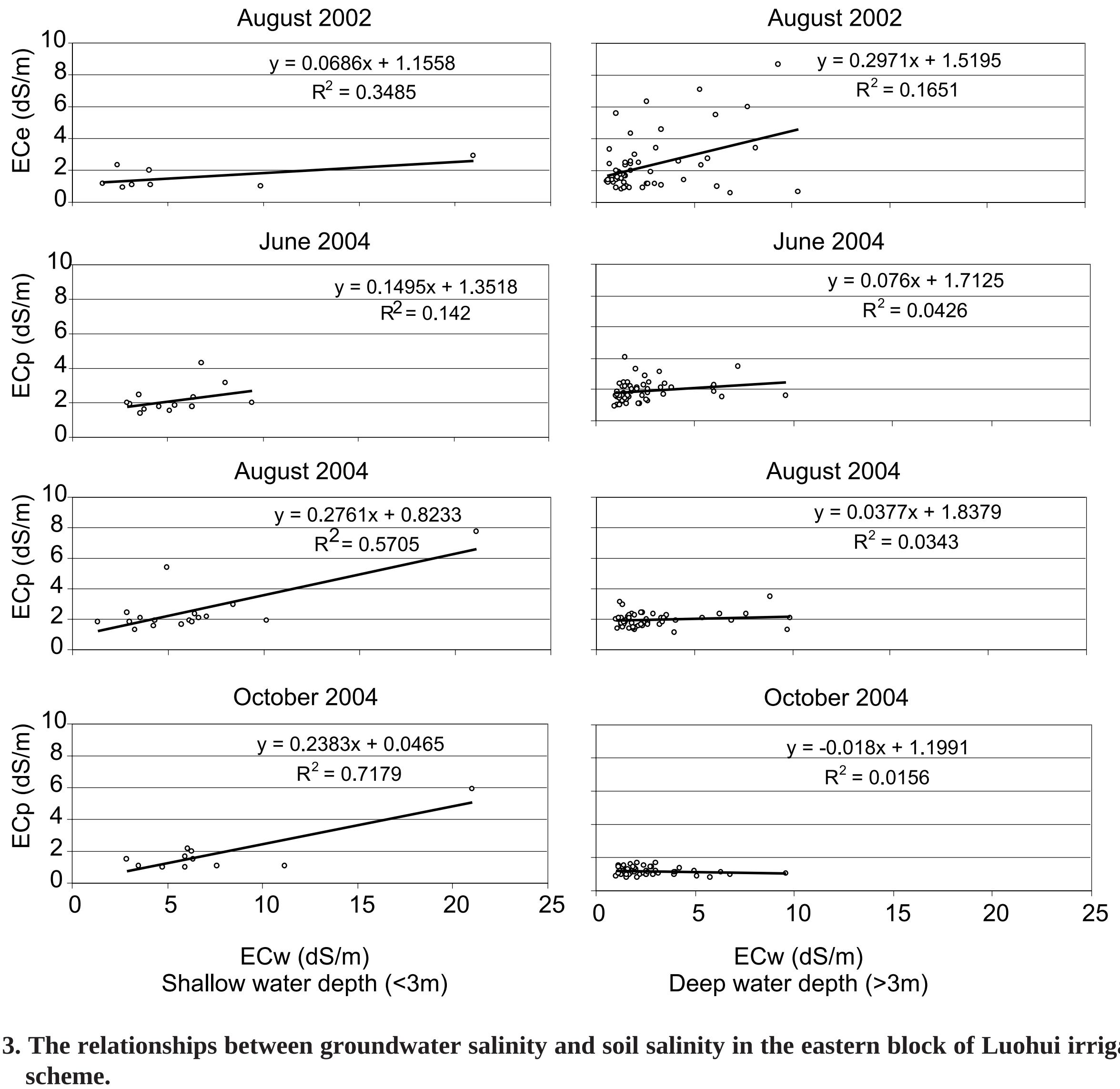

Fig. 3. The relationships between groundwater salinity and soil salinity in the eastern block of Luohui irrigation scheme.

Salinization due to use of saline irrigation water

The continuous use of ground water from wells for irrigation in the study area is another cause of salinization. The farmers use some of the wells for irrigation when there is shortage of water from the Luohui River. Out of all of the observation wells, about 50 are used for irrigation regardless of the water quality. Such practice in the long run would cause accumulation of salinity in the soil surface. In Fig. 4, it is shown that wells like 33 and 53 (indicated by O) had higher ECw (9.8 and 7 dSm^{-1} respectively) but smaller ECe (0.7 and 0.6 dSm^{-1} respectively) in the surrounding soil. The possible reason for the lower effect of these wells on the surrounding soil is because of the rare use of water for irrigation purpose (Table 1). However, wells 41, 64, and 34 (indicated by X) had higher ECw (more than 4 dSm^{-1}) and the surrounding soils at these wells also had higher ECe (more than 4 dSm^{-1}). The measured ECw values were 7.7, 6.3, and 7 dSm^{-1} and ECe values 6, 7.1, and 5.5 dSm^{-1}, respectively. The agreements of these values indicated that soil salinization process around these wells was due mainly to the frequent use of saline irrigation water from their corresponding wells.

Salinization due to dumping of saline soil

In the study area some wells were dug and the excavated soil was dumped in the nearby fields. The excavated soil often has higher primary salinity. Thus, the original salt is transported from underground to the agricultural fields. Besides, even if the excavated soil had lower amount of salts, the compaction activity would favor capillary rise and salt accumulation at the surface. The primary information regarding the direction of dumping obtained from the local people tallied well with the measured higher ECp and MC values in the nearby areas. The eastern direction of well 30 and northern direction of well 51 were the spots where dumping took place. These spots had the highest ECp (10.2 and 24.4 dSm^{-1} respectively) and high MC (31.9 and 45.5 %), whereas the average ECp and MC in the other three directions around these two wells were 2.3 and 2 dSm^{-1}, respectively, and MC 39.9 and 28.4 %, respectively. Based on the averaged values of the measurements in the other wells, the minimum and maximum values of ECp and MC ranged from 1.1 to 7.8 dSm-1 and 11.5 to 39.2 %, respectively (Fig. 5). Lesser values were observed in the other wells as compared to wells 30 and 51 (indicated by D in the same Figure). The highest average value of ECp for well 45 observed in Fig. 5 is an exception that was due possibly to direct capillary water rise as higher values of ECp and MC were measured throughout the four directions of this particular well and no dumping and compaction had taken place there.

Salinization due to variation in surface topography and drainage

The variation in surface topography contributes to the variation in the groundwater quality. This is because the quality of the surface water recharging the groundwater aquifer varies from place to place depending on the surface drainage direction, geology of the catchment, soil types, and agricultural practices (application of chemicals fertilizers,

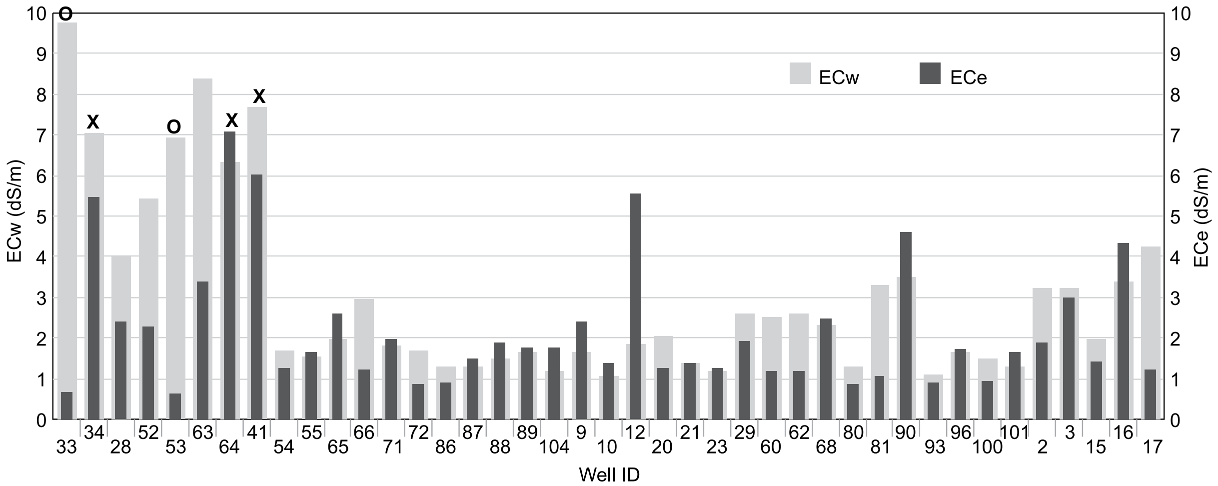

Fig. 4. The relationship between ECw and ECe of irrigation wells in the eastern block of Luohui irrigation scheme.

livestock husbandry and others). The surface water flow in the study area concentrated from northern, north-western and north-eastern parts of the scheme to the center. This would have provided it exposure to get laden with increased mineral content until it reached the downstream area (place of flow concentration) (Hassan, 1974).

Relationships between surface elevation and groundwater salinity

The average groundwater salinity and surface elevation (contour of topography) were overlaid in Fig. 6. The ECw of groundwater increased along the main drainage line (indicated by white dotted line and coming from northwest towards the salt lake). Along this drainage line, ECw increased from about 2 to 6 dSm^{-1}. Thus, salt accumulation increased along the downstream direction of the drainage line and it is an indication of salinization due to topographic difference.

In addition, there are areas like the central area, which have poor drainage and higher salinity level (Fig. 6). The field indicator of poor drainage in the area was the stagnating water observed in October 2003 after unusual and heavy rainfall.

Summary and conclusions

The identified indicators for the salinization processes due to capillary water rise were: the higher ECw found at shallow groundwater depth (less than 3 m groundwater depth); relatively higher correlation between water salinity and soil

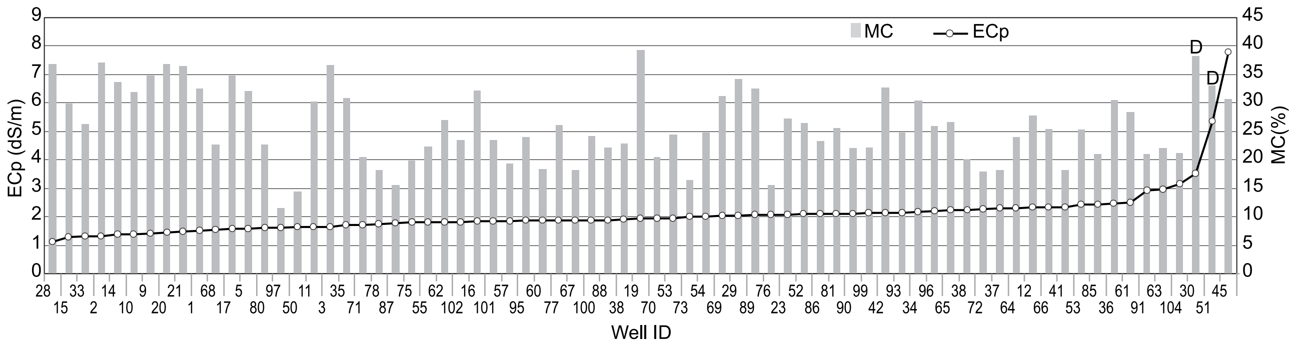

Fig. 5. The horizontal distributions of average ECp and MC around each well in the eastern block of Luohui irrigation scheme.

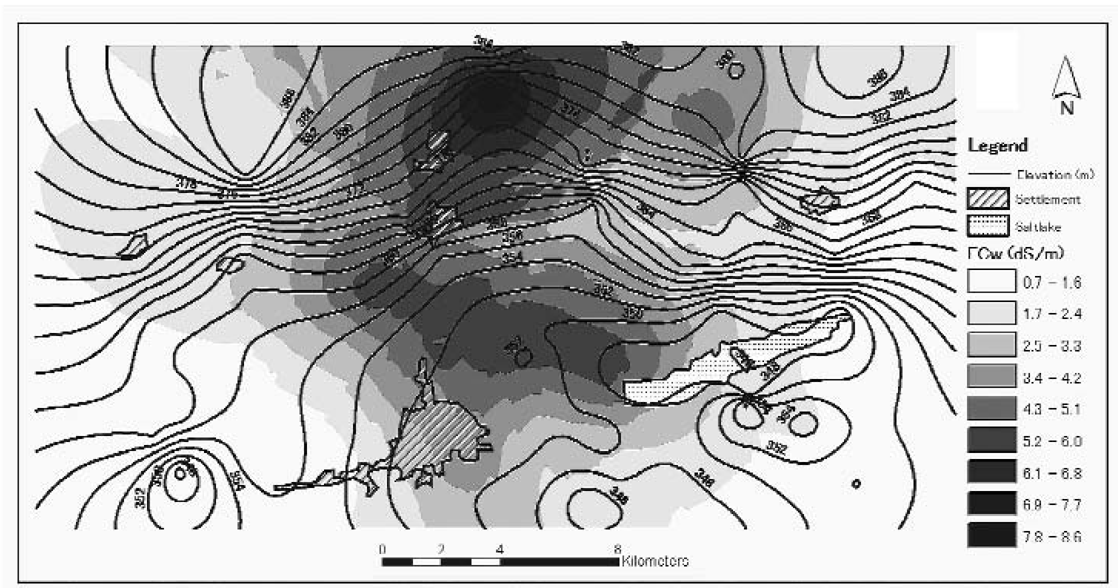

Fig. 6. The relationship between surface elevation and average ECw in the eastern block of Luohui irrigation scheme.

salinity for the cases of shallower groundwater depth (less than 3 m); dominance (63%) of loam textured soil and lesser annual rainfall (513.6 mm) as compared to the annual evaporation (1689.3). The identified indicators for the salinization process due to use of saline irrigation water were: higher values of ECw and ECe for some of the irrigation wells like 41, 64, and 34, which had ECw of 7.7, 6.3, and 7 dSm^{-1} and ECe of 6, 7.1, and 5.5 dSm^{-1}, respectively. Wells like 33 and 53 are exceptions as they had smaller ECe (0.7 and 0.6 dSm^{-1} respectively) and higher ECw (9.8 and 7 dSm^{-1} respectively), possibly because of rare use of water from these wells for irrigation in the surrounding area. The identified indicator for the salinization process due to dumping and compaction of soil excavated during well sinking is the agreement between local information and higher ECp (10.2 and 24.4 dSm^{-1}) and higher MC (31.9 and 45.5 %) in the eastern direction of well 30 and northern direction of well 51, respectively. The identified indicators for the salinization process due to variation in surface topography and drainage are: the increasing concentration of ECw (from about 2 to 6 dSm^{-1}) along the downstream direction of the main drainage line and the poor drainage conditions like in the central area, which had higher ECw (up to 8.4 dSm^{-1}).

Based on the investigated salinization processes and identified indicators, the following suggestions are forwarded in order to deal with the salinization problem in the study area: lowering the groundwater level by installing effective drainage systems; managing the use of saline irrigation water; controlling dumping and compacting saline soils in the fields; and giving priority attention to the central and northern part of the scheme for further investigation as higher values of water salinity were more or less concentrated in these parts of the study area.

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The image of the desert in Chinese literature: Examining the poetry on Wang Zhaojun

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Abstract

In 33 B.C. the Western Han Emperor of China sent one of his many wives, a beauty named Wang Zhaojun (also known as Ming Fei), to the Hun leader, Hu Han-yeh (r. 49-33 B.C.) in order to secure a treaty with the Huns. She is known to the later generations as a great beauty who was a tragic victim of the times. Her legend is popular not only in China, but also in Japan. In 1983, the author was able to visit and conduct research in the Dunhuang caves, where the variations in the narrative cave paintings could be observed, and an enormous amount of material could be collected. Especially fortunate was the opportunity to be able to work in Cave No. 17. Later, searching for more information, the author travelled to examine the Dunhuang documents in the Pelliot collection of the National Library of France in Paris and the Stein collection of the British Library in London for research. Based upon this intensive study, the author wrote a doctoral dissertation. A portion of that work is used as one example to introduce the concept of "the image of the desert" in Chinese literature.

Introduction

In 33 bc, in the Land of the Xiong-nu (or Huns), China, there was a woman named Wang Zhaojun, a star-crossed beauty who was given to the leader of the Huns as part of a peace treaty between the Huns and the Emperor of the Han Dynasty. The name of Wang Zhaojun has remained known to the later generations as a tragic beauty who lived during the reign of the Han Emperor Yuan (r. 49–33 bc).

In *Climate and Culture (Original title in Japanese: Fudo)*, Tetsuro Watsuji wrote: Humans did not choose farming and fishing occupations because they thought that someday they might want meat or fish. Because they chose farming or fishing due to climatic and cultural reasons, they later came to want meat or fish. In the same manner, people who are vegetarian did not debate whether to eat meat or vegetables and did not embrace the ideology seen in some 'dyed-in-the-wool' vegetarians, but owe it to climate and culture. Thus, the agricultural practices of Chinese civilization, which sprang up along the Yellow and Yangtze rivers, and the nomadic lifestyle of the horseback riders known as the Xiong-nu, were decided by their culture and climate. Differences in their food, clothing, and shelter led to differences in their cultures. Their weather, languages, and religions are different, and their customs (such as the Xiong-nu tradition of the widow marrying her late husband's son and heir) and morality are different. It is said that "When in Rome," one should "do as the Romans do" — but for the parties concerned, certain things were inescapable. Women were victims of political marriages arranged in order to gain peace, and, over the ages, they took place in both East and West.

The legend of Wang Zhaojun in Chinese literature

From the *Xian Qin-Han-Wei-Jin-Nanbei Chao Shi* (Poetry of the former Qin, Han, Wei, Jin, and Northern and Southern Dynasties) and *Lefu shiji* (Collection of Poetry from the Department of Music) to the *Quan Tang Shi* (Complete Tang Poems), there are numerous poetic works that are sung in praise of Wang Zhaojun. In the *Lidai Geyong Zhaojun Shici Xuanzhu*, Poems and Songs throughout History: Odes and Lyrics on Zhaojun, selected and Annotated the titles and authors of almost all of these works are included. There, the transition of Wang Zhaojun to the ideal female beauty is depicted with the flow of time and the dramatic nature of the "Wang Zhaojun Legend" is presented.

In the anthologies named above, there are several poems in which we can infer the long journey to the land of the Huns, the progress through the deserts and high plateaus, the crossing of the Yellow River, and the passage through Suiyuan province. These poems begin with the departure from the lush greenery of the capital of Chang'an and tell of the sad plight of Wang Zhaojun through narrating her experiences in the harsh environment of the desert.

In *The Parting of Zhaojun,* Shen Yue (441-513) writes:

"In the morning, Wang Zhaojun went forth from Pixiang Hall,
In the evening, she crossed the Yellow River near Fenyin;
At that place, nine times she called to mind her lord,
From that place, her moth-like brows joined in sorrow.
Her tears fell so deep they were mistaken for dew;
Her thoughts spun in her breast like flowing waves.
Day by day she saw many dusty deserts hurry by;
She noticed that many withered lotuses were rolling by.
The cold wind of the Huns violated skin and bones;
And not just her fine brocades became tattered.
While weeping, she longs for her home in the south,
As checkpoints and mountains rise up lonely and lofty.
At first she tried to write tunes on the warmth of spring;
But they turned out to be songs of the bitter winter.
And now, the only thing that soothes her mind is the full moon,
Which visits on the 15th night from the distant capital."

The desert imagery

When considering the *Wang Zhaojun Bianwen* (The Popular Narrative of Wang Zhaojun; *bianwen* literally means "transformation text"), one must consider that although the *Ming-fei Dian*, "The Legend of Ming-fei" ("Bright Consort" was one of the titles of Wang Zhaojun), was previously expounded and propagated throughout the Court through Tang-dynasty poems, the *Wang Zhaojun Bianwen* arose among and for the common people of the Tang era. One reason for this is the number of orthographic and lipographic errors, as well as the use of popular writings that have been pointed out in the copy of the *Wang Zhaojun Bianwen* preserved in the collection of the National Library of France. However, on this occasion, in attempting to edit the text, I have discovered that looking only at the popular writings and correct orthography leads to a problem in evaluating the work (Horie, 2002; 2003). The omitted and wrongly written characters were the result of the level of proficiency of the copyist(s), and they should not be considered in evaluating the work itself. In my personal opinion, a number of copyists were involved in producing this version of the work.

One reason for that is that the verses quoted within the *Wang Zhaojun Bianwen*, although they do contain some rather peculiar usages in couplets, are not wrong, even in ancient terms, in regard to the use of rhyme and rhythm when compared with other works, and are similar to lines appearing in Bai Juyi's *Chang hen ge* (Song of Everlasting Sorrow). In particular, the lines *Xi ri tong mian ye ji duan / Ru jin du qin jue tian chang* (translated: '*In the past we slept together, and nights seemed so short;/ But now I lie alone, and the hours feel so long*') are similar to those of the *Chang hen ge.*

The vivid description of the desert landscape in these verses testifies the hardship to which people were subjected by the desert environment. This ancient literature should be of great interest to all who would like to know how human being adapted to these harsh environments.

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Groundwater chemistry in the Badain Jaran Desert region of China

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Abstract

The comparative chemistry of surface and subsurface waters and their geographical distribution in the Badain Jaran Desert of northwestern China was assessed through field sampling. The chemical properties of the phraetic water fraction showed the recharge from atmospheric precipitation to be significant; however, the temporary runoff can only recharge groundwater in the desert margins. While montane bedrock fissure water plays an important role in recharging groundwater in the piedmont alluvial-diluvial layers, its contribution to that of the desert interior is very limited. Artesian water recharges shallow groundwater through the scuttles, particularly in interdune lands. Water salinity ranges from 1.0-1.5 g L^{-1} at the top of sand mountains to 1.5-2.0 g L^{-1}, or even above 10 g L^{-1} in lakes of interdune lands. Between these locations water chemistry shifts from HCO_3^--SO_4^{2-}-Cl^--Na^+ to Cl^--SO_4^{2-}-HCO_3^--Na^+. The more soluble Cl^--Na^+ accumulate in the topsoil layer, while insoluble bicarbonates accumulate in deeper layers, resulting in a vertical zonation. Strongly, slightly and very weakly salinized zones form at depths of 3-6 m, 10-12 m, and 15 m, respectively. In the Bayinnuer area, the salinity of shallow (0.5-10 m) and deep (20-80 m) wells were 1.74 g L^{-1} and 1.39 g L^{-1}, respectively, their water chemistry was characterized by Cl^--SO_4^{2-}-HCO_3^- and HCO_3^--SO_4^{2-}-Cl^-, respectively, and the total hardness of both was 32.9 German degrees. The existence of low salinity water or even freshwater beneath the shallower highly saline groundwater is significant in terms of the development and use of water resources in this arid region.

Introduction

The Badain Jaran desert, third largest in China, is situated in a basin enclosed by Mount Alten to the north, Mount Beida to the south, and Mount Zongnai to the east, in the western portion of Inner Mongolian Plateau of northeast China. The desert covers some 47,100 km^2, with its westernmost region composed of stone Gobi. A continuous landscape of sand dunes and huge sand mountains (mega-dunes) precludes runoff occurring in the Badain Jaran; however, significant water storage occurs in groundwater and shallow lakes. Consequently, the formation and distribution of water resources in the Badain Jaran differs significantly from that in other Chinese deserts.

The Badain Jaran desert belongs to a sag in the activated Alxa tableland that is separated from Alan Plateau by a fracture on the western flank of Mount Zongnai. There are Cretaceous, Jurassic and Tertiary stratigraphic outcrops at the edge of the basin. Affected by the neotectonic movement, the Alxa tableland began to rise from early Quaternary, thereby producing fractures in the basin, which resulted in the formation of fractured terraces (Sun, 1964). This was followed in the lower Pleistocene by the deposition of alluvial and lake deposits on the terraces, but by the mid-lower Pleistocene thick alluvial/diluvial deposition only at the periphery of the basin. The lower Pleistocene alluvial-lacustrine deposits at Angcik, Badain Jaran Temple, Bayinnuer and Engliwusu, in the hinterland of the desert, consist of medium and fine sandy silts or semi-cemented sandstone, forming a good, stable aquifer with little lithologic variation (Wang, 1990). Upper part of the Badain Jaran consists of thick layers of medium-fine sands and marl. The northwestern portion of Lake Gurinai and the region east of the Ejin River are also zones of lower Pleistocene alluvial and lacustrine deposit outcroppings, whereas mid-Pleistocene lacustrine deposits occur predominantly at the western edge of the desert (Han, 1985; Cheng et al., 1998). The upper Pleistocene and Holocene alluvial-diluvial deposits in the piedmont region of Mount Beida consist predominantly of thick layers of sands and gravels in proximity to the mountain, medium-coarse sands interbedded with subsand and subclay lenses in others montane regions, and thin and discontinuous deposits in the piedmont region. Holocene lacustrine deposits occur mainly in and around lake basins on the desert margins. For example, deposits in Lake Gurinai and Lake Guaiz consist predominantly of subsand, subclay, black mud and associated organic-rich deposits (Gao and Du, 1996).

The Badain Jarain Desert slopes to the northwest. The elevations in the south range from 1800-2300 m, in the east from 1300-2200 m, and in the northwest from 970-1200 m. Mount Beida and Mount Yabulai are short, tectonic denudated mountains, with elevations of 100-400 m relative to the point in the desert. Due to past tectonic movements and denudation, the weathering of tectonic and other fissures in the bedrock are well developed. A 10-km wide diluvial/alluvial fan has developed in the piedmont belt of Mount Beidain in Pleistocene. The relative height difference of denuded hills, such as Mount Zongnai and the Mount Alten, varies from 50 to 200 m. Weathering fissures and shallow-dissected gullies are well developed in the piedmont belts (Zhang, 1985).

The soil surface over virtually the entire current desert basin is composed of Holocene æolian sands, including, for example, 1-5 m high fixed sand dunes in northern portion of Lake Gurinai. Barchans dune chains and dune ridges occur around the periphery of the desert. In the desert hinterland very large sand mountains (megadunes), with a relative elevation of 100-500 m, occupy 55.3% of the desert's total area (Zhu et al., 1998). Inland lakes, or *haiz*, are formed in the deep and wide valleys distributed between these megadunes and in areas peripheral to the desert. According to a preliminary survey conducted in the 1970s, some 144 small inland lakes are scattered about the desert, representing the main surface water resources and source of exchange for groundwater (Second Geology Investigation Team of Northwest China, 1995).

Due to the predominance of Mongolian high-pressure systems, the climate in study area is a typical continental one, dry and cold in winter, hot in summer, short spring and autumn, with some distinctive variation from east to west. Mean annual air temperature (AAT) ranges from 6-7°C in the eastern sandy desert, and from 8.0-8.5°C in western Gobi areas. On a daily basis, air temperature generally varies by 10-20°C, with a maximum variation of over 30°C, whereas variation on an annual basis may reach 60°C or more. Precipitation in the region declines from the southeast to the northwest: mean annual precipitations (MAP) in Bayemaodao, Shangjinzi, the north Lake Guaiz region, and Dalaikubu are 98.7, 114.4, 47.1 and 35.5mm, respectively (Fig. 1, Table 1). With little year to year variation, roughly half the annual rainfall results from storm events occurring in July and August (Table 1). The mean relative humidity varies from 32 to 41%. Evaporation varies widely over the study area: in the southeast it ranges from 3000-3500 mm, whereas in the northwest it ranges from 4000 to 4200 mm. Solar radiation is plentiful and sand storms are frequent.

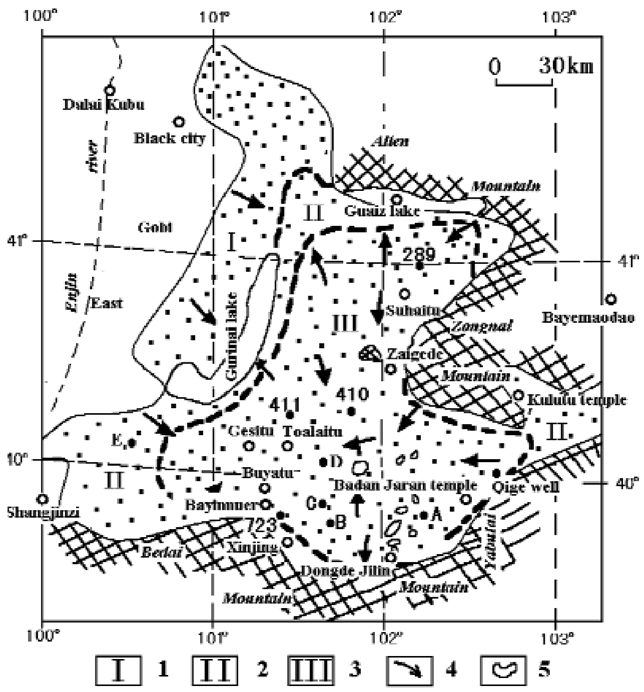

Fig.1. The location of study area and the flow direction of artesian water. 1. Honeycomb dunes area; 2. Barchanoid ridges and longitudinal dunes; 3. Compound longitudinal dunes; 4. Flow direction of artisan water; 5. Lakes.

Table 1. Weather characteristics of Badain Jaran desert

Station*	Annual temperature (°C)			Annual precipitation (mm)		Mean total annual evaporation (mm)	Relative humidity (%)
	Mean	Max.	Min.	Mean total	July-August		
Bayinnuer	6.3	14.3	-1.7	127.7	69.6	2879	41
Bayemaodao	6.8	14.2	0.3	98.7	55.9	3199	38
Guaiz lake	8.4	16.6	0.8	47.1	24.0	4111	34
Dalai Kubu	8.2	16.4	0.6	35.5	18.8	3769	35
Shangjinzi	8.3	15.2	1.7	114.4	58.8	3937	38

**Station locations shown in Fig. 1*

The water chemistry of the Badain Jaran Desert has becomes a widespread and high priority concern. To protect valuable water resources, one must not only understand the issues of anthropogenic water pollution, but also the natural spatio-temporal evolution of water chemistry under natural water circulation processes. This is essential for the evaluation, rational use and protection of water resources and also in the assessment of water quality. Therefore, in common with other deserts, studies of water inventory and chemistry in the region have an important practical and strategic significance (Zhang, 2002). Through the investigation and analysis of chemical properties of surface and ground waters in Badain Jaran Desert, we sought to characterize the factors influencing water chemistry and distribution and provide some basic data for the rational exploitation and use of water resources in the surrounding regions.

Material and methods

Given that Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-} and CO_3^{2-} account for roughly 98% of ions in natural fresh waters, these were measured. Along with ion concentrations, total salinity, chemical type of water and pH were used as the main indicators in the analysis and evaluation of river water chemistry and its spatio-temporal evolution (Greiner, 1997).

In order to assess water chemistry under natural conditions, water samples were collected at 33 sites ranging from lowland of Badan Jaran Desert to lakes (Fig. 1). The chemical composition of bulk samples was determined by Philips PW1404 and 1480 X-ray fluorescence spectrometry (Munsell, 1975; Goldsmith and Graf, 1958). Once sealed, samples were taken to the laboratory of the Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI), Lanzhou, China, for chemical analysis (Sueki et al., 1996; Latif et al., 1999). A total of 30 constituents including macro-and microelements were analyzed. Samples not treated with acid were used to determine anions by way of a titrimetric method (Yonezawa et al., 1993).

Owing to the limitation of field investigation time and complex natural conditions in sandy lands, the collection of water samples was neither systematic nor complete. Triplicate water samples were obtained at each of 33 sites distributed in lowland of Badan Jaran Desert in the spring of 2002, resulting in a total of 99 samples The concentrations of major elements were measured at the activation lab in Lanzhou, China, by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) coupled with X-ray diffractometry (XRD), while trace elements were measured by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The details of the methods of analysis are given in Rhoades (1978). The pH, electrical conductivity (EC), alkalinity, and total anion and cation concentrations were measured *in-situ* with a Hach Field Chemistry Kit and by ion-chromatography (IC) at the Geochemistry Laboratory of the CAREERI.

Formation of ground water resources

Precipitation

Mean annual precipitation in the Badain Jaran Desert varies from 80-120 mm in the southeast to only 40-50 m in the northwest. Due to significant evaporation under the high air temperatures prevalent in the region, only 20-50 mm of precipitation from the sudden short-duration rainstorms infiltrates into the soil. Precipitation events of over 10 mm occur 1-3 times per year, particularly in the southeastern part of the desert. Individual rainfall events of over 20 mm have been recorded; for example over a 7-year period in the 1970s such events were the norm in the Bayinnuer region, the largest event (30 Aug. 1978) reaching 44.3 mm. In the same period, Lake Shangjinzi and Lake Guaiz stations recorded the individual precipitation events of 50.3 and 47.1 mm, respectively. Assuming an annual effective precipitation of 20 mm, and a runoff coefficient of 0.5, the surface of the desert would receive a volume of water of 1000 m^3 km^{-2} (i.e. 1.0 L m^{-2}). The recharge of groundwater from rainfall would thus be considerable.

The chemical properties of shallow groundwater (phraetic water) show that the recharge from atmospheric precipitation is detectable. While the salinity of phraetic water in the desert remained uniformly below 1.0 g L^{-1}, the chemical properties were irregularly distributed over the full Badain Jaran Desert region. The two predominant chemistries were of Cl^- - SO_4^{-2} - HCO_3^- and HCO_3^- - Cl^- types. Groundwater chemistries from Xinjing to Lake Guaiz (south to north) are presented in Table 2. Both the complex chemistries and relatively low salinities are related to continuous freshwater recharge of the high-salt strata, under high evaporative rates. Over the 60 km from Mount Yabulai (Qige well) to Location C (Fig. 1), the hydraulic gradient for groundwater runoff varied between 1-3%, but the chemical composition of groundwater showed no significant change. However, over these 60 km, the salinity of the phraetic water

Table 2. Chemical composition of groundwater in Xinjing-Guaiz lake regions

Site*	Salinity (g L^{-1})	Anion content (mg L^{-1})			Cation content (mg L^{-1})			Water chemistry type
		HCO_3^-	SO_4^{2-}	Cl^-	Na^+	Ca^{2+}	Mg^{2+}	
Xinjing	0.96	256	230.4	262.7	330	40		Cl^--SO_4^{2-}-HCO_3^--Na^+-Ca^{2+}
723	1.1	286	268	355	46	148	131	Cl^--SO_4^{2-}-HCO_3^--Ca^{2+}-Na^+
Bayinnuer	0.5	130.2	124.8	71	140	22		HCO_3^--SO_4^{2-}-Cl^--Na^+-Ca^{2+}
Buyatu	1.87							HCO_3^--SO_4^{2-}-HCO_3^--Na^+-Mg^{2+}
Gesitu	0.57							HCO_3^--Cl^--Na^+
411	0.52	133	220	63.4	119	28	24.3	SO_4^{2-}-HCO_3^--Cl^--Na^+-Mg^{2+}
410	1617	172	78		48	2179		HCO_3^--Mg^{2+}
Zaigede	1.2	524	346	210	227	124	69	HCO_3^--SO_4^{2-}-Cl^--Na^{2+}-Ca^{2+}-Mg^{2+}
Suhaitu	0.98	272	230	200	250	52	42.7	Cl^--HCO_3^--SO_3^{2-}-Na^+-Mg^{2+}
289	1.24	491.7	297	287.5	245	72	94	HCO_3^--Cl^--SO_3^{2-}-Na^+-Mg^{2+}
Guaiz lake	0.8	149.5	355.7	107.9	224.3	63.1		SO_3^{2-}-Cl^--Na^+-Ca^{2+}

**Site is shown in Fig. 1*

Table 3. Chemical composition of groundwater in Qingejing-Toalaitu regions

Site*	Salinity (g L^{-1})	Anion content (mg L^{-1})			Cation content (mg L^{-1})			Water chemistry type
		HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	
Qigejing	0.6	162	264	61	43	20	139	SO_4^{2-}-HCO_3^--Na^+-Ca^{2+}
Badain Jaran								
Temple	0.34	156.2	76.8	56.8	20	20	109.5	HCO_3^--SO_4^{2-}-Cl^--Ca^{2+}
A	0.55	186.0	172.8	85.2	10.4	0	196.6	SO_4^{2-}-HCO_3^--Cl^--Na^+-Ca^{2+}
B	0.78	267.9	230	102.9	16	0	276	SO_4^{2-}-HCO_3^--Cl^--Na^+
C	0.76	290	240	227	64	24	1	Cl^--SO_4^{2-}-HCO_3^--Na^+-Mg^{2+}

*Sites shown in Fig. 1

increased by 0.42 g L^{-1}, from 0.34 to 0.76 g L-1, and the water chemistry shifted from HCO_3^- - SO_4^{2-} - Cl^- - Na^+ to SO_4^{2-} - HCO_3^- - Cl^- -Na^+ - Ca^{2+}, to Cl^- -SO_4^{2-} -HCO_3^- - Na^+ - Mg^{2+} (Table 3). This confirmed that the subsurface flow process recharged shallow groundwater with freshwater.

Temporary runoff

Temporary runoff from surrounding mountains and bedrock fissure water are another source of recharge of the desert's phraetic water. Since the mountains around the desert are mostly relics of tectonic denudation with little difference in altitude compared to the desert floor, precipitation-driven runoff is of short duration, rapidly percolating into friable layer of the piedmont. A further portion of mountain runoff recharges the deep groundwater along the piedmont fractures. Field investigations have shown that the outlet of the flow of phraetic water in the piedmont gravel zone of Mount Yabulai is limited to the Badain Jaran temple area, whereas that originating in the piedmont diluvial layer of Mount Beida can reach both Dongde Jilin and Bayinnuer regions. Therefore, surface and subsurface runoff in the mountainous areas can only provide a limited recharge to desert groundwater, i.e. they can only recharge the groundwater in the marginal areas of the desert.

Water chemistry of phreatic water at the Qige well in the piedmont belt of the Mount Yabulai shows that the cation and anion concentrations are greater than those of spring water in the Badain Jaran temple region (Table 4). Given that the hydraulic gradient from the Qige well to Badain Jaran Temple is 9%, and the distance some 80 km, it appears unusual that the down slope water would show a lesser salinity. Nonetheless, similar changes in ionic concentrations were observed between the Mount Beida piedmont and Dongde Jilin. From the piedmont belt to the lower plain, the ionic concentrations in groundwater rose gradually; however, after entering the desert, both ion concentrations and salinity declined, resulting in essentially freshwater being found inside the desert, near Dongde Jilin. There is a gradual decline in salinity along the axis of groundwater movement from Mount Beida to Dongde Jilin: salinity on Mount Beida and at Zaigede varied from 1 to 3 g L^{-1}, declining to 0.57, 0.76 and 0.44 g L^{-1}, respectively, at Glist, Toalatu, and Bayinnuer. These observations suggest that bedrock fissure water in the mountain areas plays an important role in recharging groundwater in the piedmont alluvial-diluvial layers, although its contribution to the groundwater in the interior of the desert is very limited.

Lake Gurinai is located in the western part of the desert at the eastern edge of the alluvial fan of the Ejin River. The lake is recharged to some extent by infiltration flow from the Ejin River, but given the great distance of groundwater flow necessary, this only accounts for 19% of the total recharge volume of the lake area, or 16 million m^3.

Leakage water

Artesian aquifers formed by lower Pleistocene alluvial-diluvial deposits and tertiary sand layer under the Holocene æolian sand and lacustrine deposits are common in the Badain Jaran desert.

Table 4. Spring water chemical characteristics in Badain Jaran Desert

Location*	PH	Anion and cation contents (mg L^{-1})							Salinity (g L^{-1})	Water chemistry type
		Cl^-	SO_4^{2-}	HCO_3^-	CO_3^-	Na^+	Mg^{2+}	Ca^{2+}		
1	8.9	61.7	60.0	109.8	2.4	86.5	4.5	14.8	0.3	HCO_3^--Cl^--SO-Na^+
2	9.0	56.1	99.8	167.1	18.0	116.2	17.8	12.9	0.5	HCO^--SO_4^{2-}-Na^+
3	8.9	204.9	177.6	358.6		245.0	34.8	37.1	1.1	HCO^--Cl^--Na^+
4	8.8	68.4	117.6	119.6		91.5	14.1	24.1	0.4	SO_4^{2-}-HCO_3^--Cl^--Na^+
5	7.5	355.0	57.6	195.2		174.8	34.2	80.2	0.9	Cl^--Na^+-Ca^{2+}
6	7.1	1988	48.0	231.2	12.0	993.6	85.1	220.4	3.6	Cl^--Na^+
7	7.0	266.2	144.1	183		264.5	12.2	20.1	0.9	Cl-Na
8	9.1	112.5	129.6	414.8	64.2	188.6	42.0	55.0	1.0	HCO_3^--Na^+-Mg^{2+}
9	9.0	81.9	98.9	179.3	9.3	109.9	13.1	35.2	0.5	HCO_3^--Cl^--SO_4^{2-}-Na^+

**Locations 1-9 are shown in Fig. 2*

Their roofs are discontinuously distributed due to weathering, denudation and non-uniform deposition. Artesian water recharges shallow groundwater through scuttles; this is particularly obvious in the interdune land. Around the smaller lakes it emerges as rising spring water and serves as an important source of recharge for interdune lakes. This is also one of the main sites of deep groundwater discharge. Rising springs, with outflows generally lesser than 5 L s^{-1}, are commonly found in the Lake Guaiz and Lake Gurinai regions. Their water quality and chemical composition differ greatly due to different recharge sources and runoff conditions. Artesian water in the tertiary strata generally has a salinity of 1-3 g L^{-1} and generally exhibits a SO_4^{2-} - Cl^- - HCO_3^-, Cl^- - HCO_3^- or SO_4^{-2} - Cl^- chemistry. The lower salinity (<1 gL^{-1}) of outcrop water in the Lake Guaiz region is related to the nearby recharge of bedrock fissure water from the north side of the Mount Alten. Deep artesian aquifers of early Pleistocene have a better water quality, with salinities below 1 g L^{-1}. Shallower artesian water, which rises in the centre of lakes, exhibits poorer water quality, as is the case for all of Lake Tualaitu and the Bayinnuer.

Condensation water

It is generally believed that the Badain Jaran desert possesses the conditions to produce condensation water (Wang, 1990). Firstly, the desert has plentiful groundwater and a thick vadose zone, particularly in the megadune region where there is abundant vadose water. Field observations indicate that wet sand layers are widespread in the interior of the sand mountains. Dry sand layers are generally 0.3 m thick. On the leeward slope and dune ridges, dry sand layers vary between 1.0-1.5 m in thickness, whereas at the base of the windward slope and on gentle slopes it is only 0.15-0.20 m thick. Secondly, daily temperature differences are large. In the peripheral areas air temperatures generally vary between 10-20^{o}C, sometimes reaching 30^{o}C, while in the centre of the desert temperatures are even higher. All these conditions are favourable to the generation of condensation water. However, observations at the Minqin Experiment Station in the early 1960s, 1980s and 1990s, showed little condensation water on desert topsoil layers, indicating that condensation had little influence on the moisture content of sand layers. Upward diffusion and upper condensation of deep groundwater vapour could, however, produce much more condensation water than the former, and could redistribute soil water in the sand layer to a limited extent. Notwithstanding this, condensation water would have little influence on groundwater recharge.

As previously mentioned, groundwater in the piedmont alluvial/diluvial deposits at the periphery of the desert is mainly recharged by temporary surface runoff and underground runoff from the mountain areas, while the groundwater within the desert is mainly recharged by atmospheric precipitation and deep groundwater. According to estimates of shallow groundwater recharge in the Lake Gurinai region done in 1986 (Zhang, 2002), precipitation, infiltration flow from the Ejin River, and groundwater (shallow and deep), contributed 10%, 19% and 71%, respectively of lake recharge. Precipitation in the southern portion of the region is relatively large; contributing significantly to the groundwater.

Groundwater runoff and distribution

Holocene aeolian sand strata cover the majority of the Badain Jaran desert, and constitute the main aquifer. Aeolian sand strata mainly consist of loose fine sand and the thickness ranges from 5 to 200 m, sometimes reaching 300 m. The variation in the depth of groundwater is mainly controlled by geomorphic factors. The outflow rate of these aquifers varies from 0.015 to 0.5 L s^{-1} m^{-1}. In the interdune lands and lake margins, groundwater depth varies from 0 to 6 m and the salinity is roughly 1 g L^{-1}. In the 3-10 m thick Holocene lacustrine deposits, consisting of fine sand and subsand, outflow rates of phraetic water range from 0.1 to 0.5 L s^{-1} m^{-1}. In these areas groundwater often crops out locally, being less than 1 m deep in the central portions and 1-3 m deep in the other areas. Seasonal perched waters occur in the interdune lands, wind-eroded depressions and the leeward slope base of the mountains. Perched waters are formed by atmospheric precipitation and snow-melt water and are often rapidly lost by evaporation or in recharging phraetic water of interdune lands to form temporary ponds. Lakes, meadow, swamp and playas are the accumulation centres of surface water (temporary flooding) and groundwater in the desert. In the southern portion of the desert, groundwater runs towards the

Toalaitu area, in the western portion towards Lake Gurinai, and in the northern portion towards Lake Guaiz (Fig. 1). Two main lake types exist: water-filled lakes and grasslands-meadow lakes. Water-filled lakes are mainly concentrated in the south-eastern portion of the desert, alternating with megadunes to form a unique landscape of inland desert lakes. Owing to prolonged wind erosion, large depressions were formed among the megadunes (interdunes), and sometimes the erosion level even reached the underlying aquifer. The result is that a combination of groundwater outcrops, recharge from atmospheric precipitation, spring water and leakage water from deep groundwater, allow perennial or intermittent lakes to form. The surface of such lakes ranges from a few square meters to several square kilometres. Some of the lakes with surface areas exceeding 1 km^2 include the Lake Brudeoi, Lake Huangcao, Lake Badain Jaran, Lake Nuortu, Lake Cherig, Lake Kuhejilin, Lake Yindeirtu and Lake Ihejig Zaigede. The water level of these lakes rises in the spring and falls in summer due to high evaporation. These lakes generally store water in winter and spring, and dry up or change to grasslands in summer. From the centre of the lake to its bank a number of zones develop: a swamp meadow zone, sand mound zones populated with *Nitraria tangutorum*, fixed and semi-fixed dune zones, and a moving sand zone. Some small freshwater lakes also form at the lower part of the piedmont inclined zone, which are recharged by underground runoff from the mountain areas.

Grassland-meadow lakes form in the western and northern portions of the desert and in marginal depressions scattered amongst sand dunes. Owing to low precipitation (40-50 mm) and high evaporation, water is generally stored in sand dunes in the open depressions and beneath their base. Such groundwater cannot form perennial lakes as it only crops out in the spring at the edges of depressions. Dwarf plants *Phragmites australis*, *Achnatherum splendens* and *Nitraria tangutorum* mostly cover such lakes, including Lake Gurinai, Lake Guaiz and Lake Shugui. Meadow-swamp lands are the transitional form of these two types of lakes.

Artisan water

Artesian water in the Badain Jaran desert includes two types: the artesian water of palæogene and lower Pleistocene alluvial-lacustrine strata. Palæogene artesian water crops out at the edge of the basin. Its aquifer layer consists of greyish white coarse sandstone and conglomerate less than 10 m thick and with decreasing grain-size from the basin to the piedmont belt. Groundwater recharges by infiltration from surface water and lateral flow of fissure water in mountain areas. Salinity ranges from 1-3 g L^{-1}, and the water chemistry is of the SO_4^{2-}-Cl^--HCO_3^--Na^+ type.

Lower Pleistocene artesian water is fissure artesian water. Its aquifer layer consists of coarse sandstone in the piedmont belt and fine sandstone in the basin. Groundwater recharges by infiltration from surface water through fissures and bedrock fissure water. The water chemistry is of the Cl^--$HClO_3^-$ or SO_4^{2-}-Cl^- type, and the salinity from 1-3 g L^{-1}.

Artesian water of the lower Pleistocene alluvial-lacustrine strata is widely distributed throughout the desert. It consists of two artesian aquifers: one consisting of medium sandstone with well-developed fissures, in which groundwater is stored, and one of fine sandstone which only exists in the centre of the basin. In the case of the first type, a confining overlying clay bed in some interdune depressions has been denuded and the artesian aquifer layer is exposed, thus allowing close hydraulic interchange between the phraetic water and the aeolian sand layer. Through this window,

Table 5. Artesian water of lower Pleistocene alluvial-lacustrine strata: chemistry and quantity

Site*	Quantity (L s^{-1})	Salinity (g L^{-1})	Water chemistry type
A	3-5	0.56	SO_4^{2-}-HCO_3^--Cl^--Na^+
B		0.78	SO_4^{2-}-HCO_3^--Cl^--Na^+
D		0.76	SO_4^{2-}-Cl^--Na^+
Badain Jaran temple	2-1.5	0.33	HCO_3^--SO_4^{2-}-Cl^--Na^+.Ca^{2+}
Bayin nur	0.03	0.45	SO_4^{2-}-HCO_3^--Cl^--Na^+
E	2.0	0.50	Cl^--Na^+

**Site is shown in Fig. 1*

artesian and phreatic waters mutually supplement one another. The outflow rate of the artesian aquifer is from 1.5-5.0 L s^{-1} m^{-1} and the salinity less than 1 g L^{-1} m^{-1} (Table 5). However, the water chemistry is complex, being rather like that of ternary water. The second aquifer type, confined to the centre of the basin, has a discontinuously distributed confining overlying bed and bears water of poor quality.

Ground water characteristics

Given its particular climatic and hydrological characteristics, the Badain Jaran desert exhibits a distinct horizontal and vertical zonation of water chemistry.

Horizontal zonation:

Under the combined influence of a number of factors, horizontal zonation of groundwater chemistry results from the resolution, movement and accumulation of salts in the flowing processes of underground runoff from the inclined piedmont gravel plain to the dune-interdune lands of the desert. In the former, groundwater moves uninterruptedly, and salts dissolve into the water. When the groundwater reaches the plains near the desert basin, groundwater movement slows or even stops, local surface runoff contributes to salt accumulation, more materials come into solution, and the complexity of the water chemistry increases. For example, groundwater salinity in the Mount Yabulai area was 0.59 gL^{-1}, 1.1-1.3 g L^{-1} in the piedmont inclined plain, and 4.8 g L^{-1} in the piedmont overflow zone. Groundwater chemistry shifted from the HCO_3^--Ca^{2+}-Na^+ type, to the SO_4^{2-}-HCO_3^--Na^+ type and finally to the Cl^--Na^+ type. The salinity of groundwater on Mount Zongnai was 1.9 g L^{-1}, and the water chemistry of the HCO_3^--Cl^--Na^+ type, but in the piedmont overflow zone, salinity was up to 3.4 g L^{-1} and the water chemistry of Cl^--Na^+ type. Given the limited role of mountain surface- and ground waters in recharging those of the desert basin, little zoning of water chemistry occurs at the desert margins (Feng et al., 2001). In the interior of the basin phreatic water is recharged by deep artesian water and atmospheric precipitation, and overlying sand layers prevents significant evaporation, resulting in lowered salinity and improved water quality (Fig. 2).

Water quality varied from the top of megadunes to interdune land lakes: salinity increased from 1-1.5 g L^{-1} to 1.5-2 g L^{-1}, or even over 10 g L^{-1}, and the water chemistry shifted from HCO_3^--SO_4^{2-}-Cl^--Na^+ type to Cl^--SO_4^{2-}-HCO_3^--Na^+ type. In the discharge area, where groundwater runoff stops,

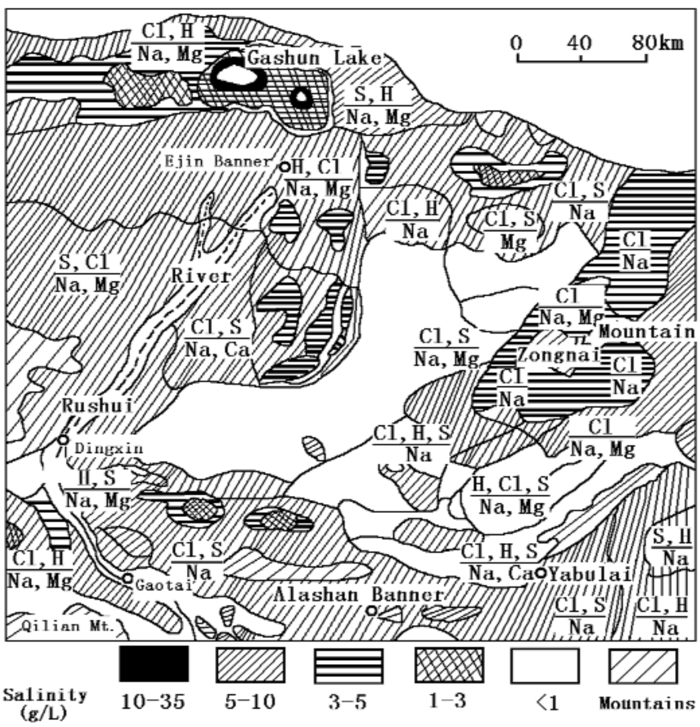

Fig. 2. Distribution of groundwater chemistries in Badain Jaran desert

water chemistry was Cl^--SO_4^{2-}-HCO_3^--Na^+-Mg^{2+} or Cl^--Na^+ type (Fig. 3), and 0.3-1.0 m thick salt layers form due to high evaporation. Such annular salinity distributions from the top of sand dunes into interdune depressions are common in the interior of the Badain Jaran Desert (Table 4).

Over the entire Badain Jaran desert, the distribution of water chemistry is irregular: while the salinity of phraetic water is generally less than 1 g L^{-1}, the chemical composition is more complex, belonging generally to a ternary water type, dominated by Cl^- - SO_4^{2-}-HCO_3^-, or more sparsely by a HCO_3^- - CI^- type (Feng et al., 2002). Recharged by atmospheric precipitation and deep groundwater, water in sand dunes generally has a low salinity of roughly 1 g L^{-1}. The water in sand dunes recharges the groundwat er and makes it fresh.

Vertical zonation:

Vertical zonation of water chemistry is one of the important features of groundwater in the arid zones. Vertical differentiation of groundwater in the desert region is a result of the limited recharge and the influence, to a certain depth, of the arid climate. Under an arid climate, groundwater undergoes strong salinization, phraetic water evaporates through soil (sand) layer and the rising saline water causes salt accumulation in surface soil layer. The more soluble Cl^--Na^+ ions accumulate in the topsoil layer and insoluble bicarbonates accumulate in deeper layers, leading to a vertical zoning. Generally, the strongly salinized zone forms some 3-6 m beneath the phraetic surface, a slightly salinized zone 10-12 m from the surface, and a very weakly salinized zone at a depth of 15

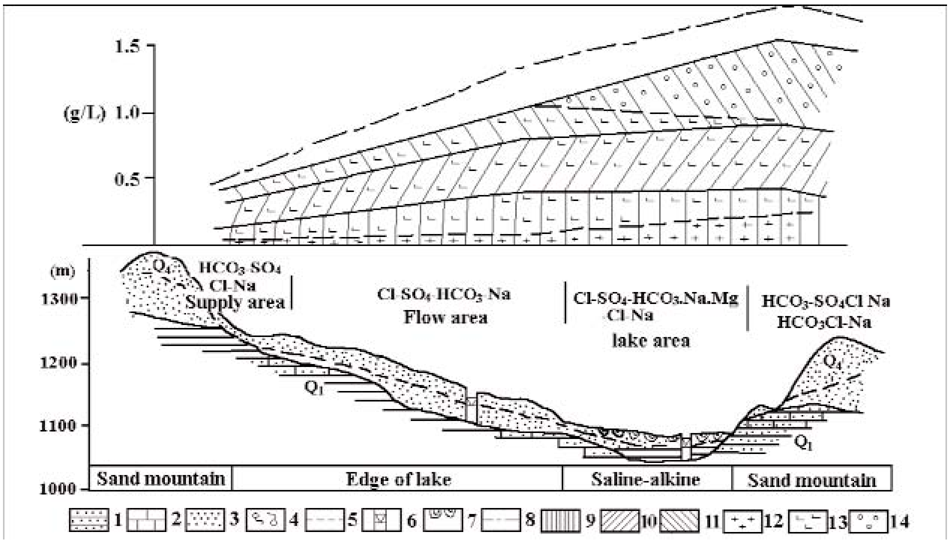

Fig. 3. Geological section from Sand Mountain to interdune depression. 1. Fine sand rock; 2. Fresh water greyish rock; 3. Coarse sand; 4. Upspring and down spring; 5. Underground water level; 6. Well; 7. Saline-alkali soil layer; 8. Salinity curve; 9. HCO_3^-; 10. SO_4^{2-}; 11. Cl^-; 12. Ca^{2+}; 13. Na^+; 14. Mg^{2+}.

Table 4. Spring water chemical characteristics in Badain Jaran Desert

Location*	pH	Anion and cation contents (mg L^{-1})							Salinity (g L^{-1})	Water chemistry type
		Cl^-	SO_4^{2-}	HCO_3^-	CO_3^-	Na^+	Mg^{2+}	Ca^{2+}		
1	8.9	61.7	60.0	109.8	2.4	86.5	4.5	14.8	0.3	HCO_3^--Cl^--SO_4^{-2}-Na^+
2	9.0	56.1	99.8	167.1	18.0	116.2	17.8	12.9	0.5	HCO_3^--SO_4^{2-}-Na^+
3	8.9	204.9	177.6	358.6		245.0	34.8	37.1	1.1	HCO_3^--Cl^--Na^+
4	8.8	68.4	117.6	119.6		91.5	14.1	24.1	0.4	SO_4^{2-}-HCO_3^--Cl^--Na^+
5	7.5	355.0	57.6	195.2		174.8	34.2	80.2	0.9	Cl^--Na^+-Ca^{2+}
6	7.1	1988	48.0	231.2	12.0	993.6	85.1	220.4	3.6	Cl^--Na^+
7	7.0	266.2	144.1	183		264.5	12.2	20.1	0.9	Cl^--Na^+
8	9.1	112.5	129.6	414.8	64.2	188.6	42.0	55.0	1.0	HCO_3^--Na^+-Mg^{2+}
9	9.0	81.9	98.9	179.3	9.3	109.9	13.1	35.2	0.5	HCO_3^--Cl^--SO_4^{2-}-Na^+

**Locations 1-9 are shown in Fig. 2*

m. In the Bayinnuer region, the salinity of shallow (0.5-10 m deep) and deep well (20-80m) waters were 1.74 g L^{-1} and 1.39 g L^{-1}, respectively, their water chemistry Cl^--SO_4^{2-}-HCO_3^- and HCO_3^--SO_4^{2-}-Cl^-, respectively, and their total hardness 32.9 German degrees. The existence of low salinity water or even freshwater beneath the upper high-salinity water is of significance to the development and use of arid land water resources.

Conclusion

Groundwater in the Badain Jaran desert is mainly recharged by atmospheric precipitation and deep groundwater and represents a considerable resource. During the upstream subsurface flow processes water continuously dissolves salts, but within the desert receives freshwater inputs from precipitation or deep phraetic water, resulting in a lowered salinity and complex chemical type. Groundwater distribution is closely related to the geomorphic conditions. Precipitation in megadune areas flows to interdune lands and forms many lakes, which provide useful water resources. Widespread artesian water in the desert is mostly low in salinity and has great exploitation value.

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Investigation on soil erosion using geomorphology and EPM models, a case study of Talegan watershed in Iran

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Abstract

Finding a suitable model for evaluation of erosion and sedimentation processes is an important area of research in soil conservation. In this study, done in Taleghan watershed in Tehran province, Iran, two empirical models, EPM (Erosion Potential Model) and Geomorphology, were used. These are quantitative and qualitative, respectively. In the Geomorphology model several factors such as erosion faces, lithology, slope, vegetation cover and soil type are studied to determine the erosion condition. EPM, which was developed in 1988 for some part of Yugoslavia, uses four factors, land use, susceptibility of soils and geological formation, current erosion condition and shape. In this research, using GIS (Arcview, Idrisi, and Ilwis), erosion faces map, geology map and slope map were crossed and homogenous unit map was produced. Erosion condition using Geomorphology model was determined in each unit and using GIS, erosion condition maps were produced. For evaluating erosion condition with EPM, coefficient of each factor was determined, and erosion intensity coefficient (Z) was calculated for entire watershed and homogenous units. Amount of erosion and sediment were calculated and erosion condition map was produced. Finally the results of two models were compared with amount of observed sediment in main river Taleghan rud, in Gilank hydrometery station. The results show that Geomorphology model was better than EPM as the prediction of Geomorphology model gave about 16% underestimation than the observed amount of sediment, while the prediction by EPM model gave an overestimation by about 27%.

Introduction

Soil erosion is a major environmental threat to the sustainability and productivity of agriculture. During the last 40 years, nearly one-third of the world's arable land has been lost by erosion and loss continues at a rate of more than 10 million hectares per year (Pimentel et al., 1995). Thus, soil erosion is a serious global problem. The average soil loss in Iran is estimated to be 20 to 30 t/ha per year, which totals to about 5 billion tons per year, and is mainly due to inadequate agricultural land use (Ahmadi, 2000). The agents of erosion are water and wind, but the main causes are improper land use and inadequate cultural practices. Quantification of the actual rates and patterns of soil erosion and sedimentation is necessary for designing degradation control strategies.

Classical methodologies for soil erosion assessment are expensive and time consuming. The direct field measurement methods do not allow for a retrospective assessment of erosion rates (Ahmadi, 2000). Modeling, however, can remove these short comings. The EPM model was developed in 1988 for some part of Yugoslavia. This model has been used in Iran and land use, susceptibility of soils and geological formation, current erosion conditions and shape have been evaluated to calculate the intensity of erosion in specific area. In a study in Ilam watershed of Iran using EPM model it was found that if the model was used with homogeneous units to calculate erosion rate the results would be better. The specific aim of this study was to use the EPM model to form a basis for erosion and sedimentation studies using available data of geomorphology, climate, geology, etc. in order to describe the condition of landscape erosion in Taleghan watershed in Iran.

Materials and methods

Model description

EPM is an empirical model which was developed in 1988 for some part of Yugoslavia. In the use of this model topographic condition, climatic factors, geology, pedology, and land use data are required as input parameters to estimate erosion potential and sediment yield in a given region. These parameters are used to calculate erosion intensity coefficient by the equation:

$$Z = X_a . Y(\varphi + I^{0.5})$$

where $\boldsymbol{Z}$ is the erosion intensity coefficient, $\boldsymbol{X_a}$ is the land use coefficient, $\boldsymbol{Y}$ is the soil and rock susceptibility coefficient, φ is the erosion coefficient, and $\boldsymbol{I}$ is the average slope (percent). Tabular values are available for each coefficient. Table 1 shows classification of $\boldsymbol{Z}$ values.

Table 1. classification of Z coefficient values

Z value	Erosion intensity
<0.20	Very low
0.20-0.40	Low
0.40-0.70	Moderate
0.70-1.00	High
>1.00	Very high

Specific erosion, sediment yield coefficient, specific sediment yield, and total erosion and sediment yield can be computed using defined equations. According to Z values the erosion intensity map can be prepared.

In the geomorphologic method, factors affecting the change in earth surface including topographic, geomorphic, climatic, geologic and pedological conditions are determined at first; mostly bedrock geology, erosion features and topographic parameters. Next step is the selection of these factors. This stage consists of providing different maps using topographic maps, aerial photos, satellite images, etc. The accuracy of the collected data is then verified by the check in the field. Overlapping these maps, homogeneous unit map is generated (Fig. 1). In these units some sources of error are eliminated, i.e. each unit has same geology, erosion face, slope, etc. and it differs from the neighboring unit in only one of this factors. These homogeneous units are the basis of soil erosion studies.

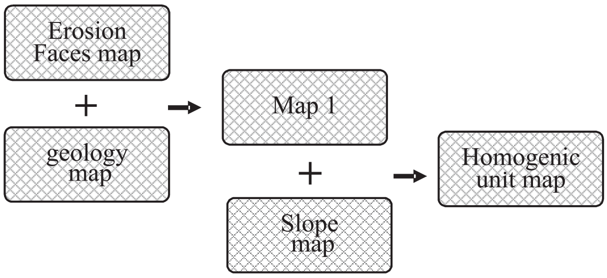

Fig. 1. Scheme for developing homogeneous unit map.

Modeled area

Taleghan watershed is located in the south-central parts of the Alborz Mountains, north- west of Tehran province. Because of its complex geological formation and high erosion potential, a large number of studies have been made there. This region lies between 36 05’ 20” to 36 21’ 30” N and 50 20’ 05” to 51 11’ 22” E, and covers approximately 84,000 ha (Table 2). Elevation ranges between 1780 and 4100 meter and the main landscape units are mountains, hills, and valleys. The study area is composed of volcanic and clastic formations and Quaternary alluvial sediments and erosion features are rock and stone, channel erosion, bad land, land slide, etc. The natural vegetation is mostly *Astragalus* spp., *Artemisia* ssp., forbs, and annual and perennial grasses. The climate of Taleghan watershed is cold semi humid. The average rainfall is about 690mm per year and the average temperature is 3°C. Water deficiency is expected from July to October and a water surplus from January to May. Soils of the study area, following USDA (1992), belong to the orders Entisol and Inceptisol, and the approximate FAO soil classification is Regosol and Lithosol. For a better study of the region 17 sub-watersheds were identified (Fig. 2).

Data acquisition

A geographic information system (GIS) was used to integrate data obtained through fieldwork as well as from various maps, aerial photographs and ETM+ Landsat images. The spatial data on the Taleghan were obtained by superimposing the administrative boundaries on seven different maps and calculating the values for each attribute within each polygon using the GIS ILWIS (ITC, 2002). The maps used include the following:

Table 2. Physiographic characteristics of sub-watersheds

Sub-watershed	Area (km^2)	Primeter (km)	Av. slope (%)	Elevation (m)			Length of main channel (km)
				Mean	Min.	Max.	
1	93.24	75.47	38.44	2698	1780	4085	19.81
2	37.47	34.63	42.07	2692	1820	4003	17.00
3	27.38	29.97	44.37	2699	1880	2917	12.58
4	30.76	30.67	42.29	2744	1880	3873	13.16
5	65.17	46.6	47.23	2852	1920	4075	19.12
6	98.16	51.83	43.19	2883	1940	4402	21.60
7	47.74	32.62	47.50	2882	2135	4198	15.15
8	47.52	33.50	45.15	2850	2220	4198	10.92
9	59.16	38.08	39.48	3008	2300	2944	13.75
10	24.49	21.88	43.37	3135	2300	4100	7.35
11	73.69	21.24	37.27	2998	2250	4100	16.65
12	26.53	24.44	53.21	2924	2120	4100	8.37
13	30.64	23.95	48.57	2759	2060	3567	9.15
14	16.57	22.07	44.83	2536	1960	3420	8.65
15	27.06	23.50	37.92	2506	1870	3280	9.28
16	22.63	24.45	31.93	2422	1840	3281	9.56
17	31.44	26.95	32.28	2448	1810	3162	9.16

1. Digital elevation model (DEM) was computed by digitizing the topographic map of the region.
2. Altitude, slope, and aspect maps were obtained from the DEM.
3. Erosion feature map was obtained using aerial photos of 1:20000 scale.
4. Land use map obtained from supervised classification of the 2000 ETM+-Landsat images of the study area.
5. Geology map (Shakran map, 1:100000 scale).
6. Land cover map provided by fieldwork and sampling of vegetation types.
7. Precipitation and temperature maps were obtained from the climatic data measured by gages placed in the watershed.

Modeling erosion process

In the geomorphologic method crossing erosion

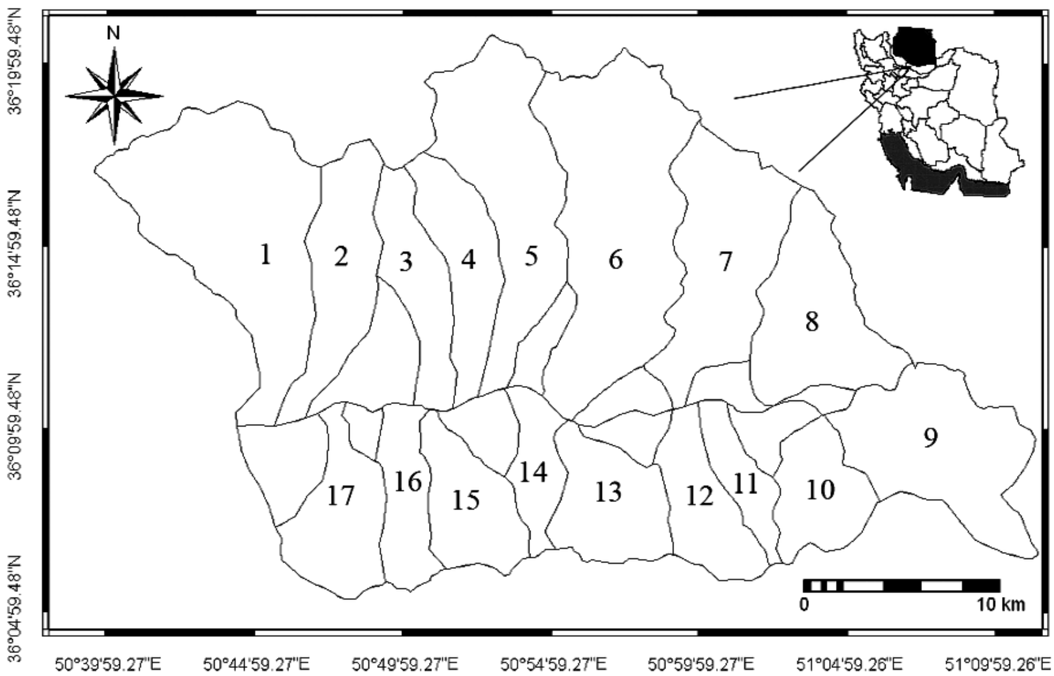

Fig. 2. Location of study area and sub watersheds.

feature, geology, and slope map, the homogeneous unit maps were obtained and then modified and confirmed by actual field check. In each polygon of this map all factors including geology, erosion feature, land use, land cover, soil class, and climatic and topographic characteristics were determined; then their susceptibility to erosion were distinguished. According to each unit, the same polygons, using GIS, were integrated in to five classes of susceptibility to erosion, named as potential erosion map.

In the EPM model ***Z*** valve was calculated from slope map as ***I*** factor, geology map as ***Y*** factor, land use map as X_a factor, and erosion feature map as factor with scoring according to the relevant tables and defining a query in GIS environment. Classified ***Z*** valves were used to make potential erosion map by GIS. Relevant equations were used to estimate specific erosion, sediment yield coefficient, specific sediment yield, and total erosion and sediment yield in the watershed.

Amount of sediment yield can be estimated from available sediment concentration data collected at sedimentary gage in the watershed outlet. Estimated amount of erosion and sediment using two models was compared to determine the accuracy of each one.

Results and discussion

In geomorphologic method the percent area of each class of erosion was 4.57, 57.99, 19.72, 11.37, and 6.35, and for EPM model this percentage was 2.81, 79.25, 2.33, 15.61, and 0.00 in the very low (1.), low (2.), moderate (3.), high (4.), and very high (5.) erosion classes respectively. There was fairly good consistency between the two models for the 1st, 2nd, and 4th class but less consistency for 3rd and 5th classes. There was no significant difference over all between the two models.

With regard to the geomorphologic method 49 homogeneous units were determined that belonged to very low, low, moderate, high, and very high classes (Table 3).

Applying the EPM model in sub-watersheds, the amount of sediment yield obtained was approximately 875439 ton/year and applying geomorphologic method led to a yield of approximately 570354 ton/year, compared to the actual observed sediment yield of approximately 686088 ton/year. From this comparison, it is clear that the first prediction model overestimated the sediment yield by about 27% and the second underestimated it by about 17%.

The EPM model estimates potential amount of

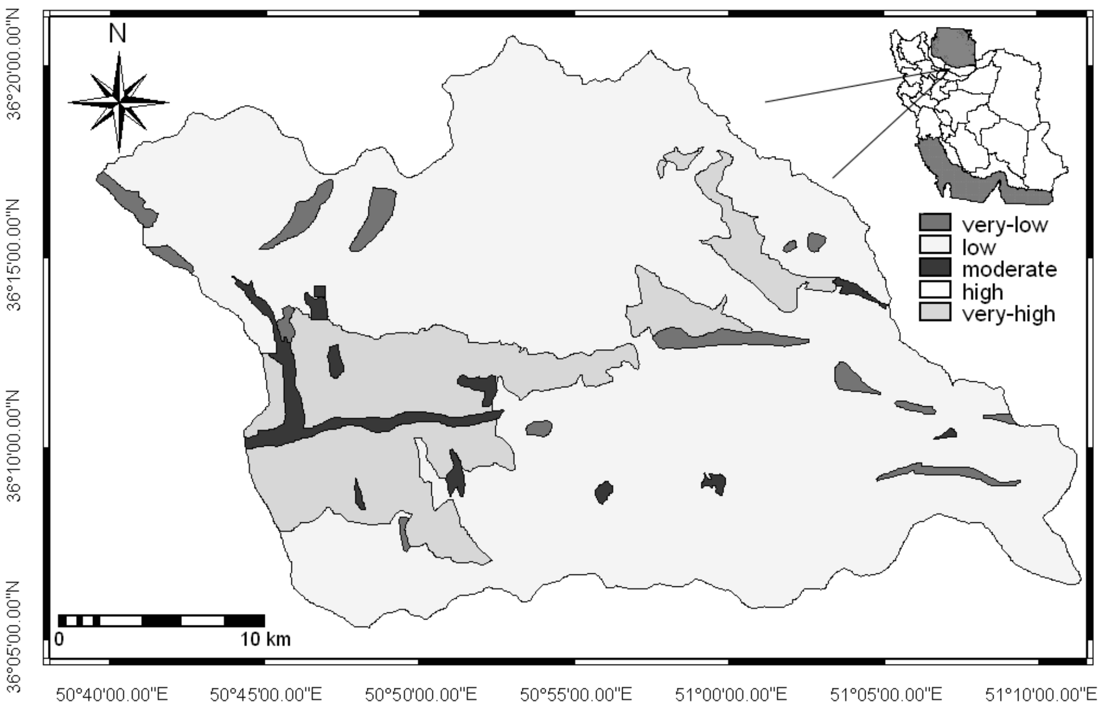

Fig. 3. Potential erosion map resulted from EPM model.

Table 3. Properties of homogeneous units

H. Unit No.	Geology	Erosion face	Ave. slope (%)	Ave. ele. (m)	Z(EPM)	Erosion (EPM)	intensity (Geomorphology)	Area (ha)
1-1-1	A	Low	29.34	2277.98	1.190	very	High	2194.42
2-1-1		High	23.68	2071.70	1.995	very	very high	2284.07
3-1-1		Bad land	26.44	2077.57	1.865	very	very high	889.62
4-1-1		With out E.	20.31	2030.18	0.461	moderate	low	242.12
5-1-1		Mass	25.56	2210.89	1.293	very	very high	476.77
6-1-1		Surface E.	25.17	2047.68	1.293	very	very high	433.56
7-1-1		Bank E.	9.23	1872.44	0.607	moderate	moderate	111.43
8-1-1		Sulifluxion	17.24	2138.87	1.400	very	very high	529.50
1-2-1	B	Low	49.97	2904.26	1.102	very	high	1334.60
2-2-1		Stony	44.94	3098.45	0.330	low	low	3596.98
3-2-1		Rock&Stony	49.42	2931.21	0.339	low	very low	1540.00
4-2-1		Pavement	45.743	216.50	0.398	low	low	2931.93
5-2-1		Snow	50.47	3365.28	0.336	low	low	1656.73
6-2-1		Solution E.	41.42	3429.65	0.332	low	low	95.86
1-3-1	C	Low	46.00	2730.91	0.324	low	moderate	2867.04
2-3-1		With out E.	32.80	2232.34	0.436	moderate	low	301.97
3-3-1		Mass	28.66	2524.87	0.330	low	high	208.00
4-3-1		Old Land	32.82	2377.41	1.310	very high	high	1026.87
5-3-1		Bank E.	14.68	1964.00	0.398	low	low	56.25
6-3-1		Stony	44.56	2770.10	0.330	low	low	20855.29
7-3-1		Rock	42.07	2799.37	0.060	very low	very low	2061.46
8-3-1		Rock&Stony	43.09	3626.96	0.339	low	very low	320.34
9-3-1		Pavement	42.20	2743.87	0.398	low	low	6091.58
10-3-1		Low	46.32	3808.29	0.345	low	moderate	164.35
11-3-1		Snow	46.60	3078.93	0.336	low	low	4402.17
12-3-1		Solution E.	53.43	3696.11	0.321	low	low	322.58
1-4-1	D	Low	47.11	2804.99	0.428	moderate	moderate	191.53
2-4-1		With out E.	39.44	2370.47	0.421	moderate	low	179.20
3-4-1		Stony	45.92	2608.81	0.330	low	low	8517.50
4-4-1		Rock	59.69	2766.98	0.060	very low	very low	226.99
5-4-1		Rock&Stony	45.61	2653.78	0.339	low	low	3087.37
6-4-1		Pavement	46.30	2684.96	0.398	low	low	1415.97
7-4-1		Snow	43.90	3282.37	0.336	low	low	2728.52
8-4-1		Solution E.	53.00	3645.17	0.321	low	low	272.72
9-4-1		Low	40.32	3756.29	0.345	low	moderate	353.63
1-5-1	E	Stony	33.04	2997.40	0.330	low	low	61.75
2-5-1		Rock&Stony	56.40	2998.11	0.339	low	very low	506.55
3-5-1		Pavement	51.17	3205.09	0.375	low	very low	352.10
4-5-1		Snow	43.36	3557.01	0.336	low	low	197.11
1-6-2	F	Low	18.90	1929.82	1.461	very high	high	286.49
2-6-2		High	16.92	1950.43	1.638	very high	very high	796.41
3-6-2		Bad land	24.65	2002.17	1.756	very high	very high	351.47
4-6-2		With out E.	19.16	2370.47	0.462	moderate	very low	283.88
5-6-2		Mass	28.76	2107.75	1.766	very high	very high	356.42
6-6-2		Surface E.	22.75	2161.03	1.310	very high	very high	1725.68
7-6-2		Bank E.	8.38	1867.81	0.502	moderate	moderate	698.71
8-6-2		Stony	29.14	2401.03	0.330	low	low	71.55
9-6-2		Pavement	51.17	2155.71	0.417	moderate	low	419.78
10-6-2		Sulifluxion	21.81	2170.67	1.421	very high	very high	306.47

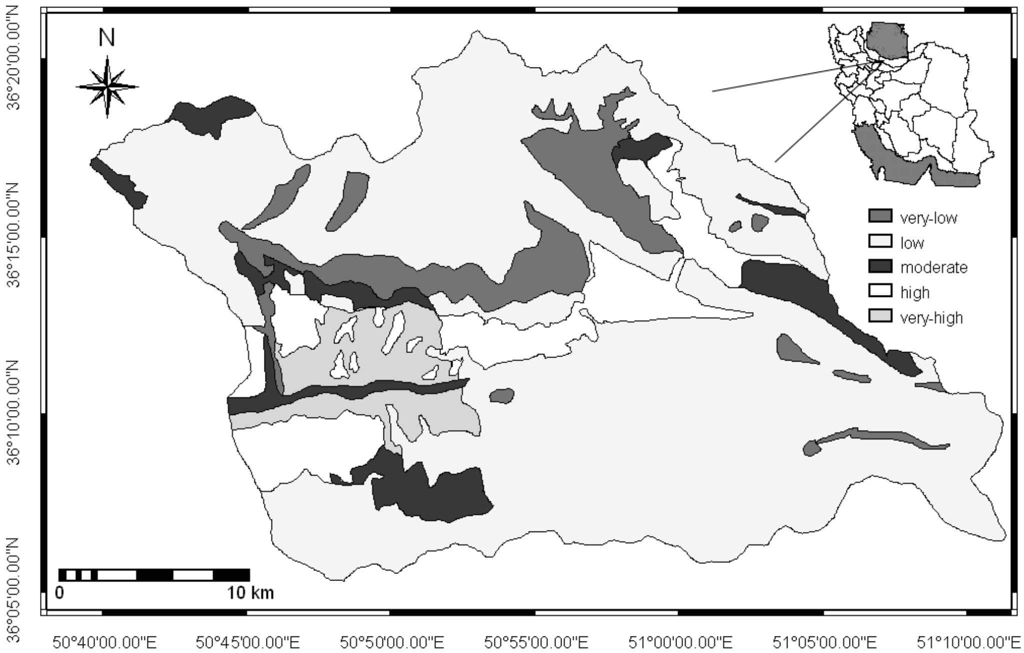

Fig. 4. Potential erosion map resulted from geomorphologic method.

erosion in a specific region and it is possible that the results of this model could be higher than the observed amounts. But the model has some limitations such as getting the effect of slope in resistant rocks and formations that have very low erosion. Further more, the scores given for different factors were developed for Yugoslavia condition. These need to be calibrated for other conditions (Fig. 3).

The geomorphologic method concerns with several factors in each homogeneous unit that could determine the potential erosion more reliably (Fig. 4). But this model is qualitative that should be quantified in future. The results of this research show that if EPM model is applied in homogeneous units, the predictions is consistent with the observed sediment yield.

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Effects of *Formica cunicularia* (Hymenoptera: Formicidae) on revegetated desert ecosystem in the Tengger Desert, northern China

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Abstract

Formica cunicularia **(FC) is a dominant mound-building ant species in arid and semi-arid regions in China. It significantly modifies soil parameters. We investigated the soil modified by FC in different landforms by studying several parameters in soil sampled in ant nests and adjacent (control) plots in different years of artificial revegetation in the Shapotou area of China. The results showed revegetation years, landforms and their interactions significantly affected anthill density and coverage. The longer the dunes were stabilized, the stronger were the FC nest; more nests were present in the hollow areas and windward slopes than in the tops of the dune and on the leeward slopes. There was increased concentration of organic matter, total and available N, P and K in the nests. Samples from ant nests had higher soil electric conductivity and water content than the adjacent soil. Bulk density of ant nests was lower in 10-20cm depths and higher in 0-10 depth than the adjacent soil. The seed bank density and diversity in anthill was higher than in the adjacent soil.**

Introduction

Ants are important components of ecosystems because they not only constitute a great part of the animal biomass but also act as ecosystem engineers (Jones et al., 1994; Patricia, 1998). Ants are important in the subsurface processes due to the alteration of the physical and chemical environment and their effects on plants, micro-organisms, and other soil organisms (Hölldobler and Wilson, 1990; Patricia, 1998).

As a result of ant bioturbation activity, the subterranean soil is turned over to the surface; the organic matter is buried deeper resulting in increased water-holding capacity (Petal, 1978); the network of galleries and chambers increases the soil porosity, drainage and soil aeration (Denning et al., 1977; Gotwald, 1986; Majer et al., 1987; Cherret, 1989) and reduces bulk density (Baxter and Hole, 1967; Rogers, 1972). Studies in agricultural fields show that ant nest affects the water infiltration (Lobry de Bruyn and Conacher, 1994; Wang et al., 1996). Ant bioturbation activities affect soil chemical properties as well. Most studies show an increase in organic matter, P, N, and K in ant mounds in comparison to the adjacent soil (Salem and Hole, 1968; Czerwinsky et al., 1969; Petal, 1978; Mandel and Sorenson, 1982). The soluble and mobile forms of soil mineral nutrients show enrichment in ant mounds (Paton et al., 1995). Soil pH is also affected (Wiken et al., 1976; Petal, 1980). Plant species composition and relative abundance differ between the mounds and the adjacent areas (Woodell, 1974; Andersen, 1982; Horvitz and Schemske, 1986). Ants can disperse plant propagules (Wilson, 1992), and anthills facilitate the appearance of invasive plant species (Bucher, 1982; Farji-Brener and Margutti, 1997). However, most of the studies have been under temperate humid climates and the functional role of ant in arid desert regions is seldom mentioned.

The objective of this study was to determine the effects of *Formica cunicularia* (FC) on soil properties, water content, soil seed bank, and functional role of FC in sand dune over time in the artificially established sand-binding vegetation along the railway line in Shapotou region in China.

Materials and methods

Experimental area

The study was conducted at Shapotou, in the Ningxia Hui Autonomous Region at the southeast edge of the Tengger Desert, which lies at 37°32´ N and 105°02´ E with an elevation of 1,339 m. It is a steppified desert zone between desert and oasis (Shapotou Desert Experimental Research Station, 1991a; Li et al., 1998). The natural predominant plants are *Hedysarum scoparium* and *Agriophyllum squarrosum* with a cover of about 1%. The area has large and dense reticulate barchan chains. The soil is loose and impoverished shifting sand with a moisture content ranging from 3% to 4%. Mean annual precipitation is approximately 180 mm, falling predominantly between June and September. Average temperature in July is 24.3°C and –6.9°C in January. Sand storms and dust events occur on about 174 days per year. Wind speeds are greatest during late spring (April–May), averaging 3.5 m s^{-1}, and are predominantly from the northwest (Shapotou Desert Experimental Research Station, Chinese Academy of Sciences, 1991b).

To ensure smooth operation of Baotou-Lanzhou Railway in the sand dune area, a protective vegetation system was established by erecting 1 m 1 m straw checkerboard sand barriers on shifting sand surface in order to stabilize the dunes. Once the sand surface had been stabilized, a number of native xerophytic shrub species, such as *H. scoparium*, *Artemisia ordosica*, and *Caragana koshinskii*, were planted in checkerboard pattern. Thus a 16-km long vegetation protective system was established, 500 m wide on the north side and 200 m wide on the south side of the railway (Shapotou Desert Experimental Research Station, 1991b; Li et al., 1998). Through more than 40 years after the establishment of artificial vegetation, soil-formation processes of moving dune have taken place. Crust thickness on sand surface has gradually increased, with the further development of soil-formation processes; numerous annual plants, algae, mosses and lichens have invaded the dune field and promoted the development of eco-environment towards the steppified desert zone. Owing to the establishment of numerous species the original moving dune land has evolved into a complex mixture of artificial-natural desert vegetation (Li et al., 2004).

Sampling method and data collection

For studying the density and coverage of anthill and soil turnover capacity, 3 quadrats were established in each landform (dune top, leeward slope, windward slope, and inter-dune depression) among the vegetations at four stages of their development in the 16-km long and 500m wide planted vegetation area in the north of the railway with a total of 48 quadrats. The area of the quadrat was 10m×10m. The anthill numbers, area, and volume of each dome in the sand stabilization areas of different years and landforms were measured. Areas of ant domes were used to estimate anthill coverage. The coverage was estimated using the following formula:

$$s = \pi \left(\frac{D+d}{4}\right)^2$$

where π = 3.1415; D is large diameter in m; and d is small diameter in m.

Soil moisture (SM) of ant mound and adjacent soil (1 m away from anthill) was measured with Trase-TDR (Soil Moisture Equipment Corp., USA) at 0-15 cm and 15-30 cm depth, two times (15^{th} and 30^{th} day) per month from April to October in 2005. Soil bulk density (BD) was measured using a cutting ring (5 cm in depth and diameter); soil pH was measured in water (soil: water ratio = 1:5); soil organic matter (OM) was measured by the method of $K_2Cr_2O_7$; All these methods are described by Liu (1996). Electrical conductivity (EC) was measured using a portable conductivity meter (Cole-Parmer Instrument Company, USA); total N was measured with Kjeltec system 1026 Distilling Unit (Tecator AB, Sweden); phosphorus and potassium were measured using standard methods for observation and analysis developed by the CERN (Liu, 1996).

To determine the effect of ant dome on seed bank composition and the abundance of two kinds of crusts (moss crust and algae crust), 10 soil cores (diameter 10 cm) were taken to a depth of 5 cm from a 25 cm × 25 cm area in these plots at each stage (1956, 1964, 1981 and 1987). These soil cores were immediately placed in flower pot trays 11 cm in diameter, in a temperature-controlled greenhouse. Trays were kept moist by spraying enough water everyday; seedling emerged was discerned and recorded every other day from 15th August to 24th October 2005; once the seedling was discerned, it was removed from the flowerpot. In this study, Simpson index *D* (Simpson, 1949), Shannon–Wiener index *H´* (Peet, 1974) and Margalef richness index *D´* (Margalef, 1958) were used to measure plant diversity, $D=1-\Sigma pi^2$; $H'=\Sigma pi \ln pi$; $d=(s-1)/lnN$; where *pi* is the number of species *i*, *S* is the total number of species *i* in the quadrat, that is, an abundance index, *D´* is the richness index, and *N* is the number of taxa.

Statistical analysis

Statistic analysis was carried out using SPSS 11.5 for Windows software (SPSS Inc., USA). One- and two-way ANOVA were used to detect significant effects of landforms and years revegetated on anthill density, anthill coverage and ant turnover capacity; effects of years revegetated and different sites on total seed bank density; and anthill effects on soil properties within anthill and microbiotic crust. Landforms and revegetated years effects on anthill density, anthill coverage and soil overturned capacity by ant, and revegetated years and sites effects on total seed bank density were analyzed separately with Tukey HSD tests at 0.01 level. Means of soil properties were compared between anthill and adjacent soil using Fisher's protected LSD test at 0.05 levels.

Results

Soil modification

Subterranean sand had been over turned to the surface by FC activity (Fig. 1a). Bioturbation activity of FC led to the presence of channels, chambers, sand aggregates, and maculae in the soil (Fig. 1a, f). The color of small/elliptical mounds was faint yellow in contrast to the soil background color. The mounds were crater-shaped, small in diameter and height, consisting of sand grains linked by a clay matrix, and very susceptible to erosion (Fig. 1b). The microbiotic crust covered by sand overturned by FC changed its color and decomposed (Fig. 1d, e).

Anthill density and anthill coverage differed significantly ($p<0.01$) among vegetation stages (year of revegetation) at different landforms. The anthill density and anthill coverage in relation to landforms was significantly different ($p<0.01$). The anthill density varied from 31.33% ± 4.67% in hollow in the 1956 revegetation to 0% in leeward slope in the 1987 revegetation. The highest mound coverage, 7.80% ± 2.44%, was at hollow in 1956. The activity of FC also led to high sand turnover capacity 0.21 ± 0.09 $m^3/100\ m^2$ at hollow in 1956 revegetation.

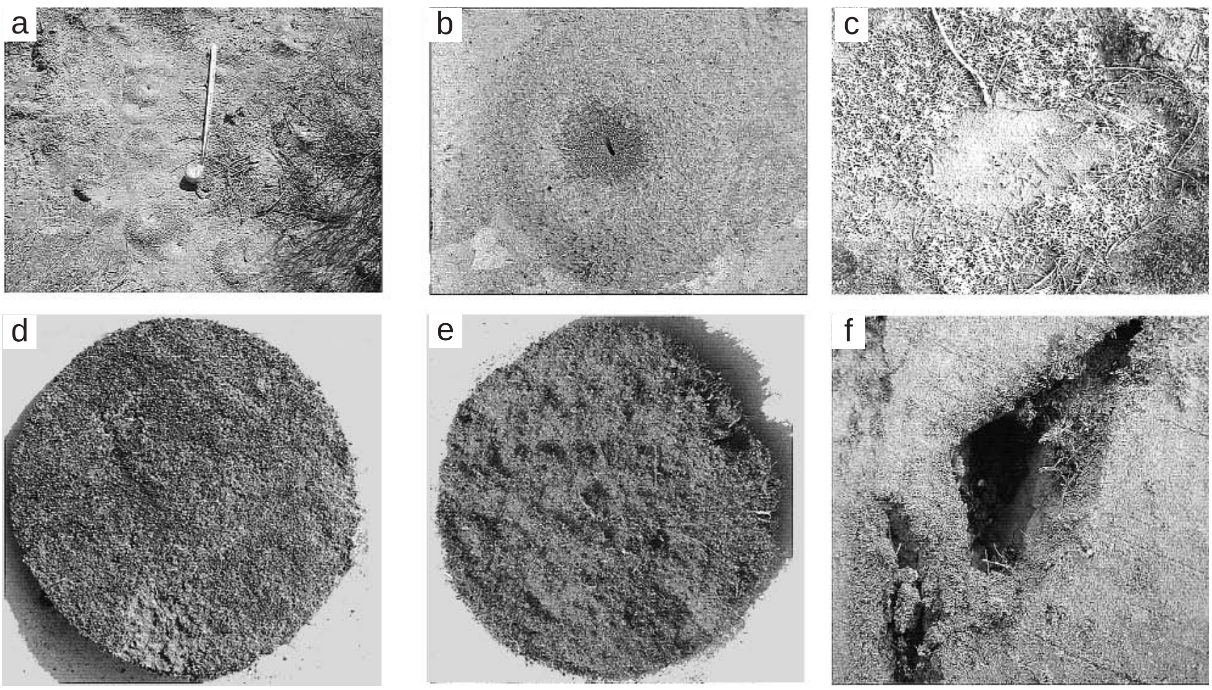

Fig.1. ***Formica cunicularia*** **modified the soil, microbiotic crust and vegetation (a: anthill landscape; b: Mound of ant; c: Annual herbs/grasses around anthill; d: Microbiotic crust uncovered by anthill; e: Microbiotic crust covered by anthill; f: Ant caves in the soil).**

The years of revegetation and landforms affected remarkably the density of anthill and its coverage (p<0.01). The longer the dunes were stabilized, the stronger were the FC nests. The activity of FC also differed with topography, more nests were in the hollow and windward slopes but less in dune tops and leeward slopes (Fig.2 and Fig.3).

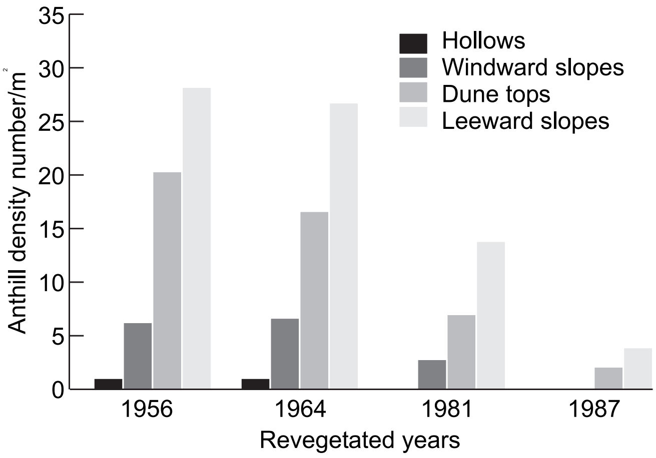

Fig.2. Effect of revegetation years and landforms on anthill density.

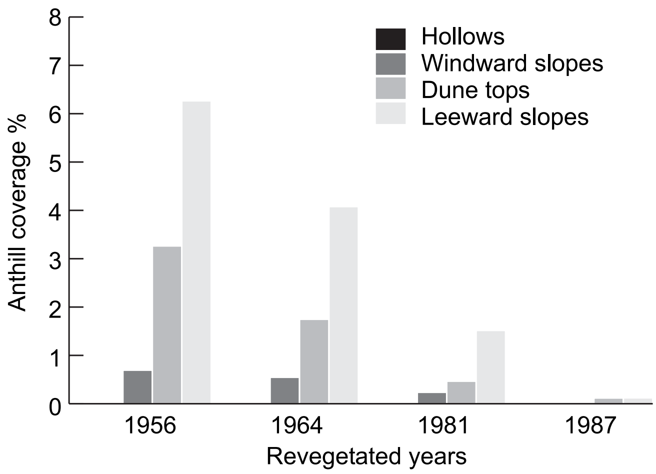

Fig.3. Effect of revegetation years and landforms on anthill coverage.

Soil properties changes

The water content at 0-15cm and 15-30cm depth of anthill was higher than the adjacent soil from April to October in 2005 (Fig. 4). Soil properties between anthill and the soil 1 m away were also significantly (p<0.05) different (Table. 1). Bulk density of 0-10cm depth, electric conductivity,

Table 1. Comparison between anthill and adjacent soil in the mean values of soil parameters.

Plot	Bulk density ($mg.m^{-3}$)		Electric conductivity ($\mu.cm^{-1}$)	pH	Organic matter ($g.kg^{-1}$)	Total nutrient content ($g.kg^{-1}$)			Available nutrient ($mg.kg^{-1}$)		
	0-10 cm	10-20 cm				N	P_2O_5	K_2O	Water-soluble N	P_2O_5	K_2O
Soil adjacent to anthill	1.45±0.02a	1.60±0.02a	136.9±25.30a	8.4±0.3a	12.27±0.4a	0.46±0.05a	0.72±0.07a	24.1±0.4a	3.6±0.4a	1.5±0.2a	16.3±0.5a
Ant hill	1.58±0.04b	1.53±0.02b	160.1±30.30b	7.8±0.2b	13.93±0.7b		0.51±0.03b	0.88±0.02b	25.8±0.5b	4.1±0.37b	1.9±0.3b
18.6±1.1b											

Mean ± S.E., values with different letters are significantly different at P<0.05 (n=10), the same represents no significantly different at P>0.05 (n=10) organic matter, total nitrogen, total phosphorus, total potassium, water-soluble nitrogen, available phosphorus and available potassium increased by 8.97%, 16.94%, 13.55%, 11.71%, 22.24%, 7.09%, 15.21%, 25.58% and 14.29%, respectively, because of the anthill; while the bulk density of 10-20cm soil layer and pH decreased by 4.38% and 7.31%, respectively.

Soil seed bank changes

Five species, *Eragrostis poaeoides*, *Argemisia ordosica*, *Setaria viridis*, *Chloris virgata*, *Bassia dasyphylla* and *Corispermum declinatum*, were found in moss/algae crust. The species composition among four plots overlapped. There were significant ($p<0.01$) differences because of the anthill (Fig. 5). The plant diversity in the crust because of anthill differed in sites revegetated in different years; the highest diversity was in moss crust with anthill, the second in adjacent moss crust , the third in algae crust with anthill, the lowest in adjacent algae crust (Table 2).

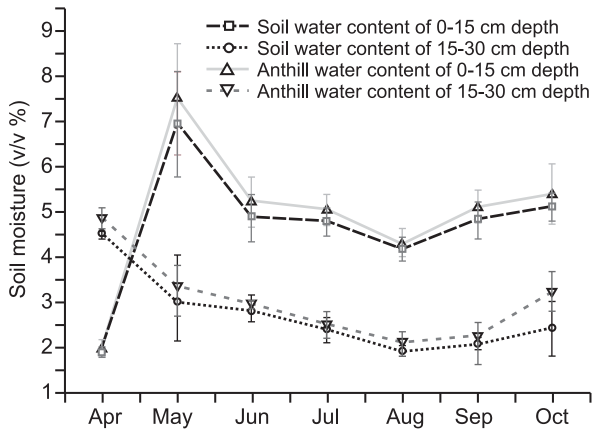

Fig. 4. Comparison of soil water content (mean ± S.E.) between ant nest and the adjacent soil in 0-15 cm and 15-30 cm depth.

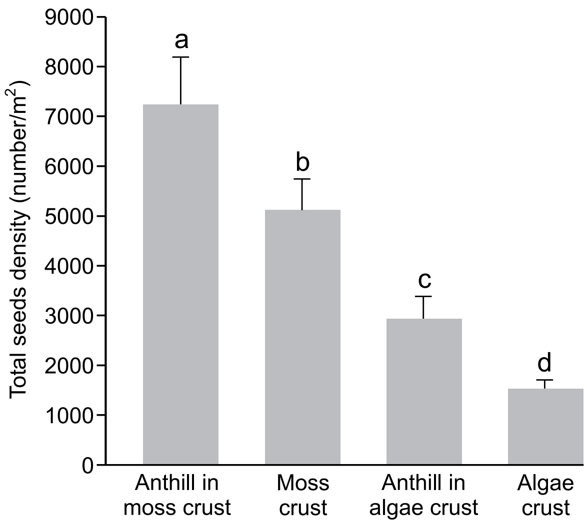

Fig. 5 Comparison of mean±S.E. of total seeds density in different sites (n=15, algae/moss crust and anthill in algae/moss crust), bar with different letters are significantly different at 0.01 level.

Discussion

Soil modification

The anthill density in the studied area depended on the year of revegetation, landforms and their interaction. The anthill density increases with the development of revegetation, because through more than 40 years of evolution after the establishment of artificial vegetation, soil-formation processes of moving dune have taken place, crust thickness on sand surface has gradually increased. With the further development of soil-formation processes, numerous annual plants, algae, mosses and lichens have invaded the dune field, and promoted the development of eco-environment towards the steppified desert zone (Li et al., 2004). These changes have contributed to FC invasion and nest construction. Anthill densities in hollow and windward slope were higher than dune top and leeward slope, because their crusts and soil were thicker than

Table 2. The comparison of soil seedbank diversity in four landscape locations (moss/algae crust and anthill in moss/algae crust)

	Moss crust	Algae crust	Anthill in crust moss	Anthill in algae crust
Simpson' index (D)	0.454	0.348	0.286	0.234
Shanon-Wiener index (H')	0.928	0.769	0.614	0.528
Margaelf richness index (D')	0.362	0.424	0.353	0.386

dune top and leeward slope; the dune top was open to wind erosion, and leeward slope did not adapt to nest construction due to its high degree of slope.

Soil property changes

Our results clearly show that ants are responsible for changes in soil water content. FC bioturbation activity results in the development of channels, chambers, soil aggregates, and maculae in the soil. Subterranean soil is turned over to the surface and the organic matter is buried deeper which increases water-holding capacity. Because of increased porosity, the water infiltration during rainfall events would be higher leading to higher moisture content. Furthermore, the crust and top soil in the anthill free area would promote the capillary rise and thus evaporative loss of the water from subsurface layer (Xiao et al., 1996), while the coarse texture of ant mound would impede capillary movement to the surface, thus conserving moisture from evaporation (Noy-Meir, 1973; Eriksson et al., 1989). Some studies have shown that the presence of microbial crusts at the surface would reduce rain permeability through soil in arid and semi-arid zones (Lee, 1997; Li et al., 2000).

Our study confirms that ants are able to modify soil chemical properties (soil pH, organic matter, P, N, and K concentration). We believe those modifications are the result of more active decomposition, ant foraging activities (because ants carry their prey to their nest and do aphid cultivation) and ant feces. Most studies have shown an increase in organic matter, P, N, and K in ant mounds in comparison to adjacent soil (Salem and Hole, 1968; Czerwinsky et al., 1969; Petal, 1978; Mandel and Sorenson, 1982). The changes seem to be greater in poorer soils (Czerwinsky et al., 1971; Petal, 1992) and depend on ant colony size, biomass and turnover (Petal et al., 1992). In some cases, the extent of nutrient increase suggests an input from external sources (Levan and Stone, 1983) or more active decomposition. The electric conductivity of soil increased in the ant mound because of the mineral nutrient enrichment in the ant. Only a few investigations have been made on the influence of ant activity on the soil pH (e.g., Wiken et al., 1976), and there is some evidence that ant activity lowers the pH in alkaline soils and increases it in acid soils (Petal, 1980).

Seed bank changes

Ants can disperse plant propagules (Wilson, 1992) and anthills facilitate the appearance of invasive plant species (Fig. 2c) (Bucher, 1982; Farji-Brener and Margutti, 1997) and sometimes change or quicken the course of plant succession (Jonkman, 1978). In arid deserts of China, such as the Tengger Desert, the windy season often begins at the end of September when seeds begin to spread, and stops at the end of April. Only 12% of the total annual precipitation occurs during this period. Under these conditions, the seed is concentrated under the canopy of shrubs or around animal holes and seed cannot lodge where crusted soil surfaces are smooth and intact. This phenomenon is particularly strong in the environment dominated by wind. Therefore, the disturbance of biological soil crust by ant activity can increase the germination due to the enhancement of seed entrapment in the soil. The seeds fall into the cracks in the crust protecting it from removal by wind, runoff or ants. This result is also supported by field evidence from sub-tropical deserts. Thus the presence of biological soil crusts can affect the amount of seeds that germinate and establish. At the same time, owing to higher water content and nutrition in anthill than in the adjacent soil, the environment for plants to establish from the lodged seeds in anthill soil is better than in the adjacent soil.

Conclusion

The establishment of planted sand-binding in the Shapotou region promoted the improvement and restoration of regional habitat and provided suitable condition for ants. Nest activities of ant also affected the soil properties. Owing to ant bioturbation, soil moisture, texture, properties and seed bank changed. All these changes resulted in increased soil heterogeneity, improved soil condition, and hastened the evolution of soil and vegetation.

Acknowledgment

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The influence of the Indian Ocean sea surface temperature on the winter precipitation in south-western Iran

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Abstract

An investigation was conducted to evaluate the impact of the Indian Ocean sea surface temperature (SST) on dry and wet conditions in south-western Iran during boreal winter. Monthly (January to March) precipitation and corresponding SST data were collected for the period 1951-1993. The marine data set comprised the mean values of 2° by 2° monthly time series of SST values for the Ocean waters between 40° to 120° E and 0° to 22° N. All monthly data were transformed into seasonal time series and a sequential correlation analysis was performed to investigate temporal and spatial strength of the SST-precipitation correlations. In addition to the correlation analysis, the SST-precipitation composites were constructed to examine the role of the positive and negative phases of the Indian Ocean SSTs on the occurrence of seasonal dry and wet events in Iran. The study demonstrated that the fluctuations in the SST data between 12° to 18° North and 60° to 66° East are positively correlated with winter rainfall in southern Iran. The applied phase analysis revealed that, while from 10% to 30% increase in winter precipitation was expected during warm SST phase, the precipitation showed about 10% to 50% decrease when the cold SST phase prevailed.

Introduction

A number of studies have shown a significant correlation between Indian Ocean SSTs and rainfall over the nearby regions (for example Nicholls, 1989; Aralikatti, 1992; Cordery and Opoku-Ankomah, 1994; Frederiksen and Balgovind, 1994; Clark et al., 2000; Gabriel et al., 2003; Kumar et al. 2005; Shinoda and Han, 2005; Wang et al., 2006; Kucharski et al., 2006). Nicholls (1989) and Drosdowsky (1993) showed that the anomalies of Indian Ocean SSTs are related to the Australian seasonal rainfall. Aralikatti (1992) found that Arabian Sea (north-west part of the Indian Ocean) SSTs can be used for forecasting the Indian monsoon rainfall. Ward and Folland (1991) reported that the central Indian Ocean SSTs are statistically correlated with the rainfall of the north Nordeste region in Brazil. Cordery and Opoku-Ankomah (1994) have shown that the major patterns of the Pacific and Indian Ocean SSTs are related to the rainfall in New South Wales, Australia.

According to Cadet (1985), both pressure and temperature fields of the Indian Ocean are negatively correlated with the Southern Oscillation (SO) phenomenon which is inconsistent. One would generally expect that positive pressure anomalies would correspond to negative temperature anomalies and vice versa. The study of Beltrando and Camberlin (1993) supports Cadet's findings as they mentioned 'between the extremity of the Horn of Africa and India, correlations (at least during the northern summer months) are of the same sign for pressure and sea temperature'. Beltrando and Camberlin (1993) also found a significant correlation between rainfalls over the eastern Horn of Africa and some surface parameters including Southern Oscillation Index (SOI) and the SST and pressure fields of the Indian Ocean.

Gabriel and Harrison (2003), found strong simultaneous and lead correlations between distinct Indian Ocean SST patterns and precipitation anomaly in the Western Ghats and the central plains region of India, but did not find similarly strong connections with all-India rainfall. Verdon and Franks (2005) investigated the relationship between SST variability occurring over the Indian Ocean and winter rainfall variability in eastern Australia. They com-

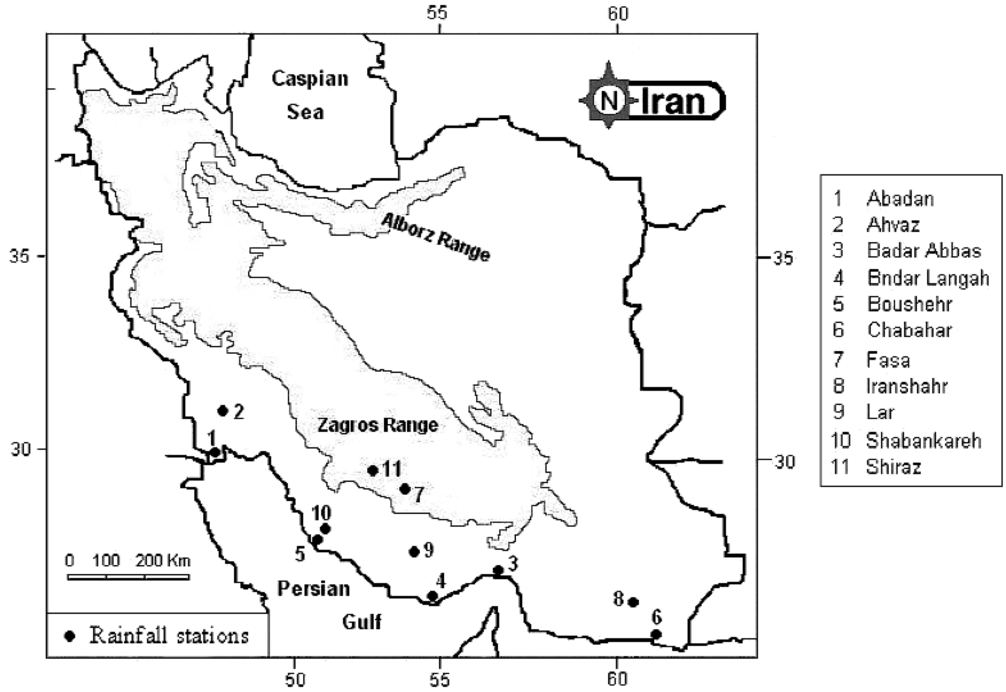

Fig. 1. The geographical location of the synoptic stations over south-western parts of Iran.

pared six indices of SST variability to rainfall and showed that a strong relationship existed between a number of these indices and winter rainfall. In particular, anomalous SSTs over the Indonesian region provide a good indication of winter rainfall variability in eastern Australia.

The Islamic Republic of Iran has an area of 1,648,000 km2 and comprises two major mountain systems, namely the Alborz and Zagros ranges (Fig.1). These two ranges influence the amount and distribution of rainfall over the country. The average annual precipitation over the country is estimated to be around 250 mm, occurring mostly from October to March. Annual precipitation is lower in the eastern and southern halves of Iran compared to the western and northern halves. While the Caspian Sea shores, with the annual precipitation ranging from about 600 mm in the east to 1900 mm in the west, are characterized as the wet zone of the country, southern and in particular south-eastern parts of the country are mostly categorized as arid or semi-arid regions.

Although the impact of the Pacific-based SSTs on Iran's precipitation has been investigated in a number of studies, e.g. Nazemosadat and Cordery (2000), Nazemosadat and Ghasemi (2004), the effect of the Indian Ocean surface climate on this precipitation has not been studied. The present study was, therefore, initiated to find a part of the Indian Ocean whose SSTs are strongly related to rainfall variability in Iran. The possibility of rainfall forecasting with the use of SOI or the Indian Ocean SSTs has also been investigated.

Data and methods

The basic data used in this study were total monthly (January to March) precipitation from 11 synoptic stations (Fig. 1) located over the south-western parts of Iran. Although the precipitation data were available till recent years, the data for the period 1951 to 1993 were considered to match the available record length of the Indian Ocean sea surface temperature (SST) data. Monthly precipitation data were transformed to seasonal averages using ordinary averaging process to obtain winter precipitation.

As a main component of ocean-atmosphere interface, sea-surface temperature (SST) is known as the most important index for climate studies. This is because the ocean has a huge surface thermal capacity to influence climate, and precipitation in particular. The mean monthly SSTs of all 2° longitude by 2° latitude of Comprehensive Oceanic and Atmospheric Data Set (COADS) cells were extracted over the tropical water of the Indian Ocean from 40° E to 120°E and from 0°N to 20°N (Fig. 2). The extracted data spanned the period 1951-1993.

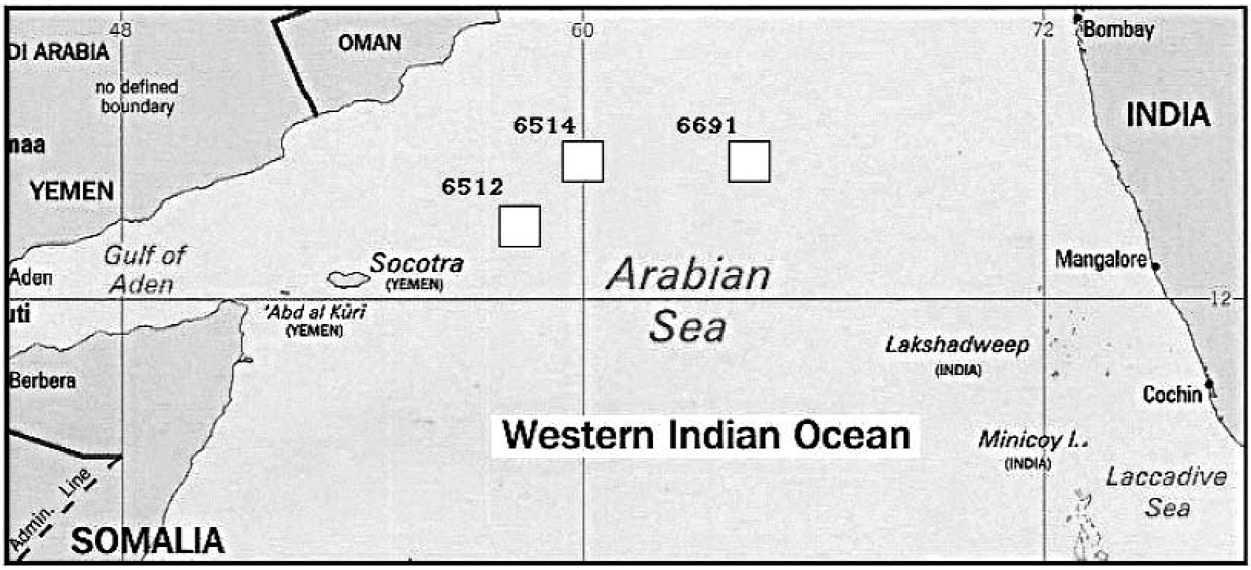

Fig. 2. The geographical location of the studied grid points in the Indian Ocean.

Due to too many missing values in some cells, the availability of data in each 2° by 2° cell was examined to decide if it was to be discarded. Those cells for which the ratio of the number of available data to the total number of possible records was more than 0.80 were retained (about 300 cells) and the others discarded from further computation. Similar to precipitation data, all monthly data were transformed to seasonal time series.

The sequential correlation analysis with 15, 20, 30 and 40 years of window widths (Nazemosadat and Cordery, 2000) was used to investigate the strength and temporal stability of the SST-rainfall relationships. The median of the obtained sequential correlation coefficients (MSCC) were then determined and used as a criterion for the evaluation of the effects of Indian Ocean surface climate on the availability of water resources in southern Iran. Although the correlation used various window widths, due to similarity, the results were provided for 25 years window width.

In addition to correlation analysis, precipitation variability during various phases of the Indian Ocean SSTs was also investigated. By the adapted definition, the warm or cold phase of the SST data comprises those years during which seasonal SST, when the data are listed in ascending order, remains respectively in upper or lower 25% of all observed values (Nazemosadat and Ghasemi, 2004; Ghasemi, 2003). The warm and cold phases of the SSTs were, therefore, specified and the mean of SST-precipitation composites were determined for these phases (Rw and Rc, respectively). The ratio of these mean values to the mean precipitation during neutral phase (Rb) [Rw/Rb and Rc/Rb for the warm and cold phases respectively] was computed and used for the evaluation of the effects of SST extreme phases on the rainfall amount as shown below.

R_w/R_b= Mediun during warm period/ Mediun during base period (1)

R_w/R_b= Mediun during cold period/ Mediun during base period (2)

Results and discussion

Correlation analysis

Sequential correlation analysis was performed between winter rainfall in all eleven stations and the SST data in the retained cells. Except for a limited area over the Ocean (12° to 18° north and 60° to 66° east), correlations was generally found to be insignificant for most of Ocean surface. Table 1 shows the MSCC values (for 25 year window width) between winter precipitation in southern Iran and corresponding SST data for some cell boxes located in this region. The given correlation coefficients have indicated that the variability in south-western Iran's winter rainfall is positively associated with the fluctuation of the SST over this particular region of the Indian Ocean. The most significant coefficients are found in the grid of 6512, for which correlations are significant at the 5% level, in Ahwaz, Bandar Lengeh, Chabahar, Lar and Shabankareh. The results indicate that the SST fluctuation accounts for about 12 to 22% variance of the winter precipitation in southern parts of Iran. To sum up, winter dry condition is generally, expected during cold winter SST and abundant precipitation tends to occur when winter SST is warmer than usual.

Table 1: The MSCC between the winter Indian SST and winter precipitation in the southern parts of Iran for four grid points. A 25 year window width is used. Bolded values are significant at 5% level.

	6512	6514	6691
Abadan	**0.36**	0.26	0.30
Ahvaz	**0.34**	0.28	**0.36**
Bandar Abbas	0.31	0.21	0.26
Bandar Lengeh	**0.34**	0.27	0.25
Boushehr	0.27	0.10	0.29
Chabahar	**0.39**	0.26	**0.34**
Fasa	0.21	0.05	0.22
Iranshahr	0.29	0.14	0.23
Lar	**0.35**	0.23	0.27
Shabankareh	**0.47**	**0.48**	**0.39**
Shiraz	0.27	**0.44**	0.16

Figure 3 outlines the concurrent fluctuations of the Indian Ocean winter SST in the grid of 6514 and rainfall for Shabankareh as an example. Both SST and rainfall values are indicated by their normalized anomalies to be more compatible. This figure suggests that, when normalized SST is positive or negative, for 60% of the recorded events, the corresponding winter rainfall anomalies are also respectively positive or negative.

Phase analysis

Figure 4 shows the values of Rw/Rt, Rc/Rt and Rw/Rc for all studied stations when the data of grid 6512 is used. As indicated, the Rw/Rt ratio is equal to or greater than 1.0 in all stations with maximum value of 1.3 in Lar indicating about 30% increase in winter rainfall of this station during warm SST events. The ratio is, however, near 1.0 in Shiraz, Boushehr, Bandar Abbas, Bandar Lengeh and Fasa suggesting inconsiderable influence of the warm episodes on the rainfall of these stations. In contrast to Rw/Rt, the values of Rc/Rt is mostly smaller than 1.0 with a minimum value of 0.5 in Iranshahr, indicating a shift towards dry condition during cold SST phase. Exception is found for Chabahar for which the ratio is about unity.

For evaluating the measure of the influence of extreme SST phases on rainfall variability in southern Iran the Rw/Rc ratio was also computed and illustrated in Figure 4. As shown there, the ratio varies between 1.1 and 2.1, indicating a considerable difference in winter precipitation due to the alternation of the SST phases over this part of the Ocean. Maximum value of 2.1 is found in Iranshahr, suggesting that the average winter precipitation during warm events is 2.1 times of the average winter precipitation during cold events.

These ratios for the grids 6514 and 6691 are shown in Figures 5 and 6. For these two grids the ratio Rw/Rt is equal to or greater than unity for all stations and the Rc/Rt ratio is less than unity. The ratio Rw/Rc is greater than unity in all stations for both grids and varies between 1.1 and 2.5 in grid 6514 and between 1.2 and 2.3 in grid 6691.

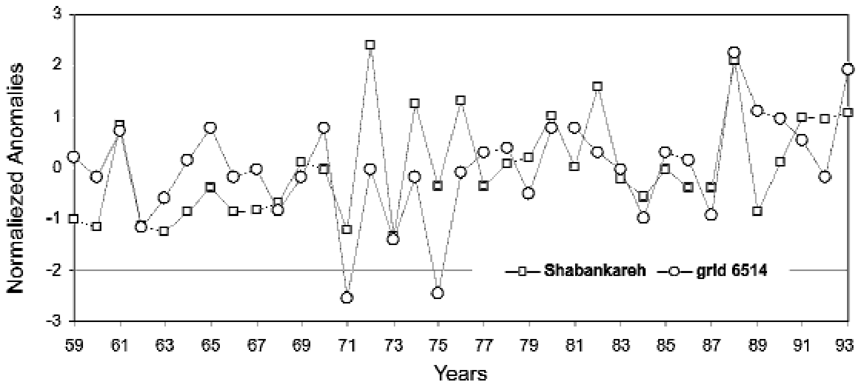

Fig. 3. The concurrent fluctuations of the Indian Ocean winter SST in the grid of 6514 and rainfall for Shabankareh. Both SST and rainfall values are indicated by their normalized anomalies.

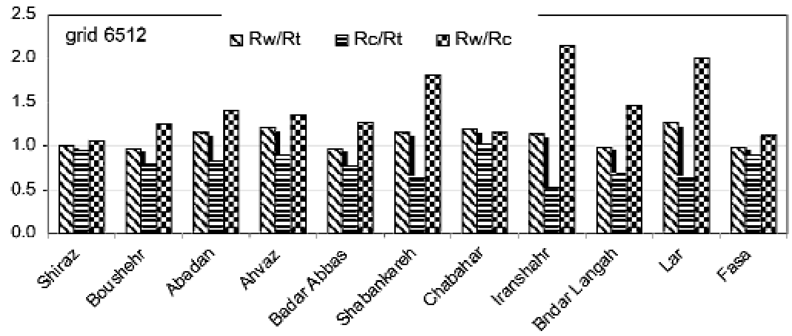

Fig. 4. The ratio Rw/Rt , Rc/Rt and Rw/Rc in grid 6512 for all studied stations.

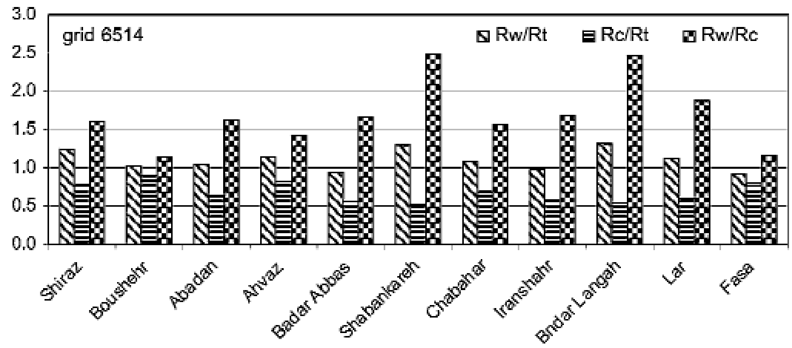

Fig. 5. The ratio Rw/Rt , Rc/Rt and Rw/Rc in grid 6514 for all studied stations.

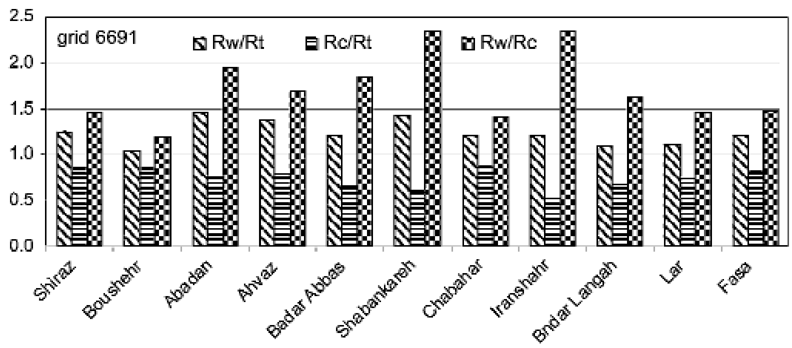

Fig. 6. The ratio Rw/Rt , Rc/Rt and Rw/Rc in grid 6591 for all studied stations.

Conclusion

The applied correlation analysis has revealed that the fluctuation in the SST data over a limited part of the Indian Ocean accounts for about 12% to 22% of variability in winter rainfall in southern Iran. Significant and positive correlations were found for the SST area bounded between 12° to 18° north and 60° to 66° east. The results indicate that positive or negative SST anomalies are generally harmonized with above and below normal winter precipitation, respectively, in southern Iran. The analysis of SST-precipitation composites revealed that about 20% increase in the precipitation was expected as the warm SST phase prevailed over this part of the Ocean. On the other hand, up to 50% suppression in winter rainfall was anticipated during cold phase of these SST data.

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Detection of soil evaporation and plant transpiration by three-temperatures (3T) model

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Abstract

Soil evaporation (*E*) and plant transpiration (*T*) are two main components of water consumption in ecosystem. Estimation of *E*, *T*, and evapotranspiration (*ET)* is required for water-saving agricultural and sustainable use of water resource. To accurately estimate *E*, *T*, and *ET*, there are three challenges. There is a difficulty to separate *ET* into its two components, *E* and *T*. The second challenge is the heterogeneity of the land cover because most of the available methods are applicable only to flat and uniform area, which is rarely the case in the natural ecosystem or in farmland. The third challenge is that most of the conventional models for *ET* estimation are based on the measurements at points. Scale up of *ET* model to a heterogenous area or to a regional level is difficult. Based on energy balance theories, a model to use surface temperature to detect of *E* and *T* is proposed. Because the three temperatures are the key components for the proposed model, it is referred as 'three temperatures (3T) model'. The major advantages of 3T model are that: (1) the quantitative information on *E* and *T* can be obtained with considerably fewer measurements and can be remotely measured; (2) *E* and *T* can be separately estimated and can be applied under heterogeneous conditions; and (3) aerodynamic resistance, surface resistance, and empirical parameters are not included. Therefore, there is no fetch requirement.

Introduction

Water saving agricultural and sustainable use of water resources are extremely important for China because of the shortage of water resource and high pressure on farmland caused by huge population and developing economy. For example, the grain yield of spring wheat-maize rotation farmland in northern China plain (main food production region in China) can be as high as 15,000 kg per hectare and the related water cost for evapotranspiration (*ET*) is around 850 mm (Liu, et al., 2002; Zhang et al., 2003). Because the annual precipitation is less than 500 mm in this region, agriculture depends heavily on irrigation by pumping of ground water. The over utilization of ground water causes serious lowering of the water table and the decrease can be as much as 1 m per year. For some of these areas, there is already no ground water available for irrigation.

Soil evaporation (*E*) and plant transpiration (*T*) are two main components of water consumption in agriculture. A high transpiration rate is usually related with high yield, which could not be reduced for maintaining high biomass productivity. Water lost by evaporation from soil surface could be as much as 30 % of total evapotranspiration (*ET*) in Northern China (Zhang et al., 2003). Because water lost by *E* is not directly related with biomass production, reducing *E* can increase water use efficiency. At a field level, decreasing *E* can be considered as one of the most practical ways to save water. To achieve this goal, accurately estimation of *E*, *T*, and *ET* is highly required.

To accurately estimate *E*, *T*, and *ET*, there are three challenges. One is the difficulty to separate *ET* into its two components, *E* and *T*. Studies of *ET* on regions characterized by partial or sparse plant canopy cover are especially difficult because the relative contributions to the total *ET* from soil and plant can vary throughout a day and the season. The second is the heterogeneity of farm lands. Because most of the available models to estimate *ET* are applicable only to a small, flat, and uniform area, the applicability of these models is seriously limited. Moreover, most of the conventional models for *ET* estimation are based on the measurements at points. Scaling up of *ET* model to a heterogeneous area or to a regional level is still a challenge.

The approaches based on surface temperature have the potential to overcome these challenges. It is well established from energy balance considerations that the surface temperatures of vegetation and ground vary with evapotranspiration, photosynthesis and other environmental factors (Fuchs and Tanner, 1990). Surface temperatures of vegetation and ground have therefore been used to detect bioenvironmental information. Ehrler (1973) suggested the possibility of using canopy-air temperature difference as a guide to irrigation scheduling because of a linear relation between the leaf-air temperature difference and the vapor pressure deficit. Weyers & Lawson (1997) reported that thermographic measurement of temperature could detect photosynthesis. By including the temperature of a dry soil surface (the surface of a dry soil without evaporation), Qiu et al. (1998) proposed and verified a model for estimating evaporation by using the infrared thermometer measured surface temperature. This model was also extended for estimation of plant transpiration (Qiu et al., 1996). On the basis of these studies, remote sensing of surface temperature has become an established technique for diagnosis of bioenvironmental information and has been widely applied in the fields of CO_2 flux monitoring, pollution monitoring, and agriculture (Jones, 1999).

Moran et al. (1994) proposed a surface-air temperature and vegetation index to estimate crop water deficit. The most significant point of this study was the applicability to the partially vegetated field. Later, Moran et al. (1996) combined the Penman-Monteith equation with measurements of surface temperature and reflectance to estimate evaporation rates of semiarid grassland. Moran et al. (1997) also suggested that measurements of soil and crop properties at sample sites combined with multispectral imagery could produce accurate, timely maps for soil and crop. By combination of the surface temperature and vegetation index, these technologies were applicable in remote sensing (Karnieli et al., 2001). Based on these studies, a simple model to use surface temperature to remotely detect soil evaporation and plant transpiration is proposed and verified in this study.

Theoretical development and analysis

Soil evaporation

The energy balance of a bare soil surface can be described by the following equation:

$$E = R_n - G - H \qquad (1)$$

where *E* is the soil evaporation, *Rn* the net radiation of the soil surface, *G* the soil heat flux (the rate at which heat is transferred into the soil profile), and *H* the sensible heat flux between soil and atmosphere. All units are in J m^{-2} s^{-1}. Positive direction for *Rn* is toward the soil surface. Positive directions for *G*, *LE*, and *H* are away from the soil surface. Sensible heat flux *H* can be expressed as:

$$H = \frac{\rho C_p (T_s - T_a)}{r_a} \qquad (2)$$

where ρC_p is the volumetric heat capacity (J m^{-3} K^{-1}), T_s the temperature of the drying soil surface (K), T_a the air temperature (K), and r_a the aerodynamic resistance (s m^{-1}). Supposing there is a small surface area of a dry and deep soil column isolated from the surrounding drying soil, we assume that the air temperature, humidity, wind speed, and other atmospheric variables of the surrounding field are not significantly modified by the presence of the dry soil column. Because there is no water in the dry soil column, LE is negligible. By assuming that the air temperature at reference height is same everywhere and r_a of the drying soil is approximately equal to the r_a of the dry soil (Fox, 1968, Ben-Asher et al., 1983), r_a can be expressed as:

$$r_a = \frac{\rho C_p (T_{sd} - T_a)}{R_{nd} - G_d} \qquad (3)$$

where T_{sd} is the temperature of dry soil surface (K), R_{nd} the net radiation of dry soil (J m^{-2} s^{-1}), and G_d the heat flux in dry soil (J m^{-2} s^{-1}).

Results of our field experiments proved the hypothesis that r_a of the drying soil is approximately equal to the r_a of the dry soil (Qiu, 1996). Combining Eq. (3) with Eq. (1) and (2), an equation to estimate evaporation from bare soil is obtained:

$$E = R_n - G - (R_{nd} - G_d)\frac{T_s - T_a}{T_{sd} - T_a} \qquad (4)$$

The necessary input parameters of Eq. (4) are temperature (T_s, T_a, and T_{sd}), net radiation (R_n and R_{nd}), and soil heat flux (G and G_d). Qiu et al.

(1996, 1998) have given detailed discussion for the development and verification of Eq. (4).

Soil evaporation transfer coefficient

We define the temperature term in Eq. (4) as 'soil evaporation transfer coefficient' and assign to it a symbol h_a (Qiu et al., 1999 a,b).

$$h_a = \frac{T_s - T_a}{T_{sd} - T_a} \quad (5)$$

Two special cases will now be examined to explain the property of h_a. (i) The wet soil dries continuously until its surface water content is equal to the water content of the reference dry soil. Under this condition, we can get $T_s = T_{sd}$, $R_n = R_{nd}$, and $G = G_d$. Consequently $h_a = 1$ and the two parts of the right hand side of Eq. (4) are equal to each other. Under this condition soil evaporation is zero. Thus, in Eq. (4) the *E* is equal to zero. (ii) The second extreme condition is saturated soil, where soil evaporation is controlled by atmospheric demand. Empirical models are often used to estimate soil evaporation under this condition. One of them was proposed by Priestley and Taylor (1972) to obtain daily potential evaporation:

$$E_p = 1.26 \frac{\Delta}{\Delta + \gamma} (R_n - G) \quad (6)$$

Eq. (6) is usually applied to calculate mean values of potential evaporation over periods of a day or longer, where *D* is the derivative of saturated vapor pressure with respect to air temperature (Pa K^{-1}) and *g* is the psychrometric constant (66 Pa K^{-1}). We examined this model and showed that there is no major difference between Eqs. (4) and (5) when soil is saturated. Eq. (6) proved to be true for high wind speed that is sufficient to mix soil and air vapors and to satisfy conditions of minimum potential evaporation (also referred to as equilibrium evaporation). As defined by Priestley and Taylor (1972), during this stage of evaporation, because the water vapor deficit near soil surface is absent, the surface temperature of the wet soil is in equilibrium with air temperature (i.e. $T_s = T_a$) and the second term in the right hand side of Eq. (4) is zero. Thus, Eq. (4) becomes an expression for potential evaporation from the saturated soil at its maximum rate. In the analysis to obtain Eq. (6) under conditions of equilibrium potential evaporation, the aerodynamic component was negligible. Aerodynamic component was also negligible in Eq. (4) under the same conditions. In spite of this similarity, Eq. (4) does not include the vapor pressure function *D/(D+g)* and the empirical factor 1.26. To resolve this discrepancy we examined and showed that during midday when evaporation is at its maximum the product 1.26 *D/(D+g)* » 1 and Eq. (4) coincides with Eq. (6). During these hours as air temperatures varies from 25 to 35 centigrade, *D/(D+g)* can vary from 0.747 to 0.824 and the product of these values with Priestley-Taylor factor (1.26 in Eq. (5)) approximates a value ranging from 0.93 to 1.03. Thus, for the theoretical case in which saturated soil surface evaporates at equilibrium potential evaporation at midday, our model complies with the model of Priestley &Taylor (1972). We can therefore conclude from the preceding that the proposed model is not dependent on aerodynamic resistance and provides consistent limits between no evaporation from a dry soil surface and potential evaporation from a saturated soil surface.

Plant transpiration

Assuming that there is an imitation leaf canopy in the plant canopy with a relatively small volume, the temperature, humidity, wind speed, and other environmental parameters of the plant canopy are not significantly modified by the imitation leaf canopy. It is assumed that temperatures of plant canopy and imitation leaf canopy are represented by temperatures of sunlit leaves and imitation leaves, respectively. Hereafter, we refer to the imitation leaf canopy as the imitation leaf and the temperature of the imitation leaf canopy as imitation leaf temperature. It is assumed that the radiation absorptive and albedo properties of these imitation leaves are similar to those of plant leaves. Transpiration does not occur from imitation leaves and the latent heat flux is zero.

The energy balance of the canopy is represented by the equation (Monteith & Unsworth, 1990):

$$R_n = G + H + LE \quad (7)$$

where *Rn* is the net radiation of the canopy, *G* the heat flux to soil, *H* the sensible heat flux from canopy to air, and *LE* the latent heat flux to air. All the units are expressed in J m^{-2} s^{-1}. Since these variables can be positive or negative, depending on their directions, positive direction for *Rn* is toward the canopy surface and positive directions for *G*, *H*, and *LE* are away from the canopy surface. It should be emphasized that we only focus on the energy balance of the canopy by using Eq. (7). The exposed soil portion of the partially covered canopy is separated by using vegetation coverage. In the vegetation-covered area, the incident radiation is intercepted by the canopy so that the partitioning of energy on the soil surface is relatively negligible (Monteith, 1965). Thus evaporation from the canopy-shadowed soil is generally low and *LE* is often expressed as canopy transpiration (*T*).

In Eq. (7), the net radiation can be measured or estimated from solar radiation and temperature. Generally *G* is negligible for the canopy on a daily basis (Ben-Asher et al., 1989; Monteith & Unsworth, 1990). Jackson (1982) expressed *H* by the following equation:

$$H = \frac{\rho C_p (T_c - T_a)}{r_a} \tag{8}$$

where T_c the canopy temperature (K). Since the imitation leaf is in the same canopy, the same value of r_a can be used for the imitation leaf (Qiu, 1996; Qiu et al., 1996). By assuming that the air temperature at reference height is the same everywhere and r_a of the canopy is approximately equal to the r_a of the imitation leaf, r_a can be expressed by the following equation:

$$r_a = \frac{\rho C_p (T_p - T_a)}{R_{np}} \tag{9}$$

where T_p is the temperature of the imitation leaf surface (K) and *Rnp* the net radiation of the imitation leaf (J m^{-2} s^{-1}). Combining Eq. (9) with Eqs. (7) and (8), an equation to estimate transpiration from plant canopy can be derived:

$$T = R_n - R_{np} \frac{T_c - T_a}{T_p - T_a} \tag{10}$$

On the basis of the above data, the plant transpiration can be estimated by Eq. (10). The necessary input parameters of Eq. (10) are the temperature (T_c, T_a, and T_p) and net radiation (*Rn* and *Rnp*).

Plant transpiration transfer coefficient

The temperature term in Eq. (10) is the key component to calculate transpiration. Therefore, a plant transpiration transfer coefficient (h_{at}) is defined as:

$$h_{at} = \frac{T_c - T_a}{T_p - T_a} \tag{11}$$

Theoretically, h_{at}= 1, and determines transpiration from its minimum value (zero) to its maximum value (potential transpiration rate).

Potential transpiration: The upper limit of transpiration rate is determined by the minimum value of h_{at}. This is the situation when there is no water shortage, and *T* is approximately equal to the potential transpiration rate. There is no major difference between this model and the canopy-air temperature difference models under this condition. If the soil heat flux under a fully covered canopy is negligible and stomatal resistance is approximately equal to zero, the canopy-air temperature difference models can be expressed (Tanner and Fuchs, 1968) as:

$$T = R_n - \rho C_p \frac{T_c - T_a}{r_a} \tag{12}$$

Meanwhile, the Penman–Monteith model gives the relationship between *T* and vapor pressure deficit (Monteith and Unsworth, 1990) as:

$$T = \frac{\Delta R_n + \rho C_p (e_s - e_a)/r_a}{\Delta + \gamma} \tag{13}$$

where Δ is the slope of the saturation vapor pressure-temperature curve at the mean temperature, *es* is the saturated vapor pressure at air temperature (mb), e_a is the vapor pressure (mb), and γ is the psychrometric constant (0.66 mb $^{-1}$). Combining Eq. (12) with Eq. (13) gives an equation that expresses the relationship between canopy–air temperature difference and vapor pressure deficit by conventional models:

$$T_c - T_a = [\frac{r_a}{\rho Cp} \cdot \frac{\gamma}{\Delta + \gamma}] R_n - \frac{1}{\Delta + \gamma} \cdot (e_s - e_a) \tag{14}$$

By substituting the variables with measured values and constants, Eq. (14) can be further simplified. Data measured on 5 July 1994 (sorghum field, Experiment 2; experimental procedures are given later.) are chosen for this purpose. The weather on this day was fine, and there was plenty of water available in the root zone. r_a = 258.91 × 10–6 d m–1; Δ = 2.51 mb $^{-1}$ (r_a and Δ were calculated from other measured parameters). Therefore, Eq. (14) is simplified as follows:

$$T_c - T_a = 44921 \times 10^{-6} R_n \\ -315457 \times 10^{-6} (e_s - e_a) \tag{15}$$

Eq. (15) shows that the canopy–air temperature difference is in proportion to the available energy for transpiration (R_n) and is in inverse proportion to the vapor pressure deficit. With the same procedures, the canopy–air temperature difference can also be linked with vapor pressure deficit by our proposed model as:

$$T_c - T_a = [\frac{\gamma}{\Delta+\gamma}\cdot\frac{T_p - T_a}{R_{np}}]R_n - \frac{1}{\Delta+\gamma}\cdot\frac{\rho C_p(T_p - T_a)}{r_a R_{np}}(e_s - e_a) \quad (16)$$

By replacing the variables with the measured or calculated values for 5 July 1995 [T_p = 34.91 , T_a = 31.18 , R_{np} = 17.78 MJ m^{-2} d^{-1}, other variables and constants as for Eq. (15)], Eq. (16) is simplified as follows:

$$T_c - T_a = 44942\times10^{-6}R_n - 315601\times10^{-6}(e_s - e_a) \quad (17)$$

Clearly, Eq. (15) is approximately equal to Eq. (17). This result indicates that, under the condition of no water shortage, our model agrees well with the conventional models. In the definition of h_{at}, the upper limit of transpiration rate is determined by the term $T_c - T_a$. In other words, h_{at} is affected mainly by available energy and water vapor deficit in conditions of no water stress.

Transpiration rate at $T_c = T_a$: This is the case where sensible heat is equal to zero, and all the energy from radiation is transformed into latent heat. Bowen ratio model is used to compare with our model under this condition. The general form of the Bowen ratio method is given in Eqs. (9) and (10). The Bowen ratio (β) is defined as the ratio of sensible to latent heat flux, and can be expressed (Bowen, 1926) as:

$$\beta = (C_p / L)\frac{\Delta T}{\Delta q} \quad (18)$$

where ΔT and Δq are the temperature and humidity gradients over the same height interval. If soil heat flux under a fully covered canopy is negligible, Bowen ratio model can be expressed:

$$T = \frac{R_n}{1+\beta} \quad (19)$$

There is no major difference between our model and Bowen ratio model under this condition, as $T = R_n$, (Bowen ratio = 0 when $T_c = T_a$). Eq. (10) also shows $T = R_n$. Thus our model agrees with Bowen's. In addition, under this condition, $h_{at} = 0$. This indicates that transpiration rate is determined only by net radiation.

Lower limit of transpiration rate: The maximum value of h_{at} determines the lower limit of transpiration rate. This is the case when the plant canopy dries continuously until its surface water content is equal to the water content of the reference non-transpiring leaf. Under this condition, $T_c = T_p$, and $R_n = R_{np}$. Consequently, $h_{at} = 1$, and the two parts of the right-hand side of Eq. (10) are equal to each other, and transpiration rate is equal to zero. In this case, transpiration is determined mainly by available water in the plant root zone, rather than by the atmospheric characteristics (available energy, vapor pressure deficit, etc.). This well-defined boundary, defined by h_{at}, is much less apparent in the conventional canopy–air temperature difference models. In the proposed model, because three temperatures (T_s, T_{sd}, T_a for evaporation and T_c, T_p, T_a for transpiration) are the key parameters, we call it 'three temperature (3T)' model here and after.

Plant water stress index (CWSI): Idso & Clawson (1986) defined plant water stress index as:
CWSI=(T_c- T_{cl})/(T_{cu}- T_{cl}),
where T_c, T_{cl}, and T_{cu} are the canopy temperature, lower limiting canopy temperature, and upper limiting canopy temperature, respectively. The lower limiting canopy temperature can be reached at the situation when the crop transpires without water shortage. On the other hand, the upper limiting canopy temperature can be reached at the situation when plant transpiration is zero. Therefore, Qiu et al. (1996) assumed that the temperature of imitation leaf T_p is equivalent to the upper limiting canopy temperature T_{cu}. The CWSI by imitation leaf method can be expressed as:

$$CWSI = \frac{T_c - T_{cl}}{T_p - T_{cl}} \quad (20)$$

Jackson et al. (1988) defined the lower bound of difference between the canopy and air temperature (T_c-T_a) by setting R_{cp}=0 in Eq. (21). Assuming the soil heat fluxes is negligible, the lower limiting canopy temperature can be estimated by:

$$(Tc - Ta)_{ll} = \frac{r_a(Rn - G)}{\rho Cp}\bullet\frac{\gamma(1+r_{cp}/r_a)}{\Delta+\gamma(1+r_{cp}/r_a)} - \frac{e_a^* - e_a}{\Delta+\gamma(1+r_{cp}/r_a)} \quad (21)$$

$$Tcl = \frac{Rn(Tp - Ta)}{Rnp}\bullet\frac{\gamma^*}{\Delta+\gamma^*} - \frac{e_a^* - e_a}{\Delta+\gamma^*} + Ta \quad (22)$$

$$\gamma^* = \gamma[1 + \frac{r_{cp} \cdot Rnp}{\rho Cp(Tp - Ta)}] \quad (23)$$

$$\Delta = 45.03 + 3.014T + 0.05345T^2 + 0.00224T^3 \quad (24)$$

where T_a is the air temperature ( ), r_a the aerodynamic resistance (s m^{-1}), R_n the net radiation of canopy (J m^{-2} s^{-1}), G the heat flux to soil (J m^{-2} s^{-1}), ρ the density of air (kg m^{-3}), C_p the heat capacity of air (J kg^{-1} $^{-1}$), γ the psychrometric constant (Pa $^{-1}$), e_a* the saturated vapor pressure (mb) at T_c, e_a the saturated air vapor pressure (mb) at T_a, Δ the slope of the saturated vapor pressure-temperature curve (Pa $^{-1}$), r_{cp} the minimum canopy resistance (s m^{-1}), R_{np} the net radiation of the limitation leaf (J m^{-2} s^{-1}), T average of the canopy and air temperature ( ). Therefore, the required parameters of the 3T model are T_c, T_p, T_a, R_n, e_a*, and e_a. The aerodynamic resistance required by Jackson's CWSI method is eliminated and accordingly the complexity of application is significantly reduced.

Verification experiments

Experiment 1 (bare soil)

The experiment was conducted on a one hectare leveled field at the Arid Land Research Center, Tottori University, Japan (35°32'N; 134°13'E). The soil was Arenosol (silicious sand, Typic Udipsamment) with 96% sand. Porosity, field capacity and wilting point were: 0.4, 0.074, and 0.022 m^3 m^{-3}, respectively. Saturated hydraulic conductivity was 2.7×10^{-4} m s^{-1}. Irrigation was done by sprinklers and this was the only source of water for evaporation. Four-reference air-dried soil samples were packed to the field bulk density in plastic pipes (one of 30 cm i.d., surface area of 706 cm^2 and 110 cm deep and three of 20 cm i.d, surface are of 314 cm^2 and 55 cm deep) and were buried in the soil up to the field surface level. During irrigation they were covered with a sheet of polyethylene to prevent wetting. We used data that were collected from the reference dry soil 2 weeks after the beginning of the experiment, to assure that data were collected from the reference dry soils only after the soils were thermally equilibrated. Actual evaporation from the wet soil was measured by a weighing lysimeter. The lysimeter had a cylindrical shape with surface area of 1.77 m^2, depth of 1.5 m, fetch of 50m, resolution of 0.028 mm evaporation depth or equivalently 50 g weight change. Samples were recorded every 15 seconds and averaged every 30 minutes.Net radiation and solar radiation over the drying surface was measured at a height of 2 m. Net radiation over the dry soil was calculated by using solar radiation and surface temperature. Surface temperature measurements were made with infrared thermometer. Soil heat flux was measured with heat flux plates. All the measurements were averaged and recorded by the system every 30 minutes.

Experiment 2 (sorghum plants field)

In a 1-ha flat field with coarse sand (95.8% in the 0.25–2.00-mm range) and a weighing lysimeter installed there, sorghum plants [*Sorghum bicolor* (L) Moench.] were grown. The plant density was about 8 plants m^{-2}. Actual evapotranspiration was measured with the weighing lysimeter. Soil evaporation was measured with a microlysimeter. Temperatures of sunlit leaves and the non-transpiring leaf were measured with thermocouples, and air temperature was measured with shielded thermocouples (recorded every 10 min). In this experiment, the imitation leaves were made from green paper by selecting a paper that had nearly the same color as the plant leaf and cutting the paper into the shape of a plant leaf. Then the green paper leaf was inserted in the upper part of the sorghum canopy to avoid shade from the canopy. Solar radiation, air vapor pressure, and other meteorological variables were obtained from the meteorological station at the Arid Land Research Center, Tottori University.

Results and discussion

Model evaluation

Mean absolute error (*MAE*) was used to evaluate the accuracy of the models (Willmott, 1982). MAE is defined as:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|S_i - M_i| \quad (25)$$

where S_i and M_i are the paired calculated and measured values, respectively, and N is the total number of observations.

Results for soil evaporation

Energy exchange over dry and drying soils:
Fig. 1 displays the behavior of daily-integrated R_n, H, and G over the wet and the reference dry soil during the study period from DOY (day of year) 142-149. Net radiation over the reference dry soil (Fig 1a.) was lower than that over the drying soil. The difference is more pronounced in the days that follow irrigation and is minimal as we approached the consecutive irrigation cycle. Soil heat flux toward the drying soil (Fig. 1b) was significantly larger than the heat flux to the reference dry soil, especially during the days in which the irrigation cycle started, as marked by the arrows.

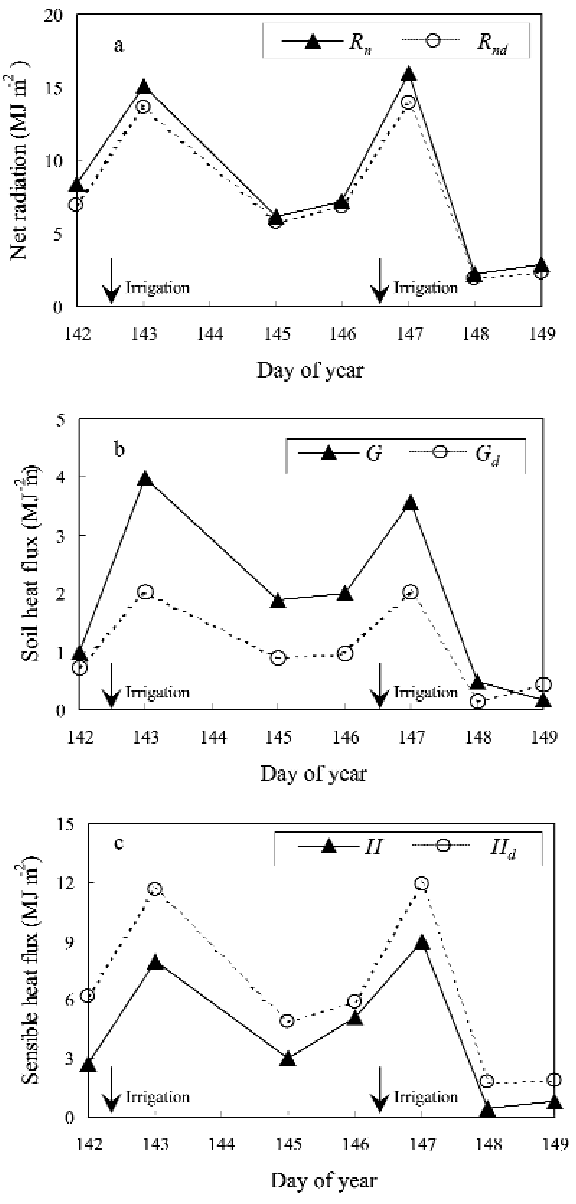

Fig. 1. The behavior of daily-integrated Rn, H, and G over the wet and the reference dry soil.

As time from the irrigation day proceeded the difference between the two surfaces became smaller and in some days even negligible. The sensible heat flux (Fig. 1c) showed similar trends. Here the dominant factor was the strong thermal gradient that was generated at the dry soil surface due to its high surface temperature relative to the surface temperature of wet soil. Since there is no apparent difference in air temperature and aerodynamic resistances over the two surfaces, the dominant factor that affected the sensible heat flux from the dry soil was its surface temperature.

In Fig. 2 we selected one day to demonstrate the course of net radiation over the dry and the drying soils. The net radiation over the dry field (Fig. 2a) was smaller than over the wet field. Maximum differences were measured from 1000 to 1130 h, indicating that more energy was available for evaporation over the wet field than over the dry field. The difference became negligible when net radiation of both surfaces approached zero. The soil heat flux (Fig. 2b) into the wet field was greater than the heat flux into the dry field due to greater thermal conductance of the wet soil.

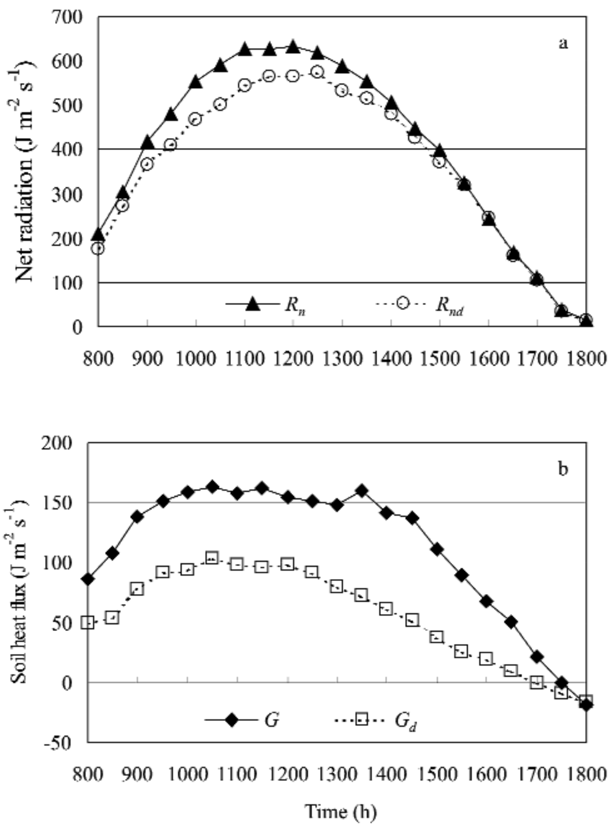

Fig. 2. Typical sampling day of: a. net radiation and b. soil heat flux over the dry and the wet soil as a function of day time hours.

The changes of surface temperatures with time after irrigation and the soil evaporation transfer coefficient h_a as a function of time after irrigation are given in Figure 3.

Calculated and measured evaporation:
The measured and calculated daily evaporations are presented in Fig. 4. Because evaporation from soil during the night time was assumed to be negligible, only daytime data are presented. Due to rainfall during the month of data collection, only 22 days data were suitable for analysis. Daily evaporation was relatively small (< 2.5 mm day^{-1}) because of the sandy texture of the soil and the formation of a dry sand layer on the surface. The correlation between the calculated and measured daily evaporation was good throughout the experiment (Fig. 4). The MAE for the daily evaporation over the 22 days was 0.17 mm day^{-1} ($r^2 = 0.89$). Most of the data points either fitted or were closely distributed around the 1:1 line. Moreover, the intercept and slope of the regression equation were not significantly different from zero and unity at the 0.05 probability level. Therefore, it is concluded that the daily evaporation can be adequately estimated by the proposed method.

The cumulative evaporation (Fig. 5) measured by the weighing lysimeter was consistently less than the evaporation calculated by the proposed method. The difference between the two lines in Fig. 5 was as high as 5%. Whether the overestimation of measured evaporation is inherent in the proposed model and would be observed under different soils and climatic conditions can not be answered with certainty. However, an indication that over estimation by the differential temperature method may be negligible was obtained from the regression equation (graph not shown) of model

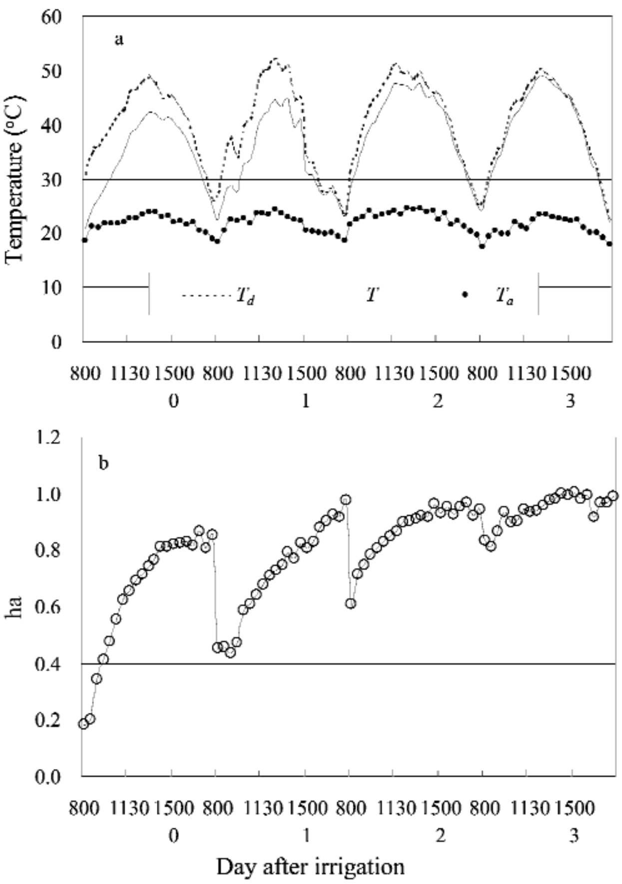

Fig. 3. The changes in (a) surface temperatures with time after irrigation and (b) the soil evaporation transfer coefficient ha as a function of time after irrigation.

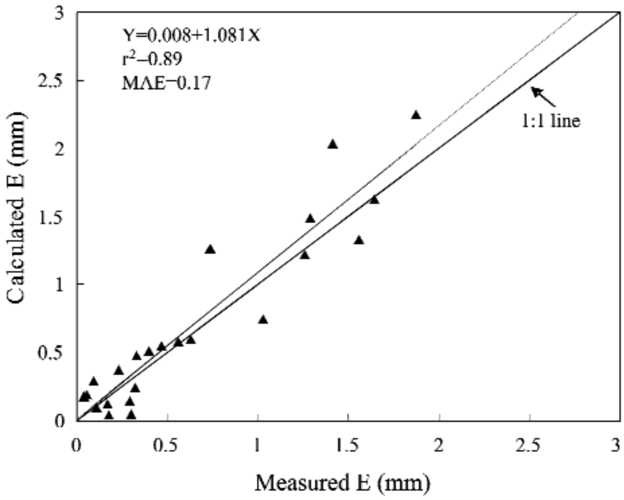

Fig. 4. The relation between calculated and measured daily evaporation from soil (22 days of measurements).

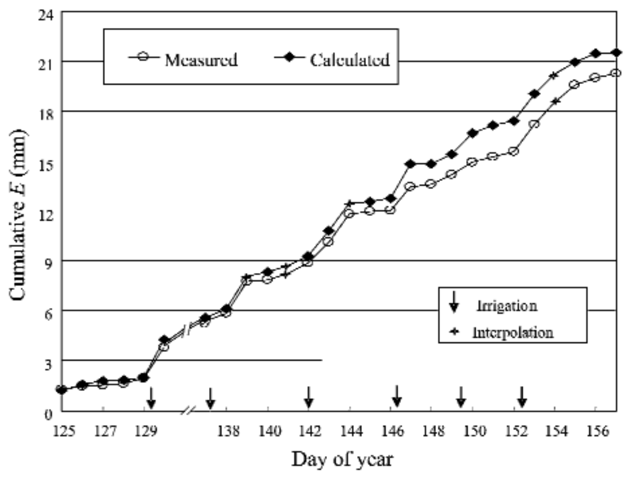

Fig. 5. Cumulative soil evaporation measured by a weighing lysimeter and calculated by the differential method as a function of time.

results as a function of measured evaporation. The best-fit line was $Y = 1.046X+0.018$, $r^2 = 0.9$. The slope close to 1 with a very small intercept indicated that the model generated reasonable quantitative results. Moreover, qualitatively, as can be further seen from Fig. 5, both curves show the cyclic fluctuations of evaporation. Shortly after irrigation (marked by arrows), when the wet soil was saturated, cumulative evaporation was controlled by the atmosphere and increased fast. This trend continued for a short time (about 1 day) and then, following drying process of the wet soil, on both curves, cumulative evaporation was controlled by the reduced soil water content and decreased gradually to its daily minimum, which appear as an intermediate asymptote between the two irrigations.

Results for plant transpiration

Because the 3T model is relatively new, it has not been compared with other conventional models. Weighing lysimeter measured results and four commonly used evapotranspiration models, Penman–Monteith (P-M), Bowen ratio, temperature difference, and Enwatbal (**EN**ergy and **WAT**er **BAL**ance) were chosen for comparison. Measured transpiration was obtained from lysimeter-measured *ET* minus microlysimeter measured soil evaporation *E*. The transpiration estimated by the 3T model was obtained by the procedures described in Qiu et al. (2000). The procedures for estimating transpiration by the other models will be described in the following sections. In our analysis, daytime transpiration was used for the P-M, Bowen ratio, and temperature difference models. The 24-h transpiration was used for Enwatbal.

Comparison with P-M model:

Combination methods are commonly used to estimate *ET*. These methods involve a combination of energy balance and aerodynamic transport of water vapor. Such equations for potential *ET* include the Penman equation (Penman, 1948), modified Penman equation (van Bavel, 1966), and P-M equation (Monteith, 1965). For an unsaturated surface, surface (or canopy) resistance is introduced (Monteith, 1965, Rijtema, 1966). The P-M equation can be expressed as:

$$ET = \frac{\Delta(R_n - G) + \rho C_p (e_s - e_a)/r_a}{\Delta + \gamma(1 + r_c/r_a)} \qquad (26)$$

where e_s is the saturated vapor pressure at air temperature (Pa), e_a is the air vapor pressure (Pa), Δ is the slope of the saturation vapor pressure–temperature curve at the mean temperature (Pa°C^{-1}), γ is the psychrometric constant (66 Pa °C^{-1}), *rc* is the canopy resistance (s m^{-1}), and *ra* is the aerodynamic resistance (s m^{-1}). Usually *ra* is estimated from the wind speed. Jackson et al. (1982) suggested that *ra* could be expressed as:

$$r_a = \frac{4.72[\ln(\frac{z-d}{z_0})]^2}{1+0.54U} \qquad (27)$$

where *z* is the height at which the wind speed is measured (m), *d* is the zero-plane displacement (m), z_0 is the roughness length (m), and *U* is the wind speed at z height (m s^{-1}). For a fully covered plant community, the empirical relationships of $z_0 = 0.13h$ and d = $0.63h$ can be used, where *h* is the height of the crop expressed in meters (Monteith, 1965). Δ (Pa °C^{-1}) can be estimated as:

$$\Delta = \frac{2502992.1}{(T_a + 237.3)^2} \exp(\frac{17.3T_a}{T_a + 237.3}) \qquad (28)$$

e_s (Pa) can be calculated (Burman et al., 1983) as:

$$e_s = 610.8 \exp(\frac{17.3T_a}{T_a + 237.3}) \qquad (29)$$

$$e_a = e_s \times \frac{RH}{100} \qquad (30)$$

where *RH* is the relative humidity of air.

In the P-M model, besides r_a, r_c is also required. Because of the variation of r_c with plant species, location, and time, it is always difficult to find a suitable r_c value for the P-M model. Empirical equations enable to estimate the canopy resistance from the leaf area index (*LAI*) and minimum stomatal resistance (*rs*), such as $r_c = r_s$/(LAI/2). Usually *rs* = 100 s m^{-1} is considered to be a suitable value (Jensen et al., 1990). By using different values of r_s in the P-M equation and comparing the calculated *ET* with lysimeter-measured values, we found that r_s = 150 s m^{-1} is a suitable value (Fig. 6). Fig. 6 shows that the P-M model is sensitive to stomatal resistance. For example, if r_s =100 s m^{-1} is selected, the error increases significantly.

The 3T model has 3 advantages over the P-M model. First, *ra* and *rc* are not required. This is important, because accurate estimates of *ra* and *rc* are the major difficulty in determining *ET* for

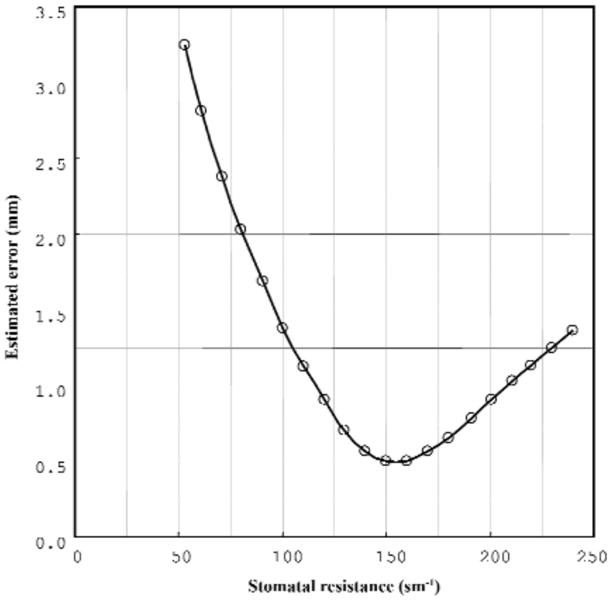

Fig. 6. Errors of estimated transpiration by Penman-Monteith model for different stomatal resistance values.

many applications. Second, fewer variables are included: 2 in the 3T model versus 6 in the P-M model. Third, measurement and analysis of the parameters involved are relatively easy.

Fig. 7 shows a comparison of the daily *T* values measured with the lysimeter, and daily *T* values estimated by the 3T and P-M models. The estimated *T* value by the P-M equation is equal to *ET* – *E*, where *ET* is calculated from Eq. (26) and *E* is measured with a microlysimeter. Fig. 7a shows that the daily *T* values estimated by the 3T and P-M models agreed with the lysimeter-measured values. Most of the values were in the range of 4–7 mm, and all the points were near the 1:1 line. Fig. 7b shows the cumulative *T* values given by the lysimeter, P-M and 3T models over the 17-day period, namely 80.31, 80.05, and 80.10 mm, respectively. The difference between the lysimeter and P-M values was 0.26 mm, and the difference between the lysimeter and 3T values was 0.21 mm. These results show that the values obtained by both the P-M and 3T models agreed well with those measured with the lysimeter.

The *MAE* between *T* measured with the lysimeter and estimated by P-M was 0.42 mm d^{-1} and that estimated by 3T was 0.45 mm d^{-1}. Therefore, the accuracy of the 3T model is as high as that of the P-M model.

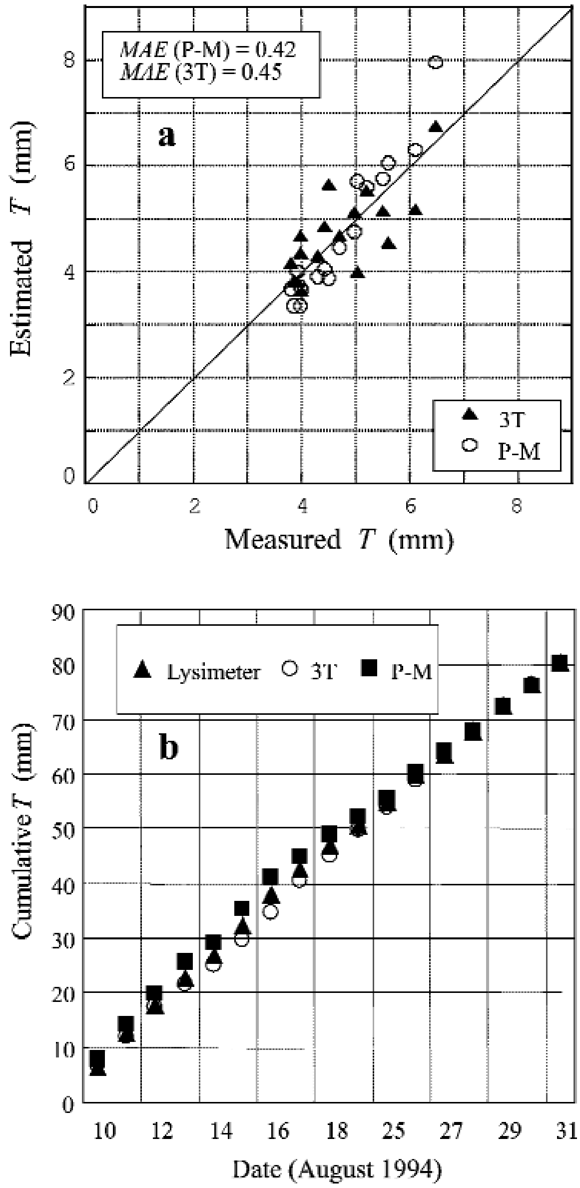

Fig. 7. Comparison of transpiration values measured with a lysimeter, estimated by the P-M model, and estimated by the 3T model. a: daily transpiration, b: cumulative transpiration.

Comparison with Bowen ratio model:

The Bowen ratio (β) is defined as the ratio of sensible to latent heat flux, and can be expressed (Bowen, 1926) as:

$$\beta = (C_p / L)\frac{\Delta T}{\Delta q} \qquad (31)$$

where ΔT and Δq are the temperature and humidity gradients over the same height interval, and L is the latent heat of vaporization (2.4 MJ kg^{-1}). *ET* is given by:

$$ET = \frac{R_n - G}{1 + \beta} \tag{32}$$

In this model, net radiation, soil heat flux, and temperature and humidity gradients are required. Measurements of ΔT and Δq close to the surface are desirable, because they minimize the effect of buoyancy and advection.

Fig. 8 shows a comparison of the *T* values estimated by the Bowen ratio and 3T models. The *T* values estimated by the Bowen ratio model were equal to *ET* – *E*, where *ET* is calculated from Eq. (32) and *E* is measured with the microlysimeter. Generally, the values of *T* estimated by both the Bowen ratio and 3T models agreed with the lysimeter-measured values. The *MAE* between the measured *T* and the Bowen ratio model estimated *T* was 0.63 mm d^{-1} and the 3T-model-estimated *T* was 0.45 mm d^{-1}. The estimated results of the 3T model were closer to the 1:1 line than those of the Bowen ratio model; the Bowen ratio model slightly underestimated the daily *T* values (Fig. 8a). This underestimation of the *T* values is further shown in Fig. 8b. The cumulative *T* values were 80.31, 80.10, and 71.62 mm for the lysimeter, 3T, and Bowen ratio models, respectively. The reason for this underestimation is not clear. The error in the measurements of ΔT and Δq close to the surface may account for the possible source of error. These results show that the 3T model performs better than the Bowen ratio model.

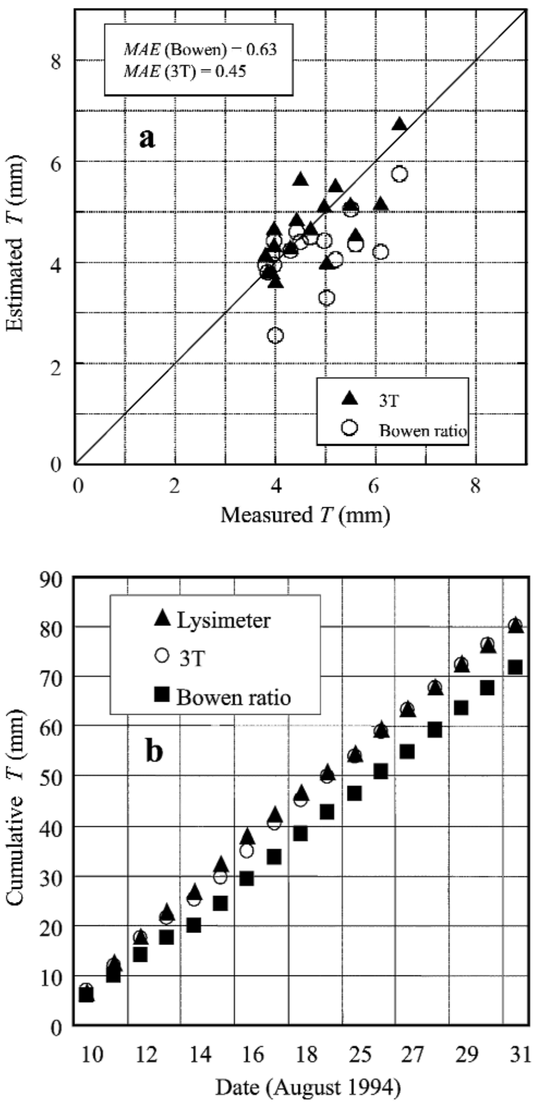

Fig. 8. Comparison of transpiration values measured with a lysimeter, estimated by the Bowen ratio model, and estimated by the 3T model. a: daily transpiration, b: cumulative transpiration.

Comparison with the temperature difference model: According to the temperature difference model *ET* is given as:

$$ET = (R_n - G) - \rho C_p \frac{T_s - T_a}{r_a} \tag{33}$$

where, in addition to $R_n - G$, r_a, T_s, and *Ta* are required. The surface temperature can be acquired through the use of infrared radiometry from above. This model has so far been used mainly for simple surfaces (Hatfield, 1985). However, as infrared thermometers and thermal graphic technologies improve, this technique could be applied to remote sensing.

Fig. 9 shows a comparison between the 3T and temperature difference models. The *T* values estimated by the temperature difference model are equal to *ET* – *E*, where *ET* is calculated from Eq. (33) and *E* is measured with the microlysimeter. Experimental results show that the performance of the 3T model can be as good as that of the temperature difference model. The *MAE* between the measurements and the temperature difference model was 0.69 mm d^{-1}. The *MAE* between the measurement and the 3T model was 0.45 mm d^{-1}.

Fig. 9a shows that the daily *T* values estimated by the temperature difference and 3T models agreed with the lysimeter-measured values. Most of the values were in the range of 4–7 mm, and all the points were close to the 1:1 line. Fig. 9b shows a comparison of the cumulative *T* values obtained with the lysimeter and the 3T and temperature difference models over a period of 17 d. The cumulative values of *T* were 80.31, 80.10, and 83.08 mm for the lysimeter, 3T, and temperature difference model, respectively. These results show that the values obtained by both the 3T and temperature difference models agree very well with the lysimeter values.

Comparison with Enwatbal model

Enwatbal (Lascano et al.,1987), a mechanistic *ET* model, can separate the calculation of *E* and *T* as a function of crop development, changes in soil water reserves, and weather. It has two advantages. First, the water and energy balances for both canopy and soil surface are simulated. Second, the energy and water balances of the entire soil profile are calculated separately from those of the plant canopy. This model was found to be a useful tool for separately estimating soil evaporation and plant transpiration in the same experimental field as in the case of this study (Qiu et al., 1999a).

Fig. 10a shows a comparison of the *T* values measured with the lysimeter and simulated daily (24 h) by Enwatbal. The model slightly underestimated daily *T*. Fig. 10b shows that the cumulative *T* values obtained by the lysimeter and Enwatbal over a period of 16 d were be 89.19 and 69.51

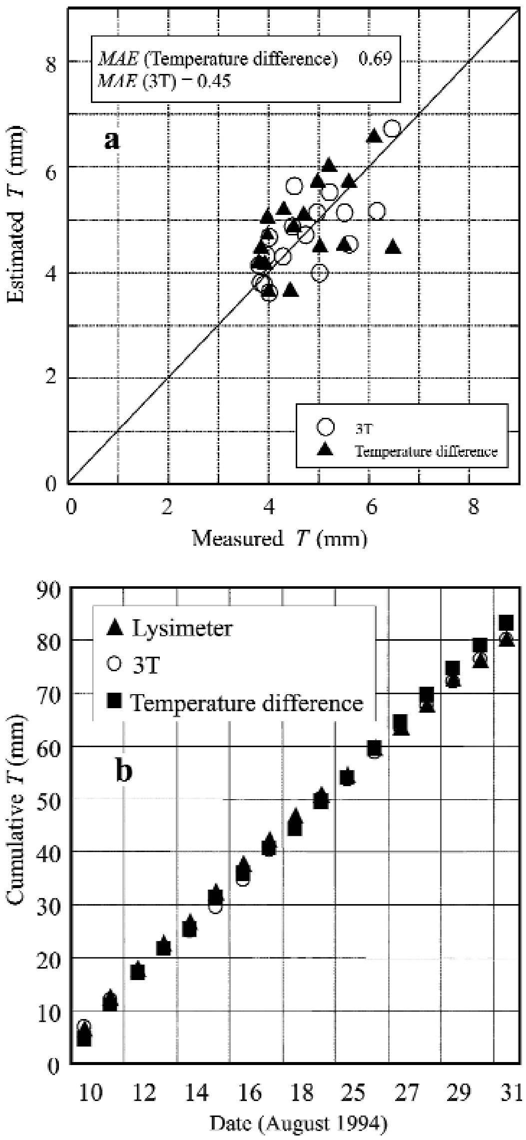

Fig. 9. Comparison of transpiration values measured with a lysimeter, estimated by the temperature difference model, and estimated by the 3T model. a: daily transpiration, b: cumulative transpiration.

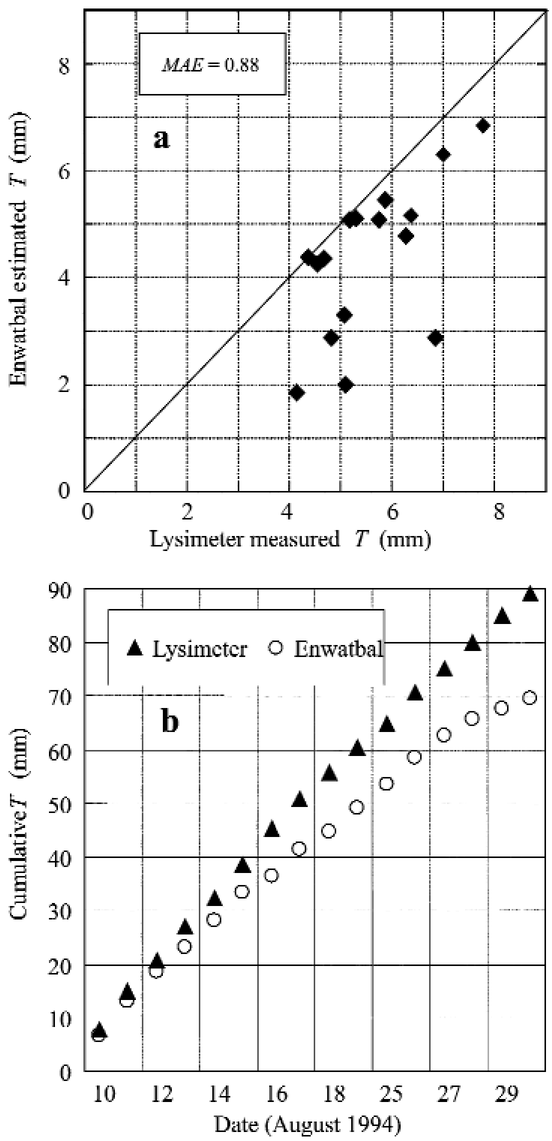

Fig. 10. Comparison of transpiration values measured with a lysimeter, estimated by the Enwatbal model, and estimated by the 3T model. a: daily transpiration, b: cumulative transpiration.

mm, respectively. The *MAE* between the measured and Enwatbal values was 0.88 mm d–1, twice as large as that given by the 3T model. Thus, 3T model is better than Enwatbal. In Enwatbal model, *T* is calculated from an energy balance approach, which is closely related to the canopy resistance and stomatal resistance. The relation between the stomatal conductance and leaf water potential and the relation between the stomatal conductance and solar irradiance are applied as initial conditions. The empirical nature of these relations may be a source of error, causing an underestimation.

Applicability

Comparison with lysimeter and conventional methods shows that the use of the 3T model is a simple and accurate method for estimating soil evaporation and plant transpiration. These advantages make the 3T model widely applicable under various conditions.

Remote sensing: Estimation of *ET* from remotely sensed observations has several advantages over other methods (Chanzy et al., 1995, Ottle & Vidal-Madjar, 1994). In 3T model, the necessary input parameters for soil evaporation are temperature (T_s, T_a, and T_{sd}), net radiation (*Rn* and R_{nd}), and soil heat flux (*G* and G_d). Under large-scale condition, distribution map of T_s could be directly measured. In the *Ts* map, the maximum value of T_s might be used as *Tsd*. Meanwhile, air temperature from nearby meteorological station could be used as T_a. Usually, *Rn* and *Rnd* could be estimated from surface temperature and solar radiation (Qiu, 1996). There are still other approaches to estimate net radiation from remote sensing data (Jiang & Islam, 2001; Norman et al., 2003). By these approaches, *Rn* and *Rnd* could be estimated. The necessary input parameters for plant transpiration are the temperature (T_c, T_a, and T_p) and net radiation (*Rn* and *Rnp*). These parameters could be estimated by the similar procedures given above. For sparse vegetation area, soil evaporation and plant transpiration could be estimated separately by 3T model. The ratio of soil evaporation and plant transpiration could be estimated by vegetation fraction (Qiu et al., 1996). Vegetation fraction could be easily estimated from remote sensed data (Gutman and Ignatov, 1998).

Strong error resistance: Because of the special form of Eqs. (4, 10), some systematic errors, such as those associated with equipment and methods, can be removed. Sensitivity analysis shows that, although the 3 temperatures are the most sensitive input parameters in estimating *E* and *T*, simultaneous changes in them will not cause a significant error in *E* and *T* (Qiu, 1996). A model with a strong error resistance is very important for many studies and applications. For example, in the studies on global warming caused by CO_2, the possible effect of an elevated CO_2 concentration on net radiation could be around 1% and on *ET* it could be within 10% (Kimball et al., 1999). These values are in the error ranges for most equipment and methods. For most of the conventional models, more studies are required to obtain satisfactory results. Under these conditions, it will be relatively easy to obtain satisfactory results with the 3T model.

Applicable under various conditions: Owing to fetch requirements, most of the conventional models can only be applied to large uniform sites. In the 3T model, because the measurement of net radiation and temperature is not affected by data collection problems, the model can be used in both large flat fields and at small heterogeneous sites. This technology has been successfully applied to estimate the crop water stress index for greenhouse melon (Qiu et al., 2000). Furthermore, *hat* was successfully evaluated for open-field-grown sorghum, potted tomato (in both growth chamber and greenhouse), and greenhouse melon. Therefore, the 3T model could be used when the use of other conventional models is limited.

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Assessing land degradation hazard intensity and management plans using subjective model and analytical hierarchy process in Gorgan semi-arid plain, Iran

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Abstract

Land-use planning is important for every sustainable development action plan. It should integrate all land resources and natural hazards management alternatives via multi-attribute decision methods such as analytical hierarchy process (AHP) under the conditions of uncertainty of data and decisions. In this study, as the first step, the land degradation potential hazard were mapped at 1:250000 scale and four hazard classes were established in the context of 14 micro (unit) and 6 macro (type) physiographic units, considering the combined effects of five key dominant processes (salinization, waterlogging, water erosion, wind erosion, and vegetation deterioration), using a five-class numerical subjective model in the Gorgan coastal plain, which is a complex mosaic for land use planning and natural hazard management. Secondly, with respect to the nature of land degradation mechanism and intensity of degradation, four hazard mitigation plans for combating desertification have been proposed consisting of: 1) drainage and surface flow water collection, 2) shrub plantation and green belt creation, 3) soil physico-chemical improvement, and 4) protection and preservation. Finally, the priorities of management plan alternatives have been determined in each hazard class zone and the cost effectiveness of implementation plan has been assessed using AHP model. Results show that land degradation hazard classes I, II, III and IV extend in a spatially-ordered pattern, from forest-covered mountain in the south to steppe coastal plain in the north, along a sharp geo-ecological gradient in the study area.

Introduction

In the Caspian lowland region about 81% of the area comprises natural deserts or other type of degraded natural landscape. In the past decades, different regions around the Caspian have been degraded, so that about 39% of the area must be classified as severely to very severely desertified. Deserts and desertification, therefore, are by no means issues limited to the eastern part of the Caspian coastal zone only (CEP, 2003). Land degradation can be defined in many ways. In brief, it refers to any changes in the land that reduce its productivity or potential production. It occurs whenever the natural balance in the landscape is disturbed by human activity, through misuse or overuse of the natural resources (Williams, 1991; Cocks, 1992). The United Nations Convention on Combating Desertification (UNCCD) defines desertification as the land degradation (CEP, 2003). There are obviously many causes of land degradation and the degradation itself takes many forms (as for example irreversible or reversible). Thus differentiation between the desertified lands and the lands under desertification and degradation is always impossible except in more humid climate and fertile soil areas than common in the arid environments. Land degradation results in vegetation deterioration, wind and water erosion, and soil fertility reduction and socio-economic poverty. The degradation can often remain unseen except by the specialists and those suffering its consequences (Williams, 1991; Wasson et al., 1998).

Desertification is a dynamic, pervasive and multidimensional hazard that is very sensitive to the spatial and temporal changes in the natural and anthropogenic causative factors (Wang et al., 2005). It has serious on-site and off-site impacts on the society in the arid regions, thus calling for efforts from planners and decision makers for combating and management. But combating degradation is a challenging task and failures are not uncommon. The desertification/land degradation in north China, as also in Central Iran and Gorgan plain, continues despite the endeavors to mitigate it over the past 50 years (Chen and Tang, 2005).

Land use planning, taking into consideration natural assets and the prevailing hazards, is a holistic problem-solving strategy used to protect and restore ecosystems, human health and social welfare, and achieve sustainable development (de Steiguer et al., 2003). Integration of land resources management and natural hazard mitigation plans is crucial for sustainable development of a region (Ramakrishan, 2003). Full understanding of the dynamic and complex nature of spatial planning process, shortage of accurate recorded data, budget shortage, and the necessity for urgent implementation of integrated land-degradation and natural-hazard management plans, have together encouraged the adoption of a vast range of multi-attribute decision methods including Analytical Hierarchy Process (AHP) and individual and group subjective models (Delphi method) as flexible and fast decision-support systems (FFDDS) since 1960s. As Ferrand (1995) states spatial planning is essentially a decision process.

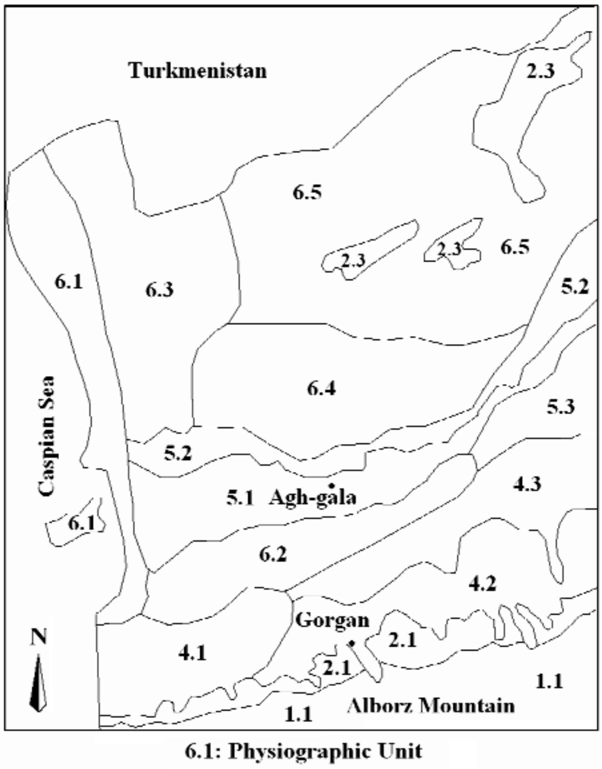
On the regional scale spatial planning, development plans and projects are difficult to rank because many important criteria are unquantifiable and non-comparable (Pathak et al., 2000). Thus, due to some critical uncertainties and complexities there is a general but conservational tendency to replacing laboratory and field measurements (actually recorded data) by subjective (observational data) and objective (hybrid data) models (Ferrand, 1995; Ownegh, 2002, 2005). AHP provides an effective tool for scoring and giving weight to the management options to the decision makers for the future development of the region (de Steiguer et al., 2003).

In spite of the widespread use of AHP, its application to the problems of natural resources, especially to land degradation/desertification hazard assessment and management, has been surprisingly limited (Schmoldt et al., 2001). However, the application of AHP and subjective models is extending in land use planning, integrated management of watershed and natural hazards, and in the environmental-pollution mitigation projects. Among numerous case studies that can be cited are the examples of application of AHP in prioritization of possible land uses (Hill and Zammet, 2000), agricultural research projects (ISNAR, 2005), national park management projects (Peterson et al., 1994), integrated management of watersheds in the USA (de Steiguer et al., 2003) and Brazil (Srdjevic et al., 2002), natural resource and environment management (Schmoldt et al., 2001), landslide hazard zonation (Ownegh, 2002, 2004), desertification hazard management plans (Ewing, 1999) and air pollution mitigation strategies and project assessment (Pathak et al., 2000). The development of spatial decision support system, for identifying priority sites (area selection between watersheds and within sub-watersheds for watershed management schemes) and for selection of priority management options for the selected sub-watersheds, has received much attention in India (Adinarayana, et al., 2000). The main purpose of this paper is to develop land degradation potential hazard zonation by a numerical subjective model and the prioritization of integrated land-degradation hazard management plans using AHP method for the Gorgan semi-arid coastal plain for formulating sustainable development strategies for the province.

Materials and methods

Study area

The Gorgan semi-arid plain (including other two local and more arid plains known as Agh-Ghala and Gomishan) is located in the northern part of Golestan province, in the southeast Caspian lowland desert region of Iran (Map1). The study area is 5693 km^2 (26%of the total province), extending from the forest-covered Albourz mountain range in the south to Turkmenistan boundary (south-western margin of the Kara-Kum Desert) in the north, and from the Caspian Sea in the west to hilly-undulated lands in the east. Due to the differences in topography (mountain to lowlands), climate (dry sub-humid to arid with annual precipitation of 630 to 220 mm and annual temperature of 16 to 18°C that both decrease towards north), lithology (from pre-quaternary rocks to quaternary



Map 1. Physiographic unit map of the study area, 1: 1250000.

marine, alluvial and aeolian sediments and soils), and vegetation (from dense deciduous forests to mild steppe), the region presents an unique geo-ecological body. This region as a "micro continent" provides a complex mosaic for land use planning (from tropical to boreal crops) and integrated management of natural hazards (from desertification to sea and river floods) (Ownegh, 2003).

Land degradation has been occurring in the Gorgan plain throughout its human occupancy, but it has accelerated mainly during catastrophic changes of climate (as succession of hot dry conditions), Caspian Sea level fluctuations (as rapid rise and transgression), and the poor management and overuse of natural resources and environment (as intense land use changes). The landscape of the Gorgan plain, which as a matter of fact is a former bed of Caspian Sea, as a mid-latitude coastal desert, is characterized by a mosaic of geomorphologic features of mild desert and land degradation including salt pan, playa, badland, puffy soil, patterned ground, seasonal mobile sand dunes (as small *nebka* and sand ridge), stabilized coastal paleo-dunes (as large *barchan* and parabolic), and more than 150 archaeological hills of artificial and natural origin (as sand dunes and mud volcanoes) with different civilization artefacts of 6400 years BP (Ownegh,1990;1996). Hence, the area can be viewed as a small regional laboratory of Golestan province and southeast Caspian Sea coast desert type (in contrast to the central deserts of Iran) for the development and calibration of desertification and land-degradation hazard zonation models. For developing local Caspian desertification action plans, Gorgan plain (mainly Gomishan coastal region) has been selected as a hot spot area in Iran (CEP, 2003).

Methodology

The research was conducted in two successive phases. **Phase1** comprised of land degradation potential hazard mapping using available data and a subjective model (expert opinion) involving: (a) Identification of work units as physiographic or general geomorphologic units (macro and micro units as mainly photomorphic units) at semi-detailed or regional scale (1: 250000); (b) Development of a simple regional four-class hazard-assessment model based on five key processes of desertification (salinization, water logging, water erosion, wind erosion, and vegetation deterioration) that mainly depend on five natural and anthropogenic basic factors (topography, climate, parent material , hydrology, and land use); (c) Determining relative importance (weight) of key processes for desertification potential hazard in each map unit using field knowledge and experience as a subjective scoring method (0-4 scale) according to available tabular and map data (database, Soil Institute of Iran; Ownegh and Mirkarimi, 2003). Each single criterion of evaluation provides a ranking of hazard classes and management plans; and (d) Preparation of desertification hazard choropleth map as a basic document for plans and project prioritization and selection.

Phase2 included the application of AHP expert system, which demonstrates a state-of-the-art solution for the standard three-step hazard management procedure comprising critical area identification, best management practices selection, and comprehensive hazard control plans (Bartholic et al.,1996), for: (a) Identification of hazard management work units as desertification hazard class zone (hazard map unit) as a key criterion for management plans prioritization ; (b) Selection of hazard management plans and strategies, consisting of four effective plans: drainage and surface flow water collection **-P1**, shrub plantation and green belt creation **-P2**, soil physico-chemical improvement **-P3**, and protection and preservation **-P4**; (c) Prioritization of plans in each hazard class zone by pair-wise comparison mainly with respect to plan implementation cost and effectiveness, and calculation of local (partial) weights of the plans (Srdjevic et al., 2002); (d) Prioritization of hazard classes with respect to managerial needs/ goals and calculation of their local weight as a new criteria and work using AHP. It must be remembered that in spite of classified numerical values, there is not any distinct mathematical relationship between the different hazard classes; i.e., class IV is not 4 times of class I (Ownegh, 2002); and (e) Calculation of management plans global (total) weights and ranks in the study area by multiplying weights of plans and classes as matrix of ranked values to assist decision-makers (Adinrarayana et al., 2000).

The decision hierarchy structure of the research phases including hazard map and AHP are shown in Fig.1.

For hazard management plan prioritization three basic assumptions were defined:1) From class I to class IV, the level of difficulty, cost, and managerial needs and priority increased non-linearly; 2) The cost of implementation and effectiveness are the most important criteria for the prioritization; and 3) From Plan1 to Plan 4, the level of difficulty, cost of operation, and limitation of land use increased non-linearly, and areas vulnerable to desertification / land degradation hazard were identified for implementing best management practices.

Results and discussion

Hazard zonation (mapping)

The final hazard map contains all four classes of the regional model with different frequency and key process combinations (Table 1). The spatial succession of hazard classes that arose from the sharp gradient of desertification key factors and processes shows a regional pattern and hazard intensity increases from the south (Class I in forest covered mountain) to the north (Class IV in steppe and gentle low coastal plains) with the exception of fossil sand dunes (as productive islands) over the vast low plains (Map 2). The frequency of hazard class area from Class I to Class IV are 4.6, 5.1, 35.7, and 54.6 percent respectively, and the average hazard class of study area is of Class III (on the boundary of Class IV) with hazard number of 12.79, and area weighted average class is also Class III with hazard number of 14.15 (Tables 1 and 3).

The relative importance of five key desertification processes is different by macro and micro physiographic units. At the global (study area) level, the order is **Ew >P>Vd>Ed>S** for un-weighted and **P>Ew>Vd>S>Ed** for weighted equations due to the difference in the surface area frequency of the map units (Tables 1 and 2).

Among the pysiographic units (unit and type) the lowest hazard numbers are for the forest covered rocky mountain and the highest are for lowlands and marshy coastal plains units (Table 2).

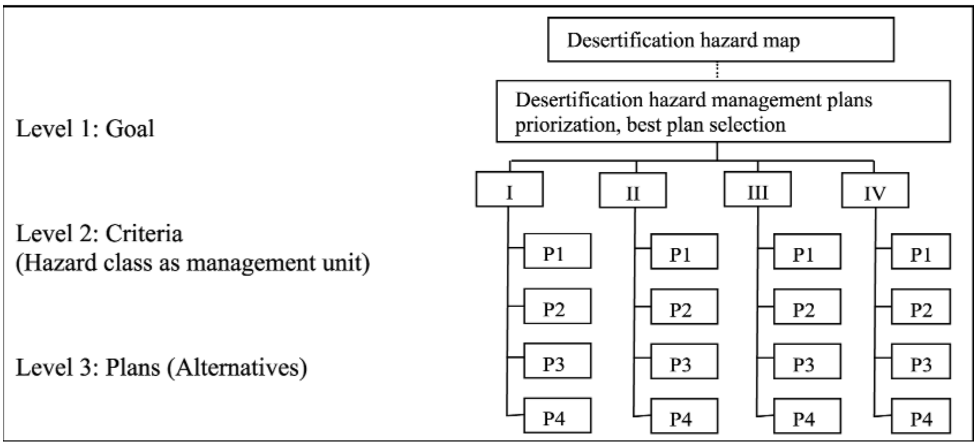


Fig.1 Decision hierarchy for desertification hazard management plan prioritization.

Table 1. Scoring of key processes effect and desertification hazard class by physiographic units

Map unit	Area %	Processes effect score					Hazard number	Hazard class	Current land use	Land use capability class
		S	P	Ew	Ed	Vd				
1.1	4.6	0	0	2	0	2	4	I	1,7	2-3
2.1	5.1	0	0	3	1	4	8	II	1,3	2
2.3	3.5	2	2	4	3	3	14	III	2,4	3
4.1	5.27	1	3	3	2	2	12	III	3,5	4
4.2	7.21	1	3	3	2	2	11	III	3,5	4
4.3	6.15	1	3	3	2	2	11	III	3,4,5	3
5.1	8.43	2	3	3	2	2	12	III	3,4,5	4
5.2	3.16	2	3	2	3	2	12	III	3,4,5	3
5.3	2.02	2	3	2	3	2	12	III	3,4	4
6.1	7.9	4	4	3	3	3	17	IV	2,6,7,8	3
6.2	8.75	3	4	3	2	3	15	IV	3,4	3
6.3	9.8	4	3	3	3	4	17	IV	2,6	3
6.4	9.15	3	4	3	3	3	16	IV	2,4	3
6.5	19.15	4	4	3	4	4	19	IV	2,4,6	3
study area	100	2.07	2.79	2.86	2.36	2.71	12.79	III	All	3
Area weighted	100	2.63	3.01	2.99	2.55	2.97	14.15	III	All	3

Process scoring: 0 None, 1 Slight, 2 Moderate, 3 High, 4 Very high
Dominant present land use: 1- Forest, 2- Range, 3-Irrigated agriculture, 4- Dry farming, 5- Urban area, 6- Barren area, 7 -Protected /Recreation area , 8-Fishery
Present and possible future land use capability class: 1-None, 2-Low, 3-Moderate, 4- High

Table 2. Desertification hazard classes by physiographic macro units (Type)

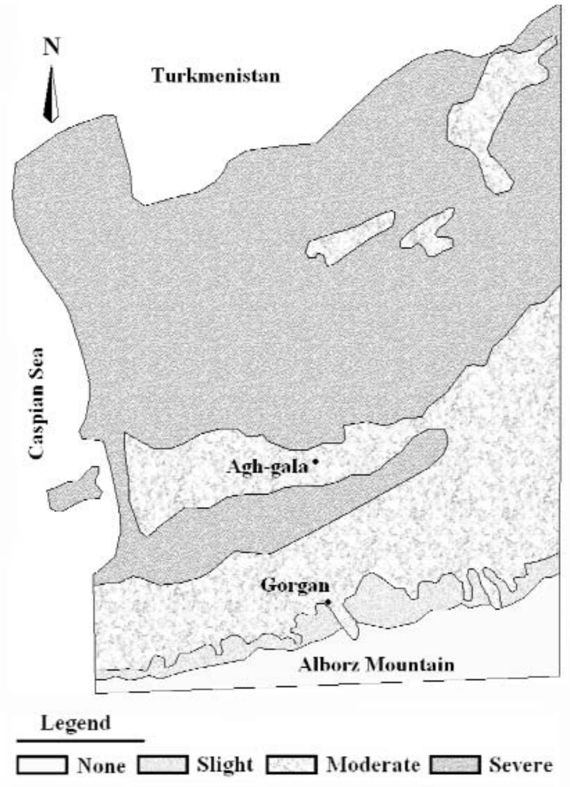
Physiographic type	Area %	Micro units	Hazard number	Class	Process important succession
1- Rocky mountain slope (Forest covered)	4.6	1.1	4	I	Ew=Vd>S=P=Ed
2- Rock/ sediment hill-slope	5.1	2.1	8	II	Vd > Ew >Ed>P=S
3- Pediment plain/ alluvial fan	18.6	4.1,4.2,4.3	11.33	III	Ew>P>Ed=vEd>S
4- Gentle plain /river terrace	13.6	5.1,5.2,5.53	11.66	III	P>Ed>Ew>S=Vd
5- Lowlands and coastal plain	54.6	6.1,6.2,6.3,6.4,6.5	16.80	IV	P>S>Vd>Ed=Ew
6 - Sand dunes(fossil)	3.5	2.3	14	III	Ew>Vd=Ed>P=S
Study area	100	All	12.79	III	Ew>Vd>P>Ed >S
Area weighted	100	All	13.94	III	Ew>Vd>P>Ed >S

Table 3. Area frequency and physiographic units of desertification hazard classes

Hazard class	Area %	Micro	Macro
I-None	4.6	1.1	1
II-Slight	5.1	2.1	2
III-Moderate	35.7	2.3,4.1,4.2,4.3,5.1,5.2,5.3	2,4,5
IV-High	54.6	6.1,6.2,6.3,6.4,6.5	6
Study area (III)	100	All	All

Hazard management plan prioritization

The local weight and rank of management plan (P1-P4) implementation priority with respect to the hazard classes are different between and within classes. Also, priority weight and rank of hazard classes with respect to managerial needs (goal) showed a non-linear difference (Table 4). Average local priority of management plans with respect to the hazard classes calculated by rank scoring method is in the order **P2>P3>P1>P4** and their global priority in the study area is as **P3>P2>P4>P1** (Table 4, 5, 6).



Map 2. Land degradation hazard map for the study area, 1:1250000.

Discussion

The synergistic effect of different temporal and spatial combinations of desertification key factors and processes has resulted in different desert landscapes and land degradation hazard intensities in the Gorgan area. The spatial pattern of hazard zones shows well the effects of distance to the positive (mountain and forest) and negative (desert and sea) sources on the desertification potential hazard intensity with some local exceptions because of the human activities and some historical reasons. The Chi square test showed that among analyzed variables, differences of hazard class weights and surface areas, and priority weights of the plans are significant at 0.01 and 0.05 levels, respectively.

Following the spatial distribution and succession of hazard classes, the implementation of proposed management plans should increase towards north and should be gradual. Local and global priority differences of the proposed plans can be related to

Table 4. Weights, priorities and the final ranking of hazard management plan alternatives (W = Local weight; R=Local priority rank).

Class		I (0.125)		II (0.235)		III (0.306)		IV (0.336)		Global &rank	weight
W&R		w	r	w	r	w	r	w	r	W	R
Plans	P1	0.483	1	0.315	2	0.136	3	0.066	4	0.198	4
	P2	0.315	2	0.483	1	0.315	2	0.136	3	0.295	2
	P3	0.136	3	0.136	3	0.483	1	0.315	2	0.302	1
	P4	0.066	4	0.066	4	0.066	4	0.483	1	0.206	3

Table 5. Valuation and comparison of global priority of hazard management plans

Score		**4**	**3**	**2**	**1**
Rank		**1**	**2**	**3**	**4**
Class	I	P1	P2	P3	P4
	II	P2	P1	P3	P4
	III	P3	P3	P1	P4
	IV	P4	P3	P2	P1
Study area	III	P3	P2	P4	P1
Caculations:		P1=4+3+2+1=10	P2=3+4+3+2=12	P3=2+2+4+3=11	P4=1+1+1+4=7

Table 6 Final hazard management plan priority ranking

Rank	1	2	3	4	Implementation
Local	P2	P3	P1	P4	More simple
Global	P3	P2	P4	P1	More complex

the effect of the hazard class relative weight in global weight calculation. In global priority, the implementation and conducting of proposed plans seems to be more difficult and complex than local priority.

In general with respect to the land use and land degradation hazard in the Gorgan area the hazard zones of class IV (54.60%) are of first priority for mitigation with plan priority sequence of **P4>P3>P2>P1,** while the hazard zones in Class I (4.60%0) with sequence of **P1>P2>P3>P4** can be temporally considered as **'**no project, no plan, no action**'** option.

Conclusion

There are forms of land degradation that are often overlooked, except by those who are directly affected, even though they are frequently very visible. Selection of best plan, and its implementation and monitoring are important steps in the integrated land and hazard management based on scientific analysis. In the land use planning and natural resources mitigation, it is difficult to weight and rank projects because many important criteria are unquantifiable and non-comparable. Well developed subjective models and AHP method provide a useful tool not only for scoring and weighting of options and decision making under uncertainties, but also for proving the non-linear relationship between the hazard class that is essential in determining mitigation needs and the plan selection.

With respect to the game theory and spatial diffusion of hazard from main sources to marginal lands, hazard zones of Class IV are of first priority for mitigation**,** while the hazard zones of Class I can be temporally considered as 'no project, no plan' options in favour of the other three relatively intense hazard zones. In many of earlier studies, the priority of plans for natural resources and natural hazards management have been evaluated only in a single geographic region (as basin, sub-basin,, province, site, etc...) and without respect to land capability or natural hazard classes. For achieving a good land use planning and sustainable development, the priority of proposed management plans must be evaluated with respect to the natural resources capability and natural hazard intensity classes in each of the management units

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Chloride dynamics as signature indicator of salinity in dryland regolith after deforestation

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Abstract

Soils inherently saline at depth (hazard) under natural forest may be at risk of becoming near-surface saline when deforested for pasture/cropping. The objectives of this study were to (i) characterise salinity hazard and risk using chloride (Cl) distribution under native forest and pasture (ii) assess the potential salinity risk after deforestation, and (iii) deduce the groundwater flow pathways. Using a hydraulic rig, soil cores were taken from 6 sites, across a catchment, representing different land use systems and soil types, at 0-0.1, 0.1-0.2, 0.2-0.3, and thereafter at 0.3 m depth increments to 6 m. Sub-samples from the depth increments were analysed for Cl, pH, and electrical conductivity (EC). Regardless of the land use, Cl and EC increased with increasing profile depth, whereas no such consistent trend was found for pH. The comparison of paired Cl distribution curves indicated that most of the changes after deforestation occurred in the top 2 m. Compared with native forest, Cl accumulation occurred in the top 2 m in 3 out of the 6 down slope pasture sites and Cl leaking from one down slope pasture. Compared with the native forest no changes in Cl distributions were observed in 5 out of the 6 upslope pasture sites and an accumulation at the remaining one site. The stepwise multiple regression analysis for the data pooled across the 6 sites indicated that Cl distribution depended on the systems variables; soil depth, EC, and landscape position and the management variable land use practices (forest vs. pasture/cropping) (R^2 = 0.66). The Cl distributions in the undisturbed forest indicated condition favourable for accelerated lateral flow at < 2 m and limited vertical flow at depths > 2 m. The results show the forest profiles are inherently sodic (hazard) and may become saline in the top 2 m (risk) at down slopes after deforestation.

Introduction

There is uncertainty with regard to potential crop root-zone salinity risk in some of the semi-arid and tropical catchments in Queensland, Australia (Biggs and Power, 2003; Keating et al., 2001; Lawrence et al., 1991; Shaw et al., 1994; Walker et al., 1999). In the Belyando-Sutter sub-catchment in Central Queensland approximately 50% of the 74,000 sq km of the native forest has been cleared for grazing and cropping. The potential salinity risk after deforestation in this sub-catchment is associated to the fact that in several other similar catchments in Australia the inherent salt at depth has been mobilised to near the soil surface after deforestation and this has led to crop root-zone salinity and aquatic and terrestrial ecosystems health issues (Cocks, 2001; Walker et al., 1999). In some catchments the near-surface salinity has been associated to substantial reduction in potential yield and in other catchments to the abandonment of large proportion of individual properties (McFarlane and George, 1992). The Belyando-Sutter sub-catchment is in a better position to undertake preventive measures before the salinity hazard becomes a risk, because deforestation and subsequent grazing/cropping has been in place in this catchment only for relatively short-period of time (< 30 yrs) compared with the other aforementioned older catchments. However, limited information exists on the mechanics of salt redistribution after deforestation in this sub-catchment to undertake appropriate preventive measures.

The procedures/methods used to assess salinity risk should take into consideration: (a) salt distribution in the deforested vs. nearby forest profiles (b) the characteristics of the groundwater flow systems that translocate salt in soil profiles and to the nearby streams, and (c) the changes in hydrology, particularly the drainage below crop/pasture root-zone after forest clearing. The potential salinity risk assessment requires an integrated approach to better understand the impact of the aforementioned three factors on salt dynamics. Though an integrated approach is the most preferred option, other constraints particularly financial, may limit one to consider the most practical one.

The groundwater (GW) is the primary driver that is responsible for redistribution of salts and nutrients in soil profiles. In the undisturbed forest system, the GW is usually in a dynamic but equilibrium state; however, after forest clearing the drainage or the water that moves below the crop/pasture root-zone is usually higher than under forest due to the inability of shallow rooted pasture/crops to use the infiltrated water and/or store the accumulated quantity in profiles over a period of time (Walker et al., 1999). The major variable controlling the direction, quantity, and rate of drainage is changes in evapotranspiration after deforestation (Cook et al., 2002; Timms et al., 2001; Petheram et al., 2000; Yee Yet and Silburn, 2003). Evpoatranspiration from shallow rooted pasture/crops are low compared with deep rooted perennial forest vegetation, thereby increasing the annual drainage and leading to rise in GW over period of time. The rise in GW has led to mobilization of salt to near soil surface (Walker et al., 1999). However, in summer-dominant rainfall areas (e.g. the study sub-catchment) the drainage is considered to be small compared with winter-dominant regions because of the rainfall coinciding with high evapotranspiration in the former (Walker et al., 2002; Heng et al., 2001).

Though changes in land use may affect drainage rate immediately, the corresponding aquifer recharge may not be noticeable for time periods of the order of <25 to >250 years (Cook et al., 2002). However, long-term quantitative information on drainage and GW dynamics is scarce even from the older catchments. Therefore researchers have resorted to scenario modelling as an inexpensive tool to predict salinity risk without adequate model calibration and validation (Walker, 2002; Zhang et al., 2002; Petheram et al., 2000; Keating et al., 2001; Yee Yet and Silburn, 2003). Modelling without proper calibration and validation may be misleading at times.

Recently, chloride (Cl) distribution in soil profiles has been used as a signature indicator of hydrologic and textural stratigraphies (Rasiah et al., 2005; O' Geen et al., 2002; Hendry et al., 2002). The aforementioned workers have shown that Cl is non-reactive and highly mobile, therefore its redistribution is a reflection of hydrologic stratigraphy, implying the changes in drainage hydrology that led to the changes in Cl redistribution. This suggests that Cl redistribution can be used as signature indicator of salinity risk and the cost prohibitive qualitative/quantitative changes in drainage can also be inferred from Cl redistribution data. However, the depth to which redistributions may occur after deforestation may vary with soil type, the land use pattern, position on landscape, and proximity to water bodies (stagnant and running), i.e. systems physical variables. Thus, the objectives of this study were to (i) characterise salinity hazard and risk using Cl distribution under native forest and pasture (ii) assess the potential salinity risk after deforestation, and (iii) deduce the groundwater flow pathways.

Materials and methods

Site description

The study was conducted in the semi-arid Belyando-Suttor sub-catchment, approximately at 22.10 – 22.12° latitude and 147.47 – 147.59° in Central Queensland, Australia, The approximate year of forest clearing, the land use pattern after forest clearing, the major nearby forest species, the broad soil textural classification, the long-term average annual rainfall, and the village or township from where samples were collected are provided in Table 1. The system variables; the proximity to nearby drainage lines and slope aspect are also included in the table.

Soil coring and sampling

Soil samples to 6 m depth were taken at 0-0.1, 0.1-0.2, 0.2-0.3, and thereafter at 30 cm depth increments using a hydraulic rig. These samples were packed in air-tight PVC bags stored at 4°C and transported to the laboratory. The air-dried samples were ground to < 2 mm and sub-samples were used for chloride (Cl), electrical conductivity (EC), and pH (in water) determinations (Rayment and Higgionson, 1992). At each site, soil cores were taken from upslope and down slope aspect of landscape and from pasture/crop and nearby remnant forest vegetation. The distance between the cultivated and the corresponding forest varied from site to site, ranging from 20 to 150 m.

Statistical analysis

The data were analysed using the SAS (1991) software package. The mean, standard deviation (sd) and coefficient of variation (CV) for each profile was computed. The associations between depth incremented Cl and EC or pH, and that between Cl and EC, Cl and pH, and EC and pH were also computed. In this study depth incremented Cl, EC, pH, slope aspect (upslope vs. down slope), and proximity to drainage lines were considered as system variables and forest clearing vs. pasture/cropping as management variables. The upslope-down slope data for cultivated or forest are considered as paired to assess landscape impact on Cl distribution. The data from down slope pasture/crop and the nearby forest down slope are considered as paired for changes in land use impact assessment. Similarly upslope cultivated and the corresponding upslope forest is also considered as paired. The stepwise multiple regression procedure was used to assess system and management variable impact on Cl distribution. In this analysis, the landscape position (LP) was used as a qualitative variable where upslope was assigned 1 and down slope zero. Similarly for the management variable land use (LU), pasture/cropping was assigned one and forest zero.

Results and discussion

Chloride distributions

The paired-site mean comparison for site 1 indicate that Cl at down slope pasture was higher than the corresponding down slope forest, suggesting Cl accumulation after forest clearing (Table 2). The accumulation under pasture was probably due to higher sub-surface lateral transport of Cl, than vertical, from upslope to down slope. However, if there was increased lateral transport of Cl from upslope pasture to down slope, then the Cl at upslope pasture should be lesser than the upslope forest. This is not the case and in fact the Cl at upslope pasture was more or less equal to the upslope

Table 1. The characterisation of the paired-sites with regard to major soil types, forest vegetation, landuse history, and average annual rainfall.

Site	Village name: Sample code number	Soil type[1]	Proximity to drainage lines	Distance between paired sites	Forest clearing year	Landuse history	Forest vegetation	Average rainfall (mm)
1	Vinabel: 545-548	Humboldt; Texture contrast	1 km	50 m	1993-95	Native and exotic grasses	Brigalow/ Blackbutt scrub	450
2	Moonstone: 549-552	Humboldt; Texture contrast	1 km	20 m	1980s	Native and exotic grasses	Brigalow/ Blackbutt scrub	500
3	Trebarney: 553-556	Banchory; cracking clay	10 m	20 m	1982	Native and exotic grasses	Gidgee scrub	525
4	Vicenza: 557-562	Moray land system(LS); cracking clay	5 km	50 m	1980s	Forage sorghum	Gidgee scrub	550
5	Coobyanga	Moray LS Cracking clay	2 km	100 m	1980	Exotic grass/crops	Gidgee scrub	550
6	Disney: 569-574	Islay LS; cracking clay	1 km	150 m	1980	Native and exotic grasses	Gidgee scrub	550

1 Broad soil classification according to Isbell (1996) forest. Further, if upslope-down slope transport has occurred then Cl at down slope forest should be more than at upslope forest, but a reverse trend was observed. The forest upslope-down slope geohydrology can be considered to be in equilibrium state with regard to flow rates and directions. Thus, less Cl at down slope forest compared with upslope forest may be reflecting a Cl leaking situation into the nearby streams. However, if we accept this scenario then the Cl at down slope pasture should be much less than the corresponding upland, because the lateral flow would have increased after forest clearing. Thus, at this stage, the Cl and groundwater (GW) dynamics seems to be not consistent. Nevertheless, higher Cl in down slope pasture suggests that Cl dynamics has changed after forest clearing. The Cl distribution curves for upslope forest and upslope pasture (Fig. 1a) indicate there were little or no changes. However, at down slope pasture there was substantial Cl accumulation throughout the profile and it increased rapidly up from 1.2 to 2.5 m and thereafter there were little or no changes.

The paired mean comparison for site 2 indicates the Cl at down slope pasture was equal to the corresponding down slope forest and upslope pasture was lesser than upslope forest (Table 2). The Cl at down slope pasture was lesser than the corresponding upslope pasture and which in turn is lesser than upslope forest. Regardless of the land use, less Cl at down slope than upslope suggests that Cl was discharged from down slope into nearby streams, if there was upslope-down slope transport. Less Cl at upslope pasture than upslope forest suggests increased Cl transport from upslope pasture to down slope, laterally and/or vertically, than upslope forest. The Cl distribution curves

Table 2. The ranges, mean, standard deviation, and coefficient of variation for chloride distribution in soil profiles at the six sites and in the land use system at each site (for n = 20 to 22 at each code number).

	Land use and topography	Range	Mean	Coefficient of variation
Code numbers at Site1				
545	Pasture downslope	0-1901	1032±672	0.65
546	Pasture upslope	164 -1379	1031±365	0.35
547	Forest downslope	0 -541	244±221	0.91
548	Forest upslope	11-1355	1030±442	0.41
Code numbers at Site 2				
549	Pasture downslope	57-747	379± 236	0.62
550	Pasture upslope	11-1523	866±560	0.65
551	Forest downslope	22-1206	415±369	0.89
552	Forest upslope	73-1853	1495±598	0.52
Code numbers at Site 3				
553	Crop	0 - 3854	2078±1359	0.65
556	Forest upslope	21-3309	2057±1052	0.51)
Code numbers at Site 4				
557	Forest downslope	18-1264	593±392	0.66
558	Forest upslope	16-1147	506±377	0.74
559	Crop	0- 3565	866±1331	1.53
561	Pasture downslope	10-2301	1176±838	0.71
562	Pasture upslope	22-2320	1241±831	0.67
Code numbers at Site 5				
563	Forest upslope	28-1623	902±505	0.56
564	Forest downslope	26-1599	893±457	0.51
565	Pasture upslope	30-1529	977±473	0.48
566	Pasture	0-1353	755±950	0.59
568	downslope	0-2441	1230±869	0.70
	Crop			
Code numbers at Site 6				
569	Pasture downslope	68-4582	2405±1605	0.67
571	Pasture upslope	341-3422	2204±727	0.33
572	Forest downslope	61-4761	2502±1326	0.53
574	Forest upslope	49-4729	2521±1374	0.55

(Fig. 1b) indicate that at upslopes, both forest and pasture, there were little or no changes. However, at down slope pasture there was Cl accumulation in the top 1.5 m and it increased rapidly from 0 to 1.5 m and thereafter there was little or no change and was similar to down slope forest.

At site 3, the mean Cl comparison indicates the Cl under cropping is equal to corresponding upslope forest (Table 2). Unfortunately the down slope data are not available. However, there were gradual increases in Cl, both in the forest and crop profiles (Fig. 1c), with depth and it reached a maximum around 2.0 m. Thereafter, there was little or no change both under cropping and forest.

The mean Cl at down slope pasture is more than at the corresponding down slope forest at site 4, suggesting Cl accumulation at down slope pasture and a similar trend was observed between upslope

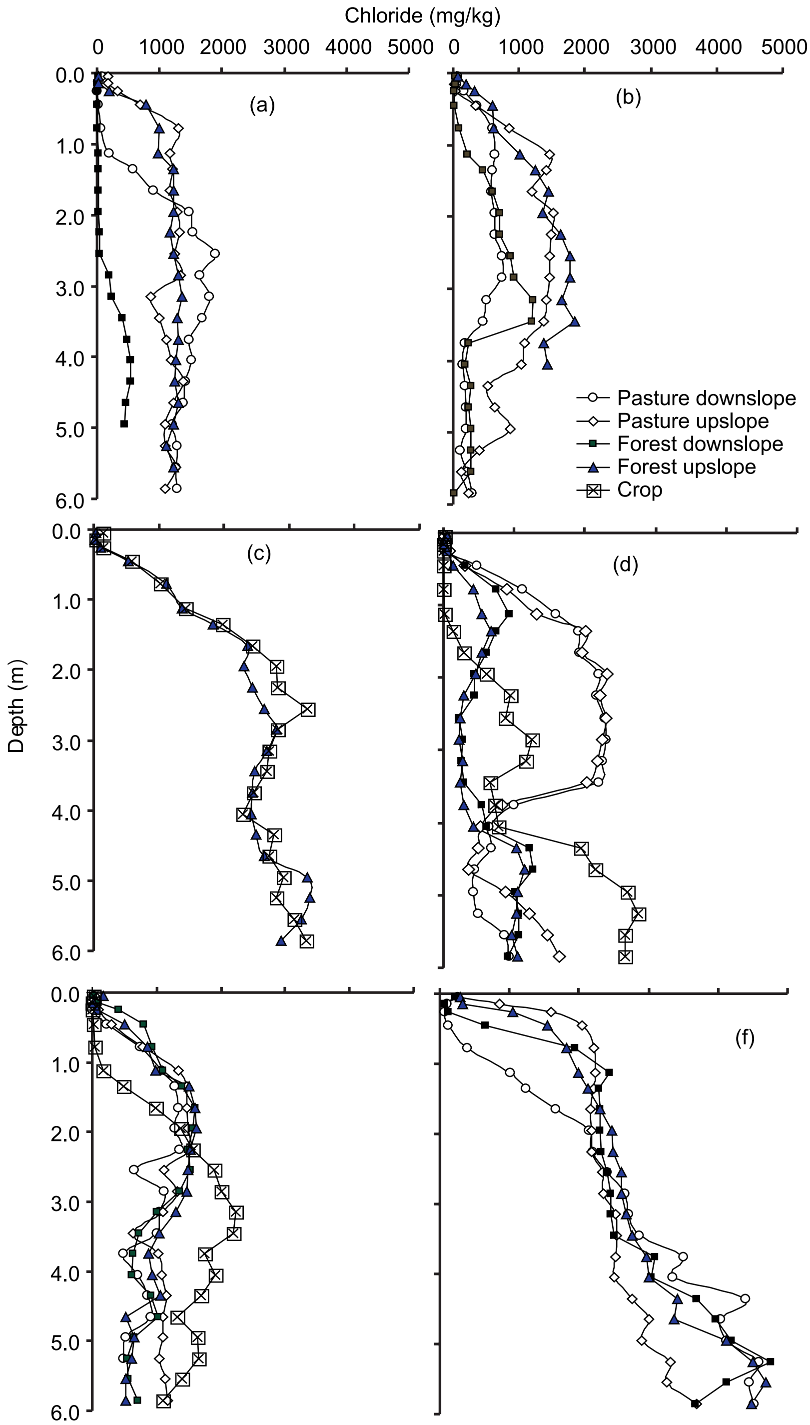

Fig. 1. Chloride distribution in the soil profiles at the 6 sites.

pasture and upslope forest (Table 2). The gradually increasing Cl in the undisturbed forest system (Fig. 1d) reached the maximum around 1.0 m and thereafter the changes were small both at upslope and down slope. A similar trend was observed under pasture, both at up- and down slopes, but the concentration increased rapidly to a maximum around at 1.5 m depth compared with forest and it remained unchanged up to 4 m. The Cl distributions under pasture, both up- and down slopes, when compared with the corresponding forest indicate substantial Cl accumulation under pasture between 1.0 to 4.0 m. The source for higher Cl under pasture, particularly at upslope, could only be from rising groundwater (GW), at least a temporary perched condition, during the rainy season. In the absence GW dynamics data, we are unable to comment further on this. Nevertheless the regional GW system in the sub-catchment is fairly deep > 20 to < 200 m, suggesting rising GW from the regional system contributing to Cl mobilisation and accumulation is unlikely. The Cl distribution in upslope annual sorghum compared with forest and/or pasture indicate substantial leaching down to 2 m and thereafter a trend existed for the leached Cl to be redeposited between > 2 to < 6 m.

At site 5, the mean Cl showed no differences, thus providing no support for lateral flow transport from upslope to down slope in either land use or for discharge into streams or for accumulation at down slope (Table 2). There were no differences between pasture and forest (Fig. 1e). The Cl increased gradually in either land use system up to 1.5 m and thereafter little or no changes were observed throughout the profiles. Compared with pasture or forest the Cl in the upslope sorghum decreased rapidly up to 2 m and thereafter the Cl under sorghum is more than in upslope forest or pasture. It seems that Cl leaching from depths < 1.5 m has occurred under the annual sorghum and the leached Cl was redeposited at depths > 2 m.

There were no significant differences in Cl means between pasture and forest and between landscape positions in a given land use system in site 6 (Table 2). However, the Cl distribution data (Fig. 1f) indicate the Cl under pasture at down slope is lesser than the forest down slope in the top 1.5 m, suggesting Cl transport laterally or vertically. A reverse trend existed for the Cl at upslopes of pasture vs. forest. There seems to be little difference in Cl distribution between upslope and down slope forest (Fig. 1f). However, the Cl in the top 1.5 m of upslope pasture is more than down slope pasture. The Cl in the undisturbed forest system (Fig. 1f) increased gradually to a maximum value at around 1.0 m and thereafter there were little or no changes up to 4 m.

The foregoing discussion on means indicates there were inconsistencies that can not be resolved on physical basis. For example the substantial Cl accumulation at 1.0 m depth under pasture at site 4 (Fig. 1 d). The within profile high variability indicated by large standard deviation (sd), as high as 1331 mg/kg for a mean of 866 mg/kg, suggests the use of mean as a parameter to characterise Cl may be misleading. The large sd has led to the mean±sd between landscape positions for pasture or forest being not significant in majority of the cases. Further, the high variability within profiles is statistically supported by large CV, 0.35 to 1.53 (Table 2). We suggest the large CV, particularly for the undisturbed under forest system, supports the hypothesis that Cl distribution is a signature indicator of soil hydrologic and textural stratigraphies (Rasiah et al., 2005; O' Green et al., 2002; Hendry et al., 2000). According to these workers when the Cl concentration increased gradually it reflected gradual decreases in vertical hydraulic conductivity. On the other hand an abrupt increase or Cl peak reflected rapid decreases in vertical conductivity through the presence of a water flow restrictive layer (WFRL) where the Cl peak occurred. In the presence of a WFRL the GW above it becomes dynamic, it is mostly a temporary perched system, and conditions favourable for accelerated lateral flow are created. Thus, our data, showing particularly for the forest systems the most variability in Cl distribution at depths < 2 m and maximum Cl at depths 1- 2 m, suggest the presence of WFRL between 1 to 2m. In general, there was a trend in which the down slope undisturbed forest is characterised by higher CV than the upslope, suggesting the Cl at down slope to be more dynamic than at upslope; possibly through deposition by lateral flow, deposition by vertical and lateral flow, discharge into streams, and redistribution.

In light of the aforementioned associations between Cl, WFRL and GW flow systems dynamics, we re-examined Cl distributions in top 2 m of the studied profiles. The re-examination indicates at least two consistent trends. First, the Cl at down slope pasture is more than the corresponding forest down slope Cl, exclusive of at site 4. Second, the Cl at down slope pasture is always lesser than the corresponding upslope pasture, which in turn is greater than upslope forest. We suggest a higher Cl scenario under pasture, both at upslope and down slope, compared with the corresponding forest, indicates Cl accumulation after forest clearing at both landscape positions. On the other hand, less Cl at Down slope pasture than upslope may be due to increased discharge from down slope into nearby streams through lateral flow discharge. Similar results for nitrate-N dynamics, upslope concentration being higher than down slope, has been reported for a perched GW system (Rasiah et al., 2004). In general, Cl distribution, particularly in the top 2 m, under pasture/cropping is different from the remnant forest indicating that after forest clearing the salt in

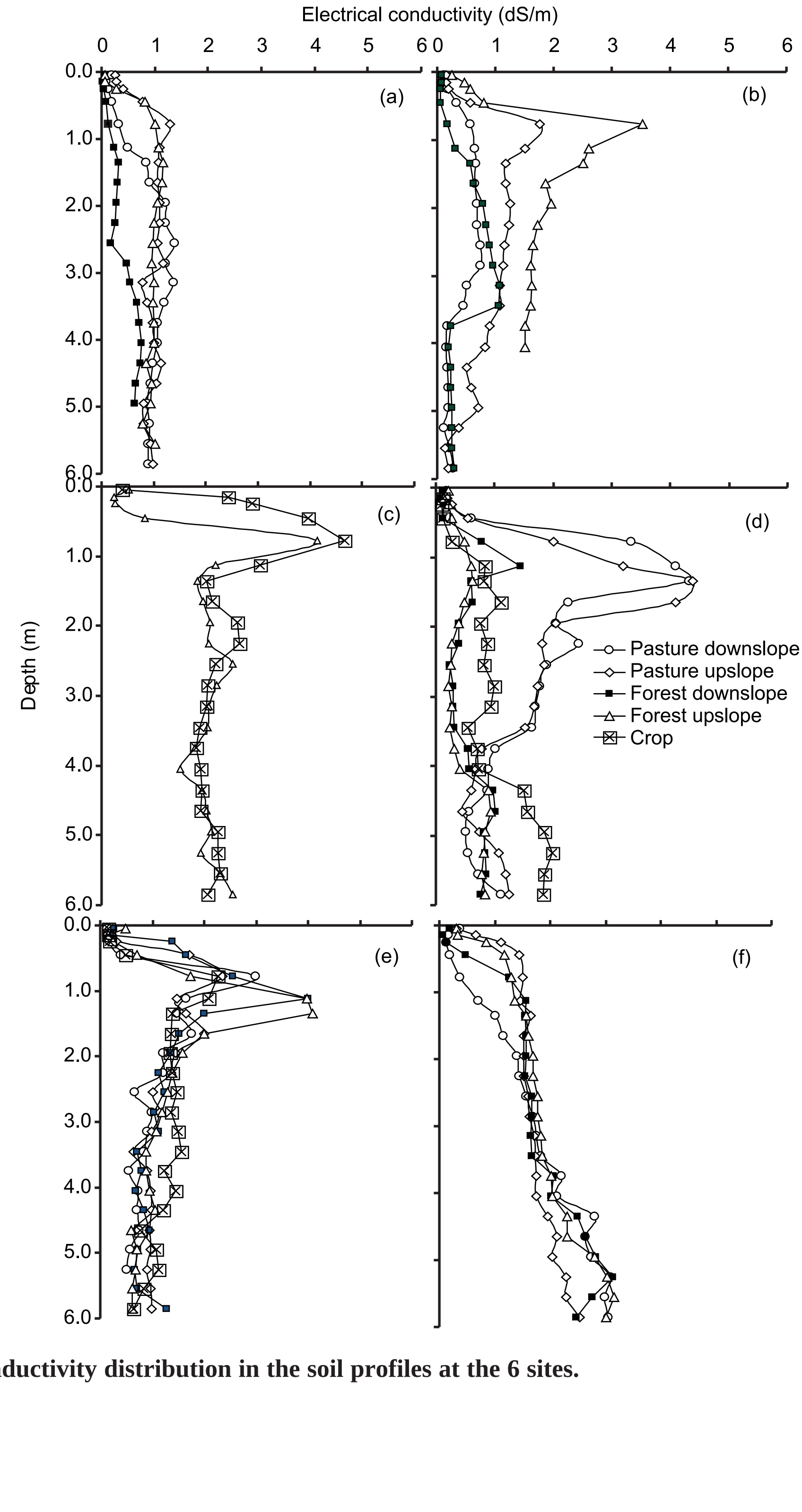

Fig. 2. Electrical conductivity distribution in the soil profiles at the 6 sites.

the top 2 m of the cultivated profile has undergone redistribution, accumulation, and/or leaching (Fig. 1). This suggests that the paired-site Cl distribution data can be used as signature indicator of salinity risk from the existing hazard. The Cl data also provide support to the hypothesis that it can be used as a tool to identify the presence of WFRL and the dynamic nature of the GW above the WFRL and relative flow direction, vertical vs. lateral (Rasiah et al., 2005; O' Green et al., 2002; Hendry et al., 2000).

The hydraulic steady state analysis for the same catchment indicated low drainage rates at all sampling times, regardless of the land use, as there was little or no difference in Cl concentrations at the bottom of crop root-zone, below 1.0 m (Thorburn et al., 1991). Thorburn et al. (1991) suggested that this does not mean that Cl was not leached from crop root-zone, but a longer time frame was required to attain equilibrium at the depth considered. In another study Lawrence et al. (1991) used the PERFECT model to predict long-term trends from 4 years of rainfall, runoff, soil water and deep drainage data from brigalow forest, buffel pasture and annual wheat cropping in similar semi-arid catchments in central Queensland. They predicted the average annual drainage (1924-1989) as 2, 0 and 23 mm yr^{-1}, for forest, pasture and crop, respectively, or 0.3, 0 and 3.2% of the average annual rainfall. Drainage was lower under pasture because runoff was higher than under forest. Most of these studies disregarded lateral flow discharge pathway.

Electrical conductivity and soil pH

The ranges in electrical conductivity (EC), the

Table 3. The range, mean, standard deviation, and coefficient of variation for electrical conductivity distribution in the soil profiles (for n = 20 to 22 at each code number).

	Land use and topography	Range	Mean	Coefficient of variation
Code numbers at Site 1				
545	Pasture downslope	0.09 – 1.38	0.83±0.41	0.49
546	Pasture upslope	0.27 – 1.28	0.90±0.27	0.30
547	Forest downslope	0.03 – 0.75	0.37±0.26	0.70
548	Forest upslope	0.06 – 1.15	0.86±0.32	0.37
Code numbers at Site 2				
549	Pasture downslope	0.08 – 0.75	0.39±0.24	0.62
550	Pasture upslope	0.13 – 0.81	0.48±0.59	0.59
551	Forest downslope	0.06 – 1.08	0.43±0.35	0.81
552	Forest upslope	0.25 – 3.52	1.61±0.84	0.52
Code numbers at Site 3				
553	Crop	0.25 – 4.13	1.86±0.84	0.45
556	Forest upslope	0.40 – 4.67	2.33±0.83	0.35
Code numbers at Site 4				
557	Forest downslope	0.11 – 1.44	0.55±0.36	0.64
558	Forest upslope	0.13 – 0.93	0.48±0.26	0.56
559	Crop	0.11 – 2.44	0.83±0.17	0.99
561	Pasture downslope	0.16 – 4.32	1.49±1.21	0.81
562	Pasture upslope	0.17 – 4.39	1.47±1.17	0.80
Code numbers at Site 5				
563	Forest upslope	0.15 – 4.08	1.21±0.82	0.68
564	Forest downslope	0.20 – 3.99	1.50±0.47	0.60
565	Pasture upslope	0.17 – 2.35	1.10±0.54	0.49
566	Pasture downslope	0.14 – 2.99	0.92±0.67	0.74
568	Crop	0.15 – 2.58	1.43±0.65	0.45
Code numbers at Site 6				
569	Pasture downslope	0.13 – 3.10	1.61±1.01	0.63
571	Pasture upslope	0.36 – 2.37	1.56±0.48	0.31
572	Forest downslope	0.07 – 3.14	1.68±0.87	0.52
574	Forest upslope	0.10 – 3.17	1.73±0.89	0.51

mean, sd, and CV for different land uses at the 6 sites are summarised in Table 3. The EC distributions shown in Fig. 2 indicate it followed the pattern of Cl (Fig. 1) and this is not surprising because the major ion contributing towards EC was Cl. The EC distributions in the profiles are characterised by high CV, similar to Cl, indicating high degree of variability within profiles. However, the large variations in distributions are confined to < 2 m, regardless of the site or the land use and are similar to Cl. This provides further support to the hypothesis that the top < 2m is in dynamic state with regard to ion fluxes. The pH in general is in the alkaline range (Table 4) and in some instances the mean pH is as high as 9.13. The relatively low CV, compared with the corresponding EC or Cl, indicates that within profile pH variations are not as large as the former two. High soil pH along with Cl indicates the soils are inherently sodic.

Though the Cl distribution in the profiles showed curvilinear patterns, positive linear associations were found between depth (d) increments and the corresponding Cl (16 out of 24), d and EC (13 out of 24) and d and pH (10 out 24) (Table 5). Some inconsistencies (+ve or –ve) were found for the association between pH and d. The Cl vs. d correlation was not significant mostly for grazing down slopes, implying high variability. Positive linear associations were found between Cl and EC (21 out of 24). The association between Cl and pH were inconsistent (+ve or -ve) and a similar trend was found for that between EC and pH.

System variable impact on Cl distribution

We showed that in general Cl distribution varied with the system variables; the location in the catchment (site) and the landscape, and with the management variable land use system (forest vs.

Table 4. The range, mean, standard deviation, and coefficient of variation for pH distribution in soil profiles at the six sites (for n = 20 to 22 at each code number).

	Land use and topography	Range	Mean	Coefficient of variation
Code numbers at Site 1				
545	Pasture downslope	7.3 - 9.6	8.78±0.56	0.06
546	Pasture upslope	8.5 – 9.6	9.13±0.30	0.03
547	Forest downslope	6.8 – 9.8	9.13±1.03	0.11
548	Forest upslope	5.3 – 9.2	7.18±1.57	0.21
Code numbers at Site 2				
549	Pasture downslope	4.6 – 7.4	5.70±0.92	0.16
550	Pasture upslope	5.2 – 8.9	7.08±1.42	0.28
551	Forest downslope	4.7 – 8.7	6.30±1.30	0.21
552	Forest upslope	7.6 – 8.6	8.15±0.34	0.04
Code numbers at Site 3				
553	Crop	7.95 – 9.23	8.61±0.35	0.04
556	Forest upslope	7.88 – 8.86	8.42±0.29	0.03
Code numbers at Site 4				
557	Forest downslope	7.54 – 9.58	8.67±0.68	0.07
558	Forest upslope	8.23 – 9.38	8.85±0.35	0.03
559	Crop	8.10 – 9.30	8.77±0.36	0.04
561	Pasture downslope	4.35 – 9.50	7.38±1.97	0.26
562	Pasture upslope	5.06 – 9.49	7.75±1.17	0.21
Code numbers at Site 5				
563	Forest upslope	5.39 – 9.26	7.73±1.40	0.18
564	Forest downslope	5.15 – 9.07	7.50±1.47	0.20
565	Pasture upslope	8.00 – 9.16	8.67±0.34	0.04
566	Pasture downslope	7.88 – 9.41	8.81±0.43	0.05
568	Crop	7.90 – 9.00	8.54±0.30	0.03
Code numbers at Site 6				
569	Pasture downslope	6.20 – 8.80	7.66±0.91	0.11
571	Pasture upslope	8.00 – 9.00	8.63±0.32	0.04
572	Forest downslope	4.70 – 8.71	6.38±0.87	0.21
574	Forest upslope	5.66 – 8.90	7.72±0.08	0.14

pasture/cropping). The other system variables that may have an impact on Cl dynamics are the presence of other ions, defined by EC and soil pH. We used the stepwise multiple regression procedure to assess the impact of the system variables; depth in soil profile (d), EC, pH, and landscape position (LP), and management variable pasture vs. forest on Cl distribution. In this analysis, the LP is a qualitative variable and converted to quantitative by assigning 1 for upslope and zero for down slope. Similarly the management variable land use (LU) was assigned 1 for pasture/cropping and zero for forest. The analysis produced the following equation,

$$Cl = 183.3\ d + 90.45\ EC + 18.8\ LU - 30.8\ LP - 245.8 \quad [1]$$

$R^2adj = 0.66$, $P < 0.001$

Though Eq. [1] may not produce perfect estimates, the physical interpretation it provides on the impact of system variables on Cl dynamics, particularly LU and LP is important. The impact of these two variables was not consistent when we discussed each site individually. However, when the data were pooled across the 6 sites, the impacts seem to be consistent. Equation [1] indicates that forest clearing and subsequent cropping had increased Cl in any segment of the profile by 19 mg kg^{-1} soil and there will be 31 mg kg^{-1} of less Cl in down slope than the corresponding upslope.

The impact of the landscape position system variable on Cl distribution is important with regard to the clarification on the issue of lateral flow. For this purpose we correlated the Cl distribution data of upslope against down slope through zero intercept. The zero intercept was used to avoid any

Table 5. The significance of the linear correlation between chloride or pH or electrical conductivity distribution in soil profile and depth (for n=20 to22 for each code number).

Land use and topography		Chloride	pH	Electrical conductivity
Code numbers at Site				
545	Pasture downslope	0.72**	ns	0.60**
546	Pasture upslope	0.54**	ns	ns
547	Forest downslope	0.92**	0.74**	0.93**
548	Forest upslope	0.68**	-0.76**	0.45*
Code numbers at Site 2				
549	Pasture downslope	ns	ns	ns
550	Pasture upslope	ns	-0.89**	ns
551	Forest downslope	ns	ns	ns
552	Forest upslope	0.85**	ns	ns
Code numbers at Site 3				
553	Crop	0.63**	ns	0.43*
556	Forest upslope	0.87**	0.59*	ns
Code numbers at Site 4				
557	Forest downslope	0.67**	0.72**	0.40*
558	Forest upslope	0.77**	0.72**	0.67**
559	Crop	0.84**	ns	0.79**
561	Pasture downslope	ns	ns	ns
562	Pasture upslope	ns	ns	ns
Code numbers at Site 5				
563	Forest upslope	ns	ns	ns
564	Forest downslope	ns	0.57*	ns
565	Pasture upslope	0.46*	0.61**	ns
566	Pasture downslope	ns	0.59*	ns
568	Crop	0.78**	ns	ns
Code numbers at Site 6				
569	Pasture downslope	0.99**	ns	0.99**
571	Pasture upslope	0.82**	ns	0.82**
572	Forest downslope	0.92**	0.76*	0.93**
574	Forest upslope	0.96**	ns	0.95**

negative intercept, which made the interpretations difficult. The undisturbed forest down slope-upslope correlation for sites 1 and 2 indicates that the Cl at down slope is significantly less than that at the corresponding upslope (Table 6). A similar trend was observed for sites 5 and 6, but to lesser degree. We suggested that less Cl at down slope indicates Cl leaking into nearby streams. The nearest natural drainage lines for sites 1, 2, and 6 are < 1 km away. Compared to these sites the Cl at down slope forest is about 1.11 times that of the upslope in site 4 and the drainage line is about 5 km away, suggesting any leaking is low, therefore Cl at down slope is more than at upslope. The undisturbed forest upslope-down slope Cl distribution data indicate the proximity to drainage lines plays an important role in Cl accumulation or leaking at down slope. If the drainage line was < 1 km, then there was a trend for Cl leaking into nearby drains, thereby minimizing the potential salinity risk at the lower aspects in the catchment. If the drainage lines were > 2 km away there was the potential for salt accumulation to occur at down slope, therefore potential salinity risk.

Conclusions

High Cl concentrations, up to 6 m depth, under native forest indicated salinity hazard in the catchment. The Cl distributions are characterised by high standard deviations and CV indicating large variability in within profile distributions, which is associated to hydrologic and/or textural stratigraphies. The paired comparison of down slope forest with the corresponding pasture indicated (i) Cl accumulation in the top 2 m after forest clearing or (ii) Cl leaking from down slope pasture or (ii) an uncertainty where no changes occurred in Cl distributions under pasture. The Cl accumulation at pasture down slopes indicates potential salinity risk, the Cl leaking to less risk, and the no difference situation to insufficient time frame under pasture for significant changes to occur. The Cl distributions in the top 2 m reached maximum values between 1 and < 2 m, and little or no changes thereafter indicate the presence of water-flow restrictive soil layers (WFRL) between 1 – 2 m. The WFTRL might have provided conditions favourable for the development of perched dynamic water table above WFRL and thereby for more lateral flow transport of Cl to down slopes. The system variables analysis indicated when Cl accumulation or leaking occurred after forest clearing at down slope pasture, the accumulation vs. leaking depended on the proximity to drainage lines. The results indicate Cl distribution data are useful to provide early warning systems for salinity risk, where it will occur in relation to natural drainage lines, and to identify preferential accelerated flow directions after forest clearing.

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Table 6. Correlations between chloride under pasture at upslope (PUS) and under pasture at downslope (PDS), and that between under forest at upslope (FOUS) and under forest at downslope (FODS) showing the magnitude of the slope for a zero intercept fitting.

Sites	Equation	Chloride dynamics scenario	r
Site 1	PDS = †1.02(0.10) PUS	Uncertain	0.83
	FODS = 0.20(0.05) FOUS	Cl leaking from downslope forest	0.60
Site 2	PDS = 0.41(0.03) PUS	Cl leaking from pasture at downslope	0.90
	FODS = 0.45(0.05) FOUS	Cl leaking from downslope forest	0.85
Site 3	CROP = 1.05(0.05) FOUS		0.95
Site 4	PDS = 0.95(0.05) PUS	Uncertain	0.96
	FODS = 1.11(0.05) FOUS	Cl accumulation at downslope forest	0.96
	CROP = 2.15(0.27) FOUS	Cl accumulation at upslope crop	0.74
Site 5	PDS = 0.79(0.04) PUS	Cl leaking from pasture at downslope	0.95
	FODS = 0.95(0.04) FOUS	Cl leaking from downslope forest	0.96
	CROP = 1.12(0.13) FOUS	Cl accumulation under cropping at upslope	0.78
Site 6	PDS = 1.08(0.09) PUS	Uncertain	0.87
	FODS = 0.95(0.09) FOUS	Cl leaking from downslope forest	0.96

† If the slope is significantly < 1.00, then there was the potential for Cl leaking to occur from downslope, if > 1.00 there was potential for accumulation to occur, and if = 1.00 there is an uncertainty. The correlations are significant at P < 0.01 and r in the table is correlation coefficient.

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Important factors affecting suspended sediment yield in arid and semi-arid areas of Central Iran

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Abstract

Almost half of Iran is characterized by arid and semi-arid climate and this needs to be taken into account for better management of natural resources directed to sustainable development. To determen the rate of soil erosion and sediment yield in the central Iran, the Esfahan and Sirjan watershed total of that accounts for one fifteenth of the country was considered. 14 sub-watersheds having 11 years' simultaneous recording were selected and categorized into two homogenous groups using clustering technique. The important factors affecting generation of mean daily suspended sediment load were then identified from 49 physiographic, hydrologic, land use, geologic and climatic characteristics, with the help of factor analysis technique. The 20 years peak discharge, rangeland percentile and ruggedness number were found as the most important factors controlling the yield of suspended sediment in the study watershed.

Introduction

Many different factors affect the rate of soil erosion and consequently sediment yield. Some of these are the inherent characteristics of the soil and cannot be easily controlled. Identifying the parameters that affect soil erosion and an evaluation of their controllability is important for devising control measures. As the number of recording stations for hydrologic studies is much limited in Iran appropriate models are required for estimating suspended sediment load.

Mathematical modeling of watershed hydrology is employed to address a wide spectrum of environmental and water resource problems. Lots of soil, as one of the hydrologic components, is annually washed out from the watersheds and deposited in water bodies, which in turn creates many in-site and off-site ill effects. Identification of sediment source areas within a watershed is useful for designing appropriate management alternatives that reduce sediment losses (Kalin et al., 2004). Many attempts have been made by different workers to recognize the relationship between suspended sediment and the geologic, physiographic, land use, and climatic and hydrologic factors that affect its yield (e.g. Varvani et al., 2002; Feiznia et al., 2002; Narayana, 2002; Carvalho, 2005). Since the importance and effectiveness of aforesaid parameters varies in spatial and temporal scales, the present study was conducted to find out important predictors for suspended sediment yield in Esfahan and Sirjan watershed in Iran.

Materials and methods

The studied watershed is located in dry and semi-dry regions of central Iran and covers an area of 99,300 km^2. It is suffering from different types of land degradation, particularly soil erosion. The area has been divided into two main parts, Esfahan and Sirjan, comprising an area of 41,521 and 57,779 km^2, respectively. According to the availability of the recording stations, the entire watershed was divided into 14 sub-watersheds. The schematic view of the study area and the location of hydrometry stations are shown in Fig. 1.

To verify the importance of some of the factors recognized important in the previous studies and to resolve some of the uncertainties in the genera-

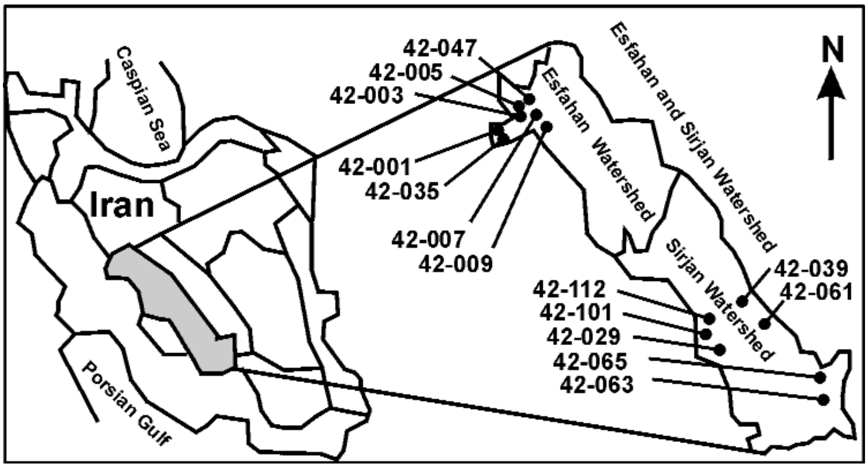

Fig. 1. Schematic view of Esfahan and Sirjan watershed, Iran (Ministry of Power, 1989).

tion of suspended sediment yield in the study area, the data on mean daily suspended sediment and different physiographic, hydrologic, land use, geologic and climatic characteristics of 14 selected sub-watersheds were examined, as these watersheds had simultaneous recording of data for 11-year period (i.e.1991-2001). All parameters were obtained with the help of geologic and land use maps, satellite images and aerial photos with the scale of 1:250,000, 1:100,000 and 1:50,000 and hydrometeorological measurements (Najafi, 2003). The multivariate regression techniques, in conjunction with factor analysis, clustering and discriminate analysis (Wheater and Cook, 2000), were used to have the best performing model for predicting sediment yield in the study area.

Results and discussions

Following the above mentioned procedure, two models were found to provide perfect fit for the relationship between the sediment yield and various parameters for two homogenous areas as given below:

$$Ye=188.937Gn+3.453Qp20-3.919Rn+4764.936Ll-5996.599 \quad (1)$$

$$Ye=-0.311P24+7.952A-5.534R-4.714Lm-6.504Gn+1.808Qp20-0.559Rn+428.484Ll+318.953 \quad (2)$$

where Ye is the daily sediment yield (t), Gn is sensitivity rate of formation to erosion, Qp20 is peak discharge with 20 years return period (m^3/s), Rn is ruggedness number, Ll is main waterway length to watershed length ratio, P24 is maximum 24h rainfall with 2 years return period (mm), A is percentile of agriculture land, R is percentile of range land and Lm is main waterway length (km). The values of coefficient of determination, error of estimation and efficiency coefficient were found to be about 99%, below 5% and beyond 71%, respectively.

Out of 49 independent variables initially considered for the modeling process, just 4 and 8 variables were retained in the final models developed for two homogenous areas. It was shown that not only the type of the affective variables may change from place to place but also their effectiveness may alter as pointed out by Varvani et al. (2002). The peak discharge having 20 years return period, rangeland percentile and ruggedness number were found to be the most suitable variables for estimation of mean daily suspended sediment yield of sub-watersheds. These variables were rarely mentioned in the previous reports. The effectiveness of peak discharge and the importance of topographic factors on sediment yield have also been recognized by Das (2000) and Mehrseresht (1996), respectively. It could be inferred from this study that the sediment yield in the studied watershed is more sensitive to the basin characteristics compared to other external forces as mentioned by Paola (2000). This information might facilitate efforts in resolving the environmental and water resources problems in the study area (Singh and Woolhiser, 2002).

Conclusion

The results show that the sediment yield in the studied watershed is more sensitive to the basin characteristics as compared to other external forces. More accurate hydrologic data as well as watershed information need to be collected for such type of study. Studying the role of other accessible parameters in generation of daily sediment yield emphasizing on peak values with the help of other computational approaches is also recommended to be taken into account in future studies.

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Evaluation of organic-based emulsions for stabilization of dryland soils in the south-western United States

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Abstract

Under the U.S. Navy's Environmental Pollution Abatement Ashore Program, and in conjunction with the Naval Facilities Engineering Service Center and Encapco Technologies LLC, the Desert Research Institute (DRI) is testing an organic-based emulsion for treating arid-zone soils of the southwest United States. The emulsion was developed to stabilize and chemically bind soil particles and contaminants. At the Nevada Test Site, the emulsion is being tested for effectiveness in preventing wind suspension of soils contaminated with $^{239+240}$Pu. The Pu is often associated with respirable size soil particles (PM10 or less) and poses an inhalation risk. DRI's Portable in-situ wind erosion laboratory (PI-SWERL) induces wind shear at the soil surface to simulate stresses caused by winds. The PI-SWERL allows a rapid means of measuring wind erosion index based on PM10 resuspension. In addition, a saltation flux sensor array was established to measure when sand-grain saltation begins, considered to be an indicator for PM10 dust generation. At Yuma Proving Ground, Arizona, the emulsion is being evaluated for its effectiveness to chemically bind and prevent the transport of depleted Uranium from ordnance testing and to determine whether significant changes to hydrologic processes, such as infiltration and surface runoff potential, occurred after field application. Soil crusting after application could lead to reduced soil infiltration and increased runoff, potentially leading to soil erosion. To test for these scenarios, rainfall simulation and infiltration experiments are being conducted.

Introduction

Dryland regions of the southwestern United States (U.S.) have been impacted by a variety of activities that have contributed to land degradation and dust generation from disturbed and damaged soils (Lovich and Bainbridge, 1999; Webb, 2002). Among the activities that have contributed to degradation are overgrazing, off-road vehicle use, and military training. In addition, munitions testing, and past nuclear testing in Nevada, has resulted in large areas of dryland surface soils with radiological contaminants, unexploded ordnance, and ordnance residue. As part of a program to investigate methods of in-place stabilization of surface soil contaminants funded by the U.S. Naval Facilities Engineering Service Center, the Desert Research Institute (DRI), along with other collaborating companies, universities, and government agencies, is investigating the effectiveness of an organic emulsion in stabilizing surface radiological contaminants to suppress their suspension by wind or transport by water. Research reported herein is ongoing at two contrasting dryland locations: the Nevada Test Site (NTS) and the Yuma Proving Ground (YPG). (See Figure 1.)

The organic-based asphalt emulsion (Topein® C), developed and patented by Encapco Technologies LLC, is 45% residue from the distillation of tall oil pitch, a by-product of the paper industry. It primarily contains high-boiling-point esters of fatty acids

Fig. 1. Location of the Nevada Test Site and the Yuma Proving Ground in dryland regions the southwestern USA. Map adapted from Taylor (1998).

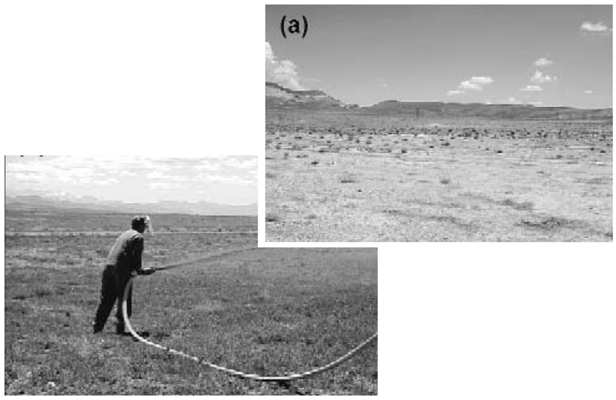

Fig. 2. The Smoky fan at the time of site selection in 2003 (a), and during emulsion application in May 2004 (b). The above average precipitation during the winter of 2004 resulted in significant vegetation growth at the site.

and rosin, as well as free fatty and resin acids, and neutral materials. The balance of the emulsion is approximately 50% water and 5% proprietary surfactants and other ingredients. The emulsion has previously been used to convert soils contaminated with metals as well as petroleum hydrocarbons into non-leachable construction material for road base and general fill (Cowdery and Warner, 2003). However, these uses of the emulsion involve physically mixing it with contaminated soil. In the applications evaluated herein, the objective was to stabilize radiologically contaminated soils *in situ* by spraying the emulsion on the soil.

However, in applying a treatment agent over large areas, stabilization of contaminants cannot be the only consideration. For example, if an emulsion were to decrease soil hydraulic conductivity (Ks) dramatically, negative effects could include 1) decreases in infiltration that could prevent the germination of seeds, decreasing the natural ability of vegetation to stabilize soils; and 2) rapid runoff that could erode, for example, desert pavements that are critical landscape features for soil stability in many drylands in the southwestern U.S. The emulsion studies are ongoing. This paper focuses on results of the effectiveness of the emulsion in reducing soil suspension at the NTS, and its impact on soil hydrologic properties at YPG.

Nevada Test Site (NTS)

The NTS, located in a transition zone between the Mojave and Great Basin deserts (Ostler et al., 2000), was the primary location where the U.S. conducted nuclear tests until 1992. Annual precipitation in the vicinity of the study site averages 16 cm with nearly 60% occurring in the winter. However, during the study period, over 25 cm of precipitation occurred. The study site, “Smoky Fan,” is downgradient of the Smoky Site, the location of a 1957 above-ground nuclear test and three “safety tests” in 1958 that resulted in surface contamination by plutonium (Pu) and americium (Am) (USDOE, 2000) (Fig.2). The study site (37.180° N, 116.059° W, elevation 1,310 m) was on the distal portion of an alluvial fan where the soils (gravelly loams to gravelly sandy loams) were finer-grained and believed to be emissive under windy conditions.

Because the primary mode of decay of ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am is through alpha decay, the main risk to human receptors is through inhalation such as could occur when finer soil particles (e.g., PM10, particulate matter with aerodynamic diameter less than 10 mm) associated with these contaminants are suspended by wind (Eisenbud and Gesell, 1997). At other Pu-contaminated sites in Nevada, as much as 50% of the Pu can be associated with PM10 or smaller particles (Bowen et al., 2001). The largest of the safety test sites covers over 6,000 hectares (Bowen and Shafer 2001).

Yuma Proving Ground (YPG)

At YPG in Arizona, as well as other U.S. Department of Defense facilities in the southwestern United States, depleted uranium (DU) oxide used in hardened penetrator munitions testing exists as a surface soil contaminant. The YPG is in the Sonoran deserts along the lower Colorado River. Average annual precipitation is 14 cm, which typically occurs primarily in the summer. However, similar to the NTS, above average rainfall of 26 cm occurred during the study period. Depleted uranium is composed primarily of a ^{238}U oxide. It is both radioactive and chemically toxic. Stabilization of DU using an organic emulsion with a chelating agent could reduce the transport of DU from air and water pathways, the latter including overland flow in both soluble and insoluble forms. Previous work at YPG indicates that most of the transported DU particles are larger than 0.50 mm in diameter (Ward and Stevens, 1996). In addition to understanding its effectiveness in suppressing DU transport, a primary objective of the YPG research has been to better understand the amount and duration of hydrologic effects of emulsion applications.

NTS methods and data collection

For emissivity measurements, ten 20-m squares were demarcated as test plots for direct testing of PM10 emissions from the soil. Emulsion dilutions (with water) of 4:1, 5:1, and 6:1 were each applied to two plots at application strength of about 2 liters/m^2. At locations where the emulsion was applied, the surface of the soil developed an approximately 1-cm-thick semi-cohesive crust. Two other test plots were treated with water at the same application rate. Finally, two control plots received no treatment. Within each plot a plywood disc 1-meter in diameter was placed roughly flush with the soil surface. The plywood served as control "surfaces" to help determine the amount of "depositional dust" that settled on the plots between times when the emissivity of the soils were tested.

The PI-SWERL: For measuring the propensity of the test plot soils to emit dust, the Portable In-Situ Wind Erosion Laboratory (PI-SWERL), designed and developed at DRI, was used (Etyemezian et al., 2003). Unlike larger field wind tunnels, the PI-SWERL provides a measure of the stability of a soil by generating wind shear above the surface rather than by emulating the atmospheric boundary layer. The PI-SWERL has a direct-current motor that sits on top of an open-bottomed cylindrical chamber (Fig. 3). The motor is coupled to an annular ring that hangs parallel to and several centimeters above the soil surface. As the annular ring revolves about its center axis, a velocity gradient forms between the bottom surface of the ring and the surface of the soil. The shear stress imposed by the velocity gradient results in an area of influence that is 5 cm in depth along the inside perimeter of the PI-SWERL cavity. The shear induced by the PI-SWERL forces soil particles to begin to move along the ground surface (similar to saltation), which causes particles in the PM10 size fraction to be dislodged and emitted as dust. The concentration of PM10 is monitored by a DustTrak, TSI, Model 8520, allowing dust emissions to be measured at different RPMs. (See Figure 4.)

The PI-SWERL provides an index of erodibility through the relationship between the revolutions per minute (RPMs) to PM10 emissions. This measurement, using an empirical calibration, can be translated into a shear stress or friction velocity vs. PM10 emissions curve, similar to those obtained from straight-line wind tunnel measurements (Gillies et al., 2005). An advantage of the PI-SWERL is the relative speed with which measurements can be performed. An average test during this study required less than 15 minutes.

The straight-line field wind tunnel is currently the

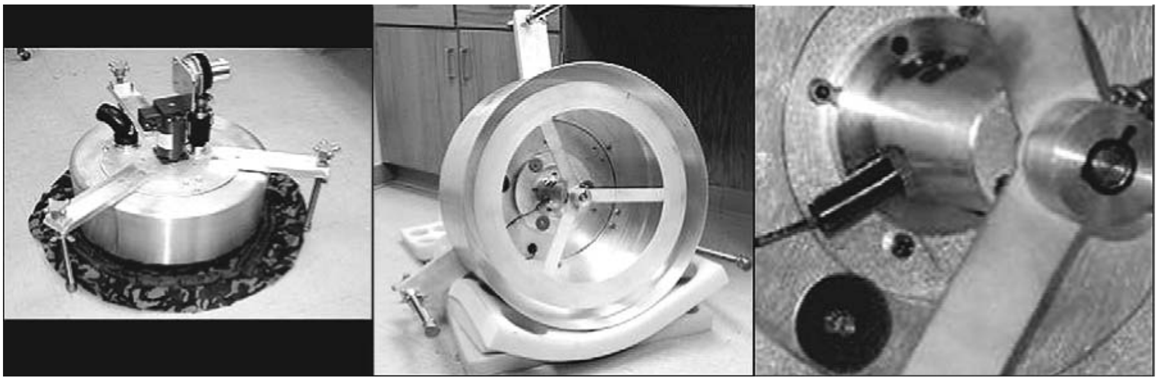

Fig. 3. The PI-SWERL in testing position (a), a view inside the instrument (b), and the shaft and RPM gange (c).

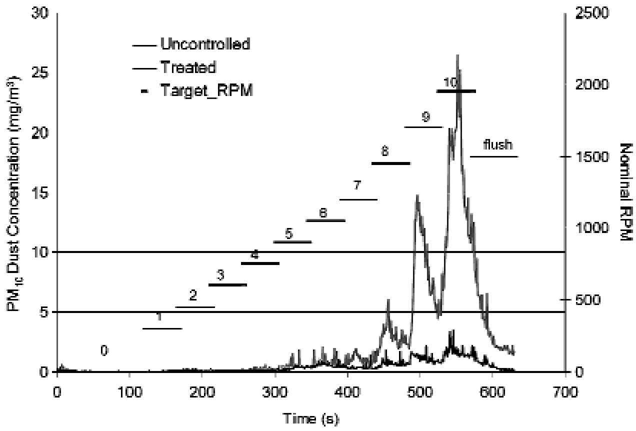

Fig. 4. Sample data output from a PI-SWERL measurement cycle. The numbered horizontal lines represent the RPM level (see right y-axis) and the duration of the test at that level (see y-axis). The two lines illustrate the dust concentration for a test plot that has been treated with a stabilizing agent versus an untreated plot at the NTS. The higher concentrations (> 25 mg/m³) of PM_{10} are from the untreated plot.

method that is closest to a "standard" instrument for direct measurement of PM10 dust emission fluxes from soils in lieu of measurements taken during wind erosion events. As part of a separate study, to compare emissions between the PI-SWERL and a straight-line wind tunnel, a series of collocated tests were completed at 23 different sites in the Mojave Desert that reflected a spectrum of soil types and surface textures and roughness (Sweeney et al., 2005).

Saltation flux: To measure saltation, Safire saltation flux sensors (Baas, 2004) were deployed. Safires (Saltation Flux Impact Responders), consisting of a piezo-electric ring on a shaft, were inserted into the ground so that the piezo-electric ring was perpendicular to and approximately 10 cm above the soil surface (Fig. 5). The Safire is capable of counting the number of sand grains impacting upon the piezo-electric ring at a frequency of 20 Hz with the output voltage being proportional to the number of impacts. Prior to deployment at Smoky Fan, the Safire sensors were calibrated at the University of Guelph (Canada) by placing them inside a wind tunnel where active saltation was simulated and independently measured. Safire sensors were deployed at Smoky Fan in three sets of four: one set each on water, 4:1 emulsion, and 6:1 emulsion-treated plots. Each set of Safires were oriented in the shape of a cross with axes 3 m in length.

Several corrections were made to ensure that Safire measurements actually represented saltation events. A simple linear, sensor-specific correction was applied to the Safire data to account for a temperature-driven drift in baseline. In addition, vibrations within the conduit structure caused by light winds sometimes caused false "impacts" to be registered. Also, herbaceous plants that germinated around the sensors because of the high precipitation were cleared during every site visit to prevent, for example, blades of grass impacting a sensor. To account for potential false measurements, a

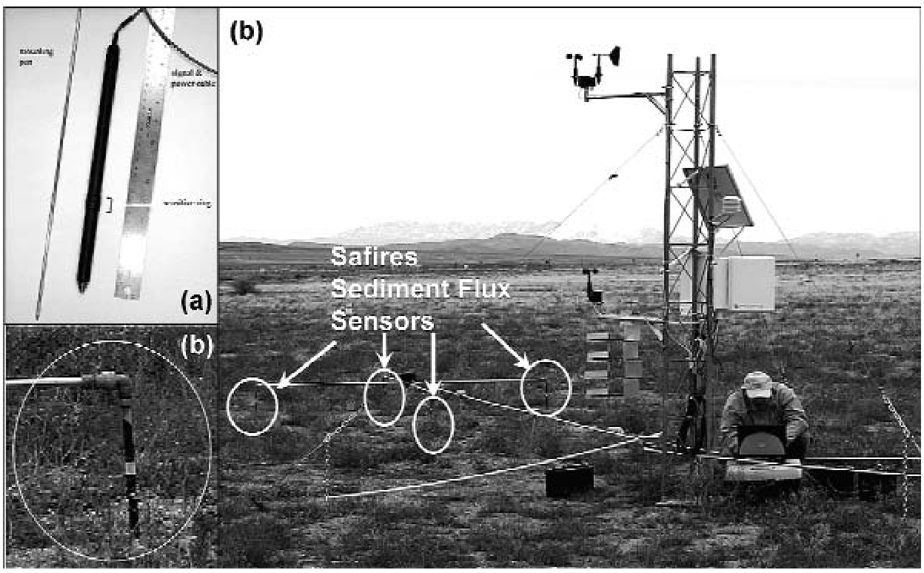

Fig. 5. The safire saltation flux sensor (a), and a configuration of four of them in the field at the smoky fan (b).

saltation event was not recorded unless at least three of the four sensors registered positive impacts. Safire data during precipitation events were also removed from the dataset.

Meteorological and soil water content instruments: A 3-m meteorological tower was established to collect measurements of wind speed and direction, ambient temperature, relative humidity, and soil moisture content. Precipitation data were obtained from a Meteorological Data Acquisition (MEDA) System station 5 km southwest of Smoky Fan. The station underwent refurbishments during the first half of 2005, likely resulting in the amount of precipitation being underestimated for the study period. Also, a Campbell Scientific CS616 reflectometer probe was buried at the foot of the meteorological tower at a depth of 5 cm to measure soil water content. Data were acquired from all sensors in 1-second intervals and aggregated over 5-minute intervals by extracting average, maximum, and minimum values from 1-second data points.

Data collection: The Encapco emulsion product and water treatment were applied to test plots on 29 April 2004. Four multi-day PI-SWERL measurement campaigns followed in May, August, and December 2004, and June 2005. Several attempts were made to do measurements between December 2004 and June 2005, but the soil surface was visibly wet due to above average precipitation. During each visit, a PI-SWERL measurement was completed on at least two locations within each test plot. In addition, the PI-SWERL was operated on at least one plywood control plot representing each level of emulsion treatment. The PI-SWERL was operated at a prescribed cycle that stepped through 450, 600, 750, 900, 1,050, 1,200, 1,450, 1,700, and 1,900 RPMs corresponding to u* of 0.17, 0.24, 0.31, 0.38, 0.44, 0.50, 0.56, 0.65, 0.73, and 0.80 m/s. These corresponded to wind speeds (assuming no vegetative cover) of approximately 2.0, 2.8, 3.6, 4.4, 5.8, 6.5, 7.5, 8.4, and 9.2 m/s. At each RPM step, lasting 45 seconds, average PM10 emissions (units of mg/m^{2}s) were calculated by multiplying the average PM10 dust concentration by the flow rate of clean dilution air. These “non-cumulative” emissions simulated emissivity during sustained winds at specific wind speeds.

During each measurement campaign, the geometric mean and standard deviation of the non-cumulative PM10 emissions were calculated for each PI-SWERL RPM level based on the replicate measurements conducted on plots with the same treatment. Emissions averaged over specific nominal values of friction velocity were then compared to values from 19 May 2004 when the first PI-SWERL measurements were made after the emulsion was applied.

YPG methods and data collection

At YPG, two study sites were selected: Site 1, to evaluate the DU complexation properties of the emulsion, and Site 2, to study the hydrologic impacts of the emulsion.

DU complexation studies: Site 1 (32.9049° N, 114.272° W, elevation 42 m) is an ordnance firing range with a well-developed desert pavement on which DU oxides are present. The experimental design was a randomized complete block design (Montgomery, 2001) of 1 by 1.5 m grided plots in which treatments included emulsion applications at 4:1 dilution, 6:1 dilution, and control plots where no dilution was applied. Soil samples were collected from plots of each of the three treatment levels five times: once prior to application of the emulsion, two weeks after application, and three times over the course of the following year. Samples were collected by scraping material from the upper 1 to 2 cm of soil into 500-mL plastic bottles. Although DU particles were often visible, no effort was made to either preferentially sample or preferentially exclude the material. Samples were mechanically split into > 500 mm and < 500 mm fractions, and then split again, one for particle size analysis, and one for total and soluble DU analyses. Analysis of the complexation tests is underway.

Hydrologic studies: Hydrologic studies were performed at a clean site (Site 2) to reduce the costs associated with safety precautions. Site 2 (32.8401° N, 114.2393° W, elevation 170 m) is located where older, desert pavement-armored surface slopes down to a desert wash with adjoining, younger alluvial surfaces (Fig. 6). Primary variables in the experimental design include emulsion treatment level, soil age, soil disturbance, and time. On the “old” surface, 5 x 5 m plots were established on which 4:1 and 6:1 emulsion dilutions were applied. In addition, for each treatment and the controls, “disturbed” and undisturbed plots

Fig. 6. An older desert pavement covered surface sloping down to a desert wash at YPG.

were established. The old surface was disturbed by raking the desert pavement off the plots. Similar emulsion treatment and control plots, disturbed and undisturbed, were also established on a "young" alluvial surface above the wash. By varying three major factors (soil age, site disturbance, and emulsion treatment levels), with three replicates of each hydrologic measurement over four time intervals, repeated analysis of variance (ANOVA) was possible. (See Figure 7.)

At Site 2, tension infiltrometers (TI) (Ankeny et al., 1988; Reynolds and Elrick, 1991) were used on all treatment plots to study changes in hydraulic conductivity (Ks). During each visit, 36 TI tests were conducted. During the first field campaign, three locations were identified on each of 12 research plots, and subsequent tests were done in

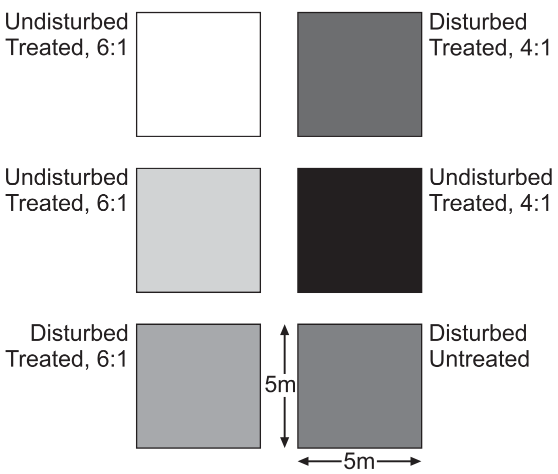

Fig. 7. Emulsion-treatment plot schematic for the "old" surface at site 2 at YPG.

the same locations so that changes to soil properties with time could be evaluated. All TIs were equipped with pressure transducers and dataloggers so that water intake rates could be monitored every 15 seconds. Two analytical methods are being used to solve for Ks. The semi-empirical, nonlinear least-squares regression routine for Wooding's Analysis (Wooding, 1968) has been used to solve for two unknowns (Ksatw and aw) by minimizing error through iterative solutions (Logsdon and Jaynes, 1993). Results reported herein are based on this analysis. Analyses are also ongoing using a numerical inversion method using the HYDRUS-2D model (Simunek et al., 1996).

In addition, sensors were placed in two plots on the younger surface at Site 2 to evaluate soil water potential, water content, soil temperature and precipitation from March to November 2005. Finally, portable rainfall simulators were used to evaluate how the emulsion affected runoff at the sites. Analysis of the rainfall simulation tests is ongoing.

Data collection: Characterization of site properties prior to emulsion application was performed in October 2004, and emulsion was applied to the research plots on 2 December 2004. Four field campaigns were conducted. The first was shortly after emulsion application (13 December to 19 December 2004), followed by March and June 2005, and January 2006.

NTS results

The Encapco emulsion was effective in reducing erosional dust generated from emulsion treated plots for at least four months, and possibly up to a year. Determining how long the emulsion was effective was complicated by the above normal precipitation. Yucca Flat has an average annual precipitation of 15.7 cm based on a 1960 to 2003 record (Shafer et al., 2004), but 25.8 cm was measured during the study period. The precipitation resulted in above-average plant cover on the plots, and long periods when soil water content to a depth of 5 cm was above 10%. Soil moisture can increase the threshold friction velocity for aeolian transport (Chepil, 1958; Saleh and Fryrear, 1995) and a moisture content of 4% (kg H_2O/kg soil mass) is usually enough to cause cessation of particle entrainment (Bisal and Hsieh, 1966). Other important results include the following:

At friction velocities corresponding nominally to sustained wind speeds around 6.5 m/s and higher, the Encapco application suppressed erodible dust emissions compared to the untreated plots for as long as one year after application, although the most significant suppression occurred in the first four months (Fig. 8). Four months after emulsion application, dust emissions were suppressed by 90% to 99% compared to untreated plots. At

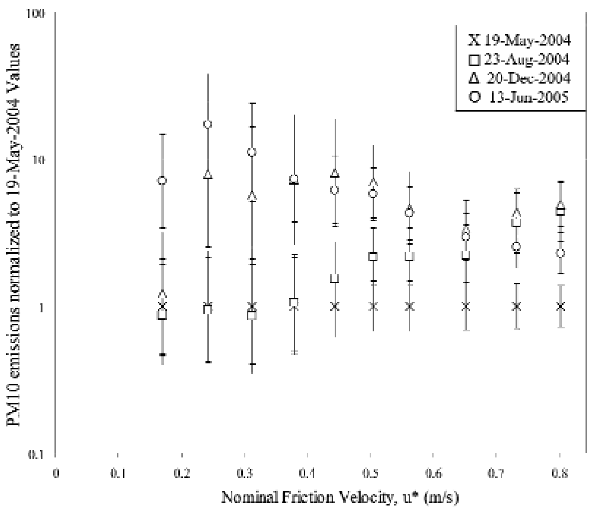

Fig. 8. Comparison of non-cumulative PM_{10} emissions (mg/m²s) versus nominal friction velocity for emulsion treated plots at the NTS. At each level of friction velocity emissions are normalized to the 19-05-2004 value for comparison. The plot indicates the most effective period of dust suppression was between 19-05-2004 and 23-08-2004 at nominal friction velocities up to 4.4m2s. Equivalent to sustained wind velocities of about 6.5m²s.

seven months and one year after application, suppression effectiveness was reduced to 60% at u* = 0.56 m/s and 92% at u* = 0.80 m/s when compared to pre-treatment values. However, after the first four months, dust emissions from untreated plots also decreased because of the stabilizing effect of high soil water content and soil crusting enhanced by rainfall. If the point of comparison is the untreated plots as opposed to the pre-emulsion treatment values, dust emissions were reduced by only 60% to 75% on emulsion plots compared to untreated plots. After seven months, the Encapco treatment offered no additional protection from dust emissions than was apparently offered by the higher rainfall on untreated plots.

At the higher friction velocities where dust emissions were reduced, no statistically significant differences were found between plots treated with 4:1, 5:1, and 6:1 emulsion dilutions. At lower friction velocities, emulsion-treated test plots actually exhibited higher emissions of depositional dust than untreated ones (Fig. 9). Emissions at low friction velocities (nominally u* < 0.5 m/s) from emulsion-treated plots were higher after seven months and after one year than initial emissions from untreated plots by about a factor of 2 to 5 and 2 to 10, respectively.

Finally, measurement of sand saltation indicated that there were few aeolian sand transport events during the study period and, in most cases, the amount of saltation measured was modest. Data from one comparatively large event on 27 November 2004 suggest that while the emulsion

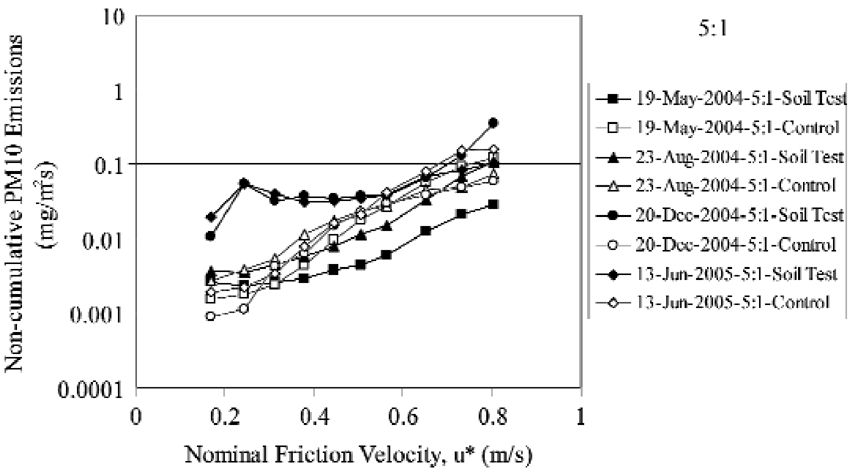

Fig. 9. Summary of emission tests from 5:1 treated plots versus plywood control plots over the study period. Higher PM10 emission at lower nominal friction velocities on 20-12-2004 and 13-06-2005 probably represent suspension of depositional dust off the treated plots.

treatment did decrease the number of saltation measurements, it did not serve to rapidly attenuate saltating sand grains that may have originated from untreated surfaces upwind.

YPG results

All infiltrometer data for the first four field visits have been analyzed using Wooding's Analysis. All emulsion-treated plots on the old and young surfaces, showed significant decreases in K_s following application. However, the reduction diminished after 6 months, with the decrease in K_s appearing to have persisted slightly longer on the young surface (Fig.10). Again, higher-than-average precipitation may have reduced the length of time when the emulsion affected the soil hydraulic properties.

Discussion and conclusions

Several hypotheses are cited for the increase in dust emissions at lower values of friction velocity from emulsion-treated plots versus control surfaces over time at Smoky Fan at the NTS. First, depositional dust that was transported across untreated plots may have become partially incorporated into the soil matrix and formed weak chemical bonds with the soil. In contrast, the emulsion-treated surfaces may not be as amenable to "absorbing" depositional dust due to the chemical crust that formed on the soil surface by the emulsion. The emulsion may have also slightly decreased surface roughness that otherwise might have caused resuspended or saltating grains to be deposited and incorporated into the soil (Logie, 1982; Gillies et al., 2000). Additionally, the untreated soil surfaces may have permitted better water vapor transfer between the surface and underlying wet soil, effectively suppressing dust emissions from untreated surfaces. In contrast, the emulsion treated surfaces may have isolated depositional dust from water vapor in the underlying soil.

There are a number of possible explanations for the absence of dependence on dilution strength on the emulsion effectiveness. The soil surface may have become saturated with emulsion at all dilutions and small changes in the amount of product (i.e., undiluted equivalent) applied had a negligible effect. Alternatively, the infiltration of the

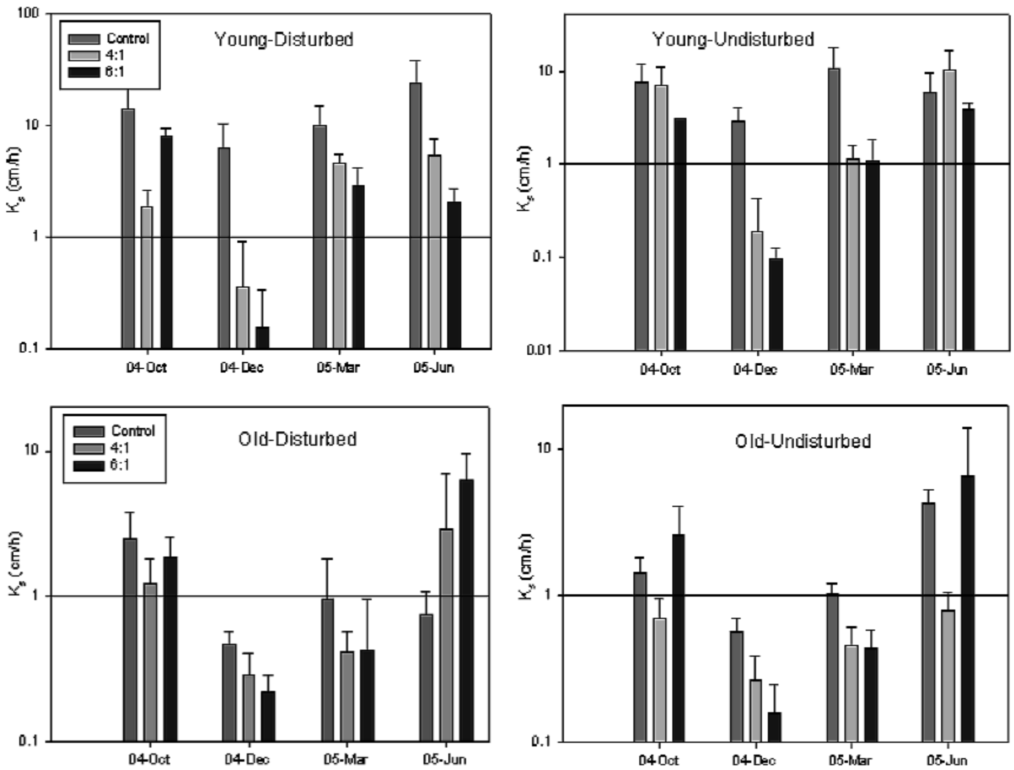

Fig. 10. K_s value as a function of time for young versus old surfaces, disturbed versus undisturbed, and the 4:1 and 6:1 emulsion treatments at YPG.Value from 4 October 2004 were from measurements taken prior to emission application.

emulsion into the soil may be less dependent on the total amount of liquid applied than on the amount of product (undiluted equivalent). That is, stabilizing the very near surface soil may have achieved the same results as would treatment deeper into the soil profile, at least for the length of time for which the plots were evaluated. Finally, findings regarding depositional dust and saltating particles do not negate the effectiveness of the emulsion in stabilizing the radiologically contaminated soil. However, understanding the behavior of other aeolian transport processes could be important in effectively using the emulsion for treatments of large areas for contaminant stabilization or simply dust control.

At YPG, the results suggest the hydrologic impact of the emulsion is relatively short-lived (approximately 6 months). This may indicate that with effective application strategies, a balance can be achieved between use of the emulsion for stabilizing soil contaminants while maintaining adequate soil water content and infiltration for germination of native seeds. If the hydrologic effects of the emulsion do diminish within approximately six months, an effective strategy at YPG could be application of the emulsion after late spring to reduce ecological effects. Research by Zitzer and Young (2005) indicates that because of the timing of emulsion application at YPG, total seed germination on emulsion-treated surfaces was reduced initially by 90%.

Ongoing research

The unusually high rainfall during the study period complicated determining how long the Encapco emulsion would be effective in stabilizing radiologically contaminated soils under average precipitation conditions. To supplement field studies, tests are underway using 1 m by 1 m test plots of soils of known composition that will be kept vegetation free. Emulsion-treated and untreated plots of the soils will also be tested for dust emissions several times during 2006 using the PI-SWERL. On these same control plots, changes in K_s will be measured using the TI. In addition, because the emulsion apparently degrades with time, controlled laboratory experiments, including exposing soil/emulsion mixes to ultraviolet light and temperature treatments, have begun to identify primary degradation mechanisms.

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Combating desertification via an integrated approach

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Abstract

Desertification is now viewed as both a development and an environmental problem. Hence contemporary approaches to combat desertification focus on ensuring that rural populations inhabiting dry lands have a sustainable livelihood that depends on a resilient natural resource base. Often agriculture is not the mainstay of the livelihoods of dry land populations and therefore there is a need for careful analysis of their livelihood strategies and a better targeting of interventions aimed at improving agricultural productivity and income generation. To achieve this aim a multi-level framework of analysis has been developed that is linked to an Integrated Natural Resource Management approach. The outputs of such an approach are technological, institutional and policy options that feed into a process of development which is in turn firmly grounded in the contextual realities of the conditions facing the rural poor in dry lands. The approach is illustrated here with examples of both institutional and technological options that are applicable to a dry land community situated in the Khanasser valley in Syria.

Introduction

Efforts to combat desertification in dry areas have now moved away from a strictly technological fix approach to a more integrated approach that ensures that the perspectives of local people are taken into account and more emphasis is being given to developing viable options with the full participation of the inhabitants of the dry areas. This inevitably involves the complex interactions of people with the environment and requires holistic and diverse interventions that are customized to the needs of different localities (Winslow et al., 2004).

To cope with this seemingly insurmountable complexity it is necessary to identify what are the main driving variables in each particular situation. This is usually a combination of 3-5 proximate and underlying biophysical and socio-economic factors (Geist and Lambin, 2005). Multi-disciplinary teams of scientists are required for this analysis. These teams engage in dialogue with land users, extension agents and policy decision makers in order to develop a common understanding of the problems and a common vision of how all stakeholders wish to see their livelihoods and environment in the future. A guideline to help implement such projects has now been developed (Campbell et al., 2006) and lessons are being learned from examples of such approaches world wide (Borrini-Feyerabend et al., 2004; Tyler, 2006).

The Khanasser Valley, Syria

The valley is a typical Mediterranean dryland rainfed region receiving approx. 220 mm rainfall annually, mainly during the winter months. Challenges include land degradation from wind and water erosion, declining soil fertility, lack of water for irrigation, financial constraints to meet customary expenses and adoption of new technologies, lack of information and knowledge on appropriate technical knowledge and unclear land property rights and policies that discourage investments. A full description of the site including habitats, climate, geomorphology, vegetation, population and major economic activities and environmental and economic constraints are published elsewhere (Thomas et al., 2004).

The integrated approach

A multi-faceted cross-disciplinary approach has been taken in the valley to introduce new land use options and to broaden the interactions between local communities, researchers and local and national government.

To help determine the main driving variables a toolbox approach has been taken that comprises diagnostic, problem solving and process tools (Thomas et al., 2004). An example of a multi-level analytical framework to identify the main constraints on the hill slopes of the valley is presented in Table 1. Biophysical and socio-economic factors are examined in a framework consisting of a ‘spatial pillar’ and a ‘stakeholder pillar’ that are linked both vertically and horizontally. The tool lists the main prioritized issues that constrain the adoption of technologies and/or resources and identifies potential solutions. This simple framework requires a multi-disciplinary approach and helps foster greater understanding and communication amongst all parties.

Another useful tool to help orientate all the project team is a simple analysis of the strengths, weaknesses, opportunities and threats (SWOT) of the marginal dry areas. This was based on the inputs of the land user, researchers, extension agents and decision makers. Table 2 summarizes the results of this exercise.

From these detailed diagnoses the project then proceeded to develop and refine a set of options that had been researched previously in the area. After on-farm trials the options were tried and tested jointly by researchers and interested land users who were organized into ‘farmer interest groups’ or FIGs on a voluntary basis. From this collaboration, the following feasible options were identified:

Table 1: Application of the multi-level analytical framework (MLAF) to the management of olive orchards on hill slopes at Khanasser valley.

SPATIAL LEVELS	STAKEHOLDER LEVELS
Marginal drylands ➢ Climate suitability: - Can olives grow properly in this type of climate? - Selection of adapted varieties.	Policy and institutions ➢ Policy regarding state land? ➢ Olive policy in Syria? ➢ Credit availability? ➢ Institutional analysis + services.
Khanasser valley ➢ Land suitability: Can olives grow on stony hillsides?	Trading links ➢ Are there marketing channels for olives?
(Sub)-catchments ➢ Runoff water use: Is there a competition between upslope and down slope?	Communities ➢ Expansion of olive orchards? ➢ Will olives have impact on equity? ➢ Competition between grazing and olive orchards & potential for communal, agreed arrangements.
Field ➢ What are the local management practices, technical knowledge and knowledge gaps? Awareness, participatory research and training about improved husbandry. ➢ Soil and water management: Soil and water harvesting, irrigation, tillage, soil erosion, use of ancient terraces. ➢ Tree husbandry: Pruning, diseases, soil fertility management, diagnosis of unproductive trees.	Household livelihood strategies ➢ Who is interested in growing olives and what are their motives? ➢ Are there gender divisions related to olive orchards? ➢ What are the technical knowledge sources? ➢ For subsistence or cash? Enterprise budgets for olives. ➢ Alternative tree crops: Are there adapted and viable alternatives?

Options that strengthen the traditional farming system:

- New barley varieties selected by using a participatory breeding approach.
- Barley production with application of phosphogypsum to improve soil fertility, and to increase and stabilize production in dry years.
- Dairy products from sheep for consumption or sale of surplus.
- Seed priming of barley seeds with nutrient solutions to improve crop establishment.

Diversification options:

- Barley intercropped with *Atriplex* spp. shrubs to stabilize forage production, increase biomass during dry years, and enhance protein content in sheep diets.
- Improved vetch (*Vicia sativa*) production by selected drought-tolerant varieties to reduce production risks.
- Improved management of rainfed cumin (*Cuminum cyminum*, a new cash crop) to stabilize and increase production and improve its marketing value.

Table 2: Major strengths, weaknesses, opportunities and threats for the Khanasser valley as an example of marginal drylands

Strengths: Indigenous knowledge and local innovations. Strong social networks and rich local culture. Comparative advantage for small ruminant production. Salt lake with rich bird biodiversity. Relatively unpolluted environment. Reasonable mobility and accessible markets. Improved basic services (electricity, roads, mobile phone network).	**Weaknesses:** Cash flow problems (resulting in lack of long-term investments). Poor nutritional status of children. Limited experience with non-traditional farming enterprises. Lack of adapted crop germplasm. Decreasing productivity. Degraded natural resource base (soil, groundwater, vegetation) and degrading management practices. Land degradation is 'masked' by variations in rainfall. Poor extension services.
Opportunities: Investments of off-farm income into productive resources. Better education levels and expertise. Increased awareness of the risks of resource degradation. Cooperatives. Improved market knowledge via mobile phones and other media. Out-migration and off-farm opportunities. Sheep fattening. Potential to improve the traditional barley system. Improved germplasm. Diversification for cash and subsistence purposes. Agro-, eco- and cultural-tourism. Runoff water harvesting and efficient small-scale irrigation systems. Soil fertility improvement. Rangeland rehabilitation and medicinal plants collection. Better government services and increased attention for poverty alleviation and environmental services in marginal areas.	**Threats:** Aging and feminization of the active Khanasser population. Declining social networks. Destruction of traditional 'beehive houses'. Increased population pressure and too small land holdings. Depletion of ground water resources Recurrent droughts. Further decline of soil fertility and ground water levels. Declining ground water quality, and salinization of irrigated fields. Population by intensive sheep fattening and untreated village sewage. Degradation of the fragile Jabul salt lake eco-system. Unreliable export markets for sheep.

- Olive (*Olea europaea)* orchards with water harvesting cultivated on hill foot slopes, to increase production and reduce summer irrigation by groundwater.

Intensification options:

- Improved lamb fattening by using lower-cost feeds.

Institutional options:

- Traditional dairy institutions (*Jabban)* for knowledge sharing and informal credit provision.
- Village saving and credit associations (*Sanadiq*, established and operated by a parallel development project led by UNDP).

For all these technologies and options, feasibility reports were prepared including an *ex ante* economic analyses (La Rovere and Aw-Hassan, 2005). An innovation of this research was an analysis of the options based on different livelihood categories and assets of the population.

Thus the options were categorized into those that are:

- profitable in the short term and which require more awareness and information,
- profitable, but that require investment and are prone to climatic risks,
- highly profitable but which need high investments, and
- profitable only in the long run, and need initial investment.

A series of workshops was held with land users and policy makers to present the results and options and to discuss their feasibility and desirability taking into account the differing perspectives of each stakeholder group. The ultimate aim of this exercise is to develop a development plan for the valley that can be jointly implemented by local people and the concerned government agencies.

Conclusions

As a result of closer integration amongst all stakeholders the study has developed a set of options that are better targeted to specific sectors of the population who have varying access to natural, physical, human and financial capital. Government researchers, extension agents and land users have appreciated the move to work more closely together and plans are underway to replicate the example of the Khanasser valley to similar areas in Syria. It is recognized that training and capacity building will be required in order to facilitate closer cooperation amongst the institutions involved in rural development.

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Two new simulation models for plant breeders and agronomists - theory and applications

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Abstract

Agricultural research in arid or semi-arid region requires a substantial investment in land, labour and other resources. Simulation models have proved useful in assisting scientists in making more efficient use of these resources by providing insight into potential plant responses as well as water use for various years and locations. Adopting a certain simulation model depends on the ease in its re-calibration and use, as well as on the availability of the inputs needed to run the model. This paper describes two simulation models of potential use to agronomists and plant breeders dealing with crop water use in dry areas. The first model, Plant Growth of Small Grain Crop (PGSGC) model, requires low input daily weather data and few soil and plant parameters and is written in simple BASIC language and is used to simulate crop growth and development as well as transpiration by the crop and evaporation from the soil. It is mainly designed to accommodate different genotypes of the same species that have different plant development characters. The simulation output is daily leaf number, leaf area, plant development and growth of straw as well as grain, together with the water. The second model, SIMWASER, simulates daily soil water balance and plant growth for any space of time from one vegetation period up to many decades thus being able to predict long term water use efficiency of different cropping patterns for a given site. However, this model requires larger input of daily weather, soil and plant data and is written in FORTRAN language. This model is particularly useful for studies in water movement within the soil profile and the soil water balance, but crop development as well as crop yield is also simulated. Both models were used in simulating plant growth and development and water consumption of barley and wheat at two locations in northern Syria. Results show close relation between simulated and measured data, but more field data are needed for further calibration.

Introduction

Agriculture in rainfed arid environments is impeded by low erratic precipitation and frequent droughts. Cereal production is important in this region, but yields are generally low. Supplemental irrigation may increase yields drastically (Oweis et al., 2000) but the potential for even limited supplemental irrigation is decreasing because of increasing competition for water for urban and industrial uses and in order to maintain environmental flows (Turner, 2004). Therefore, attention has to be increasingly focussed on enhancing the efficiency with which rainfall is used and on increasing the water use efficiency to meet the increasing demand for food for growing population. This objective can be achieved by genetic improvement and by improvement in agronomic management of crops (Turner, 2004).

Simulation models can be useful in transferring the results from experimental plots to the farmer's field, as they allow studying the outcome over many seasons as well as for differing environments. The influence of environmental variables on the growth and yield of different crops is of worldwide interest, and several approaches have been developed to analyze the effect of these variables on crop growth. Statistical approaches as well as models (descriptive, predictive, etc.) were first used and regressions obtained to correlate environmental variables and yield (e.g. Baier and Robertson, 1968; Jones and Wahbi, 1992).

The difficulties in a statistical approach are that there is little confidence for extrapolating the results beyond the original limits of the dataset, and the weather variables are confounded so that it is difficult to isolate the influence of any individual variable. As a result, mechanistic models have been developed in an attempt to sort out various factors influencing crop yield. Usually, these models consider, in a complex manner, the effect of temperature and solar radiation on crop development, growth, and grain-yield (e.g. Ritchie and Otter, 1984; Van Keulen and Seligman, 1987; Stapper and Harris, 1989). Difficulties in using these complex models arise from their use of a large number of assumptions, and the consequent large number of variables that must be defined, as well as large input data requirement. Even with complex models it may be difficult to clearly resolve the major influence of any single environmental factor.

An intermediate approach between the regression method and complex models is the use of simplified mechanistic models that define crop behaviour with a few conservative relationships. Monteith and Scott (1982) used such an approach to analyze the effects of weather on crop yield by accounting for temperature effects on leaf-area development and crop ontogeny, and solar radiation effects on biomass accumulation. This approach was also adopted by Amir and Sinclair (1991) who came up with a simple simulation model that could be used in areas where no nutrient constraints are evident.

There are many models on cereal growth, which have been developed for arid environments, e.g. SIMTAG (Stapper, 1984; Stapper & Harris, 1989), CERES-Wheat (Ritchie & Otter, 1984), SPRING WHEAT (Van Keulen & Seligman, 1987), SUCROS (Goudriaan & Van Laar, 1994), and more complex agro-ecological models like EPIC (Williams et al., 1983), DAISY (Hansen et al., 1991), RZWQM (Hanson et al., 1998) as well as decision support systems like WHEATMAN (Woodruff, 1992), APSIM (Keating et al., 2001) and CropSyst (Stöckle et al., 1994), which were mostly used by agronomists for checking performance of sustainable cropping pattern or assessing possible yields under the given environmental conditions (e.g., Gregory et al., 2000; Heng et al.; 2005).

Soil water balance modelling studies of cropping systems, involving detailed experimental field monitoring and simulation modelling, already assist agronomists to offer improved management options for greater production, profitability and minimize risks to environmental degradation, e.g. dryland, salinity and soil erosion (O'Connell et. al., 1996). Staggenborg and Vanderlip (2005) indicated that dryland cropping systems research in semiarid Great Plains region required a substantial investment in land, labor, and other resources and illustrated how crop simulation models could assist scientists in making more efficient use of resources by providing insight on potential plant responses to alterations in cropping systems before conducting field research.

Application of crop models to plant breeding has been limited, in part due to the restricted capabilities of models to accurately represent genetic differences and genotype-induced crop responses. There are only a few examples for application of crop models by plant breeders (e.g. O'Toole & Stöckle, 1991; Yin et al., 2000), some of them using crop models to define plant specific coefficients (e.g. Chapman et al., 2003) or to improve the model itself by gene-based assumptions (Hoogenboom and White, 2003). There are also applications of crop models by plant breeders for checking the impact of new traits on the potential yield in an arid environment (Aguera et al., 1997; Asseng et al., 2003).

In this paper two models are presented, which can be used by plant breeders and agronomists in their efforts to increase the water use efficiency of rainfed agriculture in arid Mediterranean climatic zones. Generally both models are based on well known relationships by which crop growth and development are defined. Using plant coefficients that can be directly measured or derived from field experiments, newly developed traits can be defined and their long term performance can be tested for different rainfall zones and soil conditions. Both models take into account soil water consumption of the simulated crop thus being able to check the effects of agronomic measures by which soil water balance may be influenced and to find out appropriate cropping systems for maximum rainfall-use efficiency in a given environment.

Both the models were developed in the Mediterranean region, first in wheat for un-restricted and restricted soil water regimes and second for soil water movement and crop yield in saline conditions. Because of their different objectives the first model is concentrating on the simulation of crop development and seed growth for different genotypes, while the second provides more scope for assessing soil water balance and soil water movement and their interaction with the crop. The aim of this paper is to describe both the models and to provide some examples of their application.

PGSGC model

Model description

This model was developed by Amir & Sinclair (1991) to analyze the effects of temperature and solar radiation on wheat (*Triticum aestivum* L.) and it was extended by Wahbi and Sinclair (2005) to barley (*Hordeum vulgare* L.). Crop development is simulated based on thermal time required to reach specific growth stages. Crop ontogeny is divided into three periods: main stem leaf growth, end of leaf growth to anthesis, and seed growth. The length of each period is defined by the "Thermal Units" (TU) typical for the simulated wheat or barley crop. The TU of each day is calculated as daily mean air temperature minus a base temperature, which is set to 0 °C. Duration of each of the growth periods together with some other crop growth parameters needed to run the model are listed in Table 1.

Leaf area is calculated from the number of leaves per plant and the plant population using an empirical relationship: maximum main stem leaf number is set to 8 leaves; maximum tiller leaf number is set to 6 leaves. Accumulation of biomass is calculated from amount of solar radiation intercepted by the leaf area using the radiation use efficiency (RUE) of the crop. Seed growth is assessed during grain development period by multiplying the accumulated biomass by an empirical harvest index (Table1).

Evaporation is calculated from amount of radiation energy reaching the soil surface below the crop leaves and from the saturation deficit of the air, using a combination formula. The saturation deficit is estimated by an empirical formula from the difference between the saturation water pressures at maximum and minimum air temperature. Unrestricted transpiration is deduced from daily gain in biomass using an empirical relationship for the water-use efficiency of cereals in Mediterranean climates, weighted by the vapour pressure deficit. Reduced biomass assimilation due to water shortage and thus reduced transpiration is calculated by an empirical expression, taking into account the fraction of transpirable soil water.

Input data

Input data needed to run the PGSGC model include the parameters that describe crop growth and development and these are crop specific (Table1). For calculation of the soil water balance, the amount of soil water at the 'field capacity' (FC) and at the 'wilting point' (WP) and the rooting depth must be known as well as the soil water content at the beginning of the simulation. Only a few weather data are needed: daily maximum and minimum air temperature, daily amount of rainfall and daily sum of global radiation. If there are no radiation data available, they can be estimated by appropriate methods (e.g., Allen et al., 1998).

Output data

Simulation output includes daily values of total dry matter of the crop (straw plus grain), dry matter of the grain, leaf area, transpiration, evaporation and the amount of soil water extracted.

Table 1: Plant parameters for PGSGC model for wheat and barley

Parameters	Unit	Wheat early season	Wheat medium season	Wheat late season	Barley early season	Barley medium season	Barley late season
TU leaf growth (l.g.)	°C*day	820	820	820	780	820	840
TU l.g. to anthesis (VAR)	°C*day	370	460	520	220	310	340
TU seed growth	°C*day	550	550	550	340	380	430
Harvest Index	g/g*day	0.011	0.011	0.011	0.018	0.018	0.018
Radiation use efficiency	g/MJ	1.10	1.10	1.10	1.10	1.10	1.10
Plant population	Plant/m²	250	250	250	250	250	250

SIMWASER model

Model description

This model is a multi-year, multi-crop soil water balance and crop growth model, which may be used for any length of cropping for which the needed weather data are available. Crop growth and development depend on thermal units (TU), which are defined as the difference between the daily mean air temperature and a base temperature which depends on the crop to be simulated. The crop is ripe when a certain amount of TU is reached, which depends on the crop type. Plant growth also depends on global radiation as well as on mean daily temperature and daily amount of assimilated biomass is calculated for the surface area of the field as a function of the green leaf area, the radiation intensity and the typical light response curve of the crop. Partition of the daily net gain to roots, stem and leaves as well as to seeds depends on the current development stage, which is defined as the accumulated amount of TU divided by the total amount of TU that is needed by the crop for ripeness.

The model assumes a direct interaction between assimilation and transpiration as both processes take place at the same time via the stomata. Potential transpiration is estimated from potential evapotranspiration, which is calculated according to the Penman-Monteith formula (Allen et al., 1998) using air and crop resistances depending on the current stage of the architecture and on the type of the simulated crop. As long as the crop roots are able to meet the transpirational demand, potential crop growth will take place. If the water extraction of the roots (= actual transpiration) is lower than potential demand, actual growth will also be reduced by the same relation.

Daily soil water balance depends on rainfall and irrigation, evaporation at the soil surface and water extraction by the roots (= transpiration), deep drainage or capillary rise at the lower end of the soil profile and surface runoff, when intensity of rains or irrigation exceed infiltration capacity of the soil.

Input data

Plant growth parameters needed by this model are given for wheat and barley in Table 2; such parameters are also available for many other crops and mean values are given by Stenitzer (2004).

For calculation of soil water movement as well as root growth and water extraction by the roots, a

Table 2: Plant parameters for SIMWASER model for wheat and barley

Parameters*	Unit	Wheat early season	Wheat medium season	Wheat late season	Barley early season	Barley medium season	Barley late season
EXCOEF	-	0.40	0.40	0.40	0.40	0.40	0.40
LEAFWGT	ha/kg	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
PLTHGT	m	1.0	1.0	1.0	1.0	1.0	1.0
RS	s/cm	2.5	2.5	2.5	2.0	2.0	2.0
ASSIM	kg/ha,h	15.0	16.0	16.0	14.0	15.0	15.0
TEMPCLSS	-	1	1	1	1	1	1
ROOTLGT	dm	20	20	20	20	20	20
ROOTDS	cm/cm³	5	5	5	5	5	5
RSTRCLSS	-	1	1	1	1	1	1
LEAFW	cm	0.5	0.5	0.5	0.5	0.5	0.5
RIPE	°C*d	1800	2000	2200	1700	1800	2000
LAI0	m²/m²	0.1	0.1	0.1	0.1	0.1	0.1
AIRMIN	%vol	5	5	5	5	5	5
CDAYL	h	10	10	10	10	10	10

**EXCOEF*	=	*light extinction coefficient*	*ROOTDS*	=	*root length density*
LEAFWGT	=	*leaf area weight*	*RSTRCLSS*	=	*root strength class*
PLTHGT	=	*plant height*	*LEAFW*	=	*leaf width*
RS	=	*stomatal resistance*	*RIPE*	=	*sum of TU at ripeness*
ASSIM	=	*photosynthetic rate*	*LAI0*	=	*LAI at emergence*
TEMPCLSS	=	*temperature class*	*AIRMIN*	=	*minimum soil air*
ROOTLGT	=	*root length*	*CDAYL*	=	*critical day length*

soil profile model must be used, where the typical soil profile of the simulated field is divided into several soil layers of usually 5 – 10 cm height. For each soil layer the soil class according to the German Standard DIN 4220 (1998) must be given together with some estimated pore volume and the actual soil moisture at the beginning of the simulation. The soil physical parameters (soil moisture characteristic, capillary conductivity and penetration resistance) of the soil in each of the soil layers are available for all soil classes and must be used in the input file of the simulated case.

For each day of the simulated period, maximum and minimum air temperature and relative humidity, wind velocity, amount and duration of precipitation, sum of global radiation and day length must be available. Missing weather data can be estimated by appropriate methods (Allen et al., 1998).

Output data

Daily values of soil water balance (precipitation, irrigation, transpiration, evaporation and surface runoff), green leaf area, rooting depth and total dry matter (straw plus grain) of the crop are given for each of the crops within the simulated cropping pattern. For each day and each soil layer simulated water content and soil suction are also given.

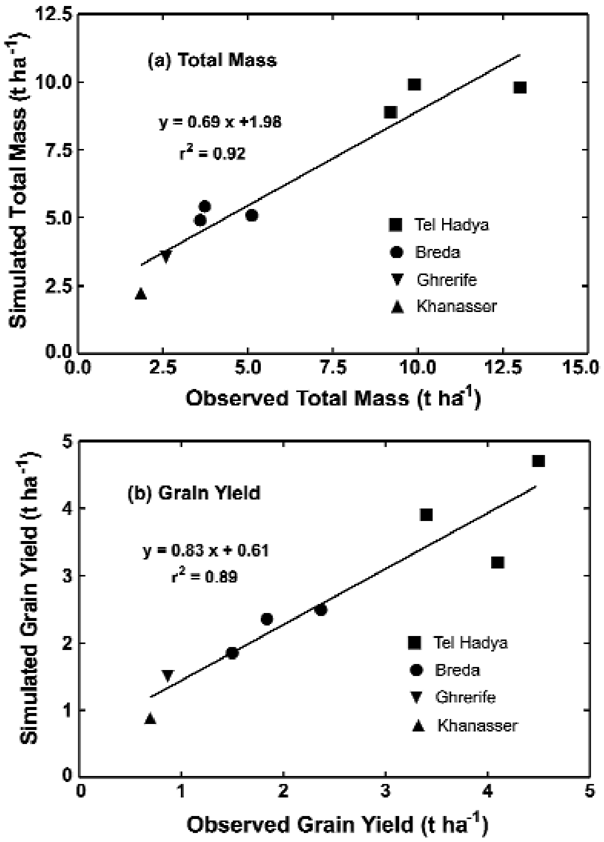

Fig. 1: Comparison of total dry matter as well as grain production of barley at different locations and years simulated by the SINCLAIR model with the respective measured values shown by symbols (Wahbi and Sinclair, 2005).

Model validation

Both models were validated using data of a barley field experiment in the 1984/85 season at Breda in Syria. This station at 35° 55’ N and 37° 10’ E has an average rainfall of 260 mm/a, which is mainly received between October and June. So cropping without supplemental irrigation is only possible during winter months, when potential evapotranspiration is rather low. The soil is very clayey (about 50 % throughout the whole profile down to 200 cm depth) with low bulk density of about 1.05 -1.10 g/cm³. In the upper layers the FC of the soil is 30-35 % and the WP is about 20 % on weight basis (Ryan, 1997). At about 70 cm depth, bulk density increases to 1.35 g/cm³, thus restricting root growth of cereals to this depth (Wahbi and Sinclair, 2005). The barley crop was sown on 12 November after receiving about 30 mm of the first winter rains. Until 5 April, another 240 mm rain had fallen; harvest was on 9 May and the grain yield was about 2.5 t /ha.

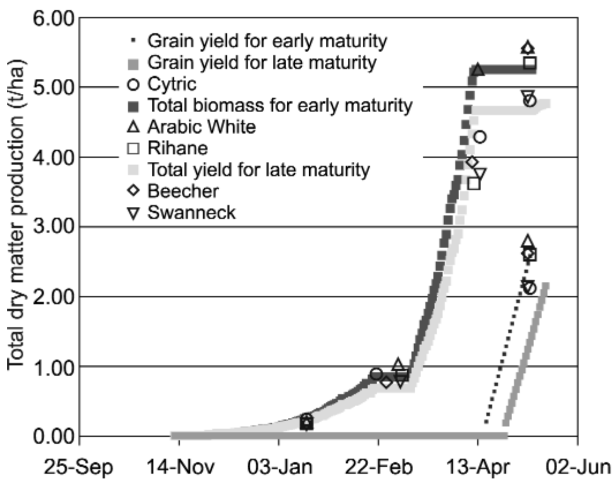

Fig. 2: Comparison of total dry matter and grain production of early and late maturing barley genotypes at Breda (1984/85 season) simulated by the PGSGC model with the respective measured values shown by symbols for the four genotypes (Arabic white, Beecher, Cytris and Rehane)

Some results of the PGSGC model are shown in Figures 1 to 3, indicating good conformity of the measured and simulated crop production and soil water extraction. The simulated early and late maturing genotypes allowed covering the full range of growth for the studied genotypes. However, the performance of the studied genotypes indicated that they were closer to early maturity group.

Nearly similar results were obtained with the SIMWASER model; there was slight over-simulation by the end of the season, and too early maturity date compared to the measured values. Soil water contents as well as water used showed close agreements between measured and simulated results (Figures 4 and 5).

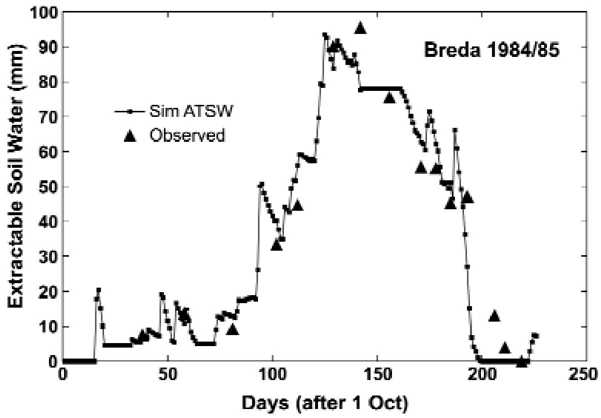

Fig. 3: Extracted soil water by barley at Breda simulated by the PGSGC model. Measured values are indicated by triangles.

Model application

Both models can be of great help in practical work aiming at an increase in the water use efficiency in the rainfed agriculture. While the PGSGC model may be used by the plant breeders to test the relative performance of a new trait, the SIMWASER model might help the agronomist to find a cropping pattern that might promise better rainfall-use efficiency, as has been illustrated by the following case studies.

Relative yield advantage of barley and wheat in north-eastern Syria: The PGSGC model was used in assessing the relative yield advantage of barley and wheat in north-eastern Syria over a period of several years with very different rainfall and temperature regimes thus giving contrasting environments (Wahbi & Sinclair, 2005). Comparison of simulated yields in different years showed that the critical difference between the two species was the cumulative effect of plant development traits that allowed barley to mature much earlier than wheat. The early maturity of barley in contrast to wheat often allowed barley to complete its growing cycle before water-deficit conditions developed in the spring. There was, however, little or no yield advantage for barley in seasons of high rainfall. Also, in the rare seasons, when significant amount of rainfall was obtained after the barley crop matured, this moisture allowed wheat to produce greater yield. These simulation results indicated that development traits are crucial in the interaction between crop yield and exposure to water deficit at the end of the growing season. Differences between barley and wheat yields were

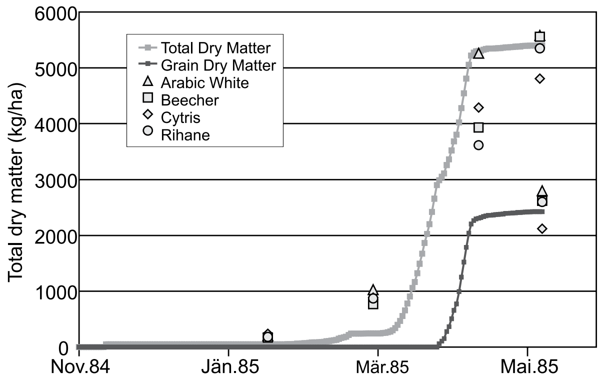

Fig. 4: Growth of barley at Breda (1984/85 season) simulated by the SIMWASER model. Measured values are indicated by the symbols for the four genotypes (Arabic white, Beecher, Cytris and Rehane).

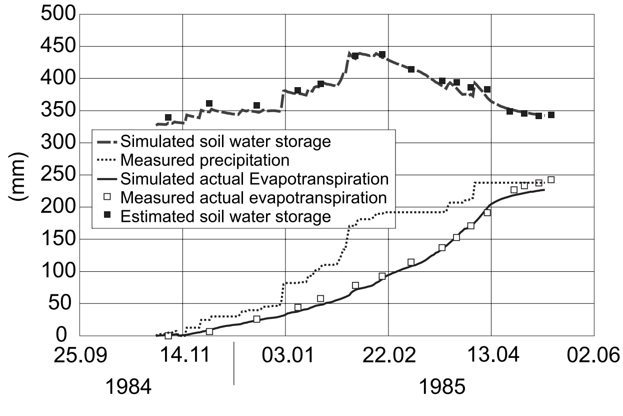

Fig. 5: Soil water storage and actual evapotranspiration of barley at Breda (1984/85 season) simulated by the SIMWASER model. Measured values are indicated by squares.

simulated for two different sites (Tel Hadya and Breda) differing in the environmental conditions (Fig. 6). In general, barley yields exceeded the yields of wheat. At Tel Hadya (Fig. 6a), the advantage of barley was greater in low rainfall seasons with little or no advantage noticed in the highest rainfall seasons. This result is a direct consequence of shorter season simulated for barley as compared to wheat. Barley reaches anthesis and maturity earlier than wheat and avoids critical water deficits late in the growing season. The average maturity across all seasons was simulated as 30 April for barley and 1 June for wheat. Consequently, barley matured before the hot, dry conditions developed late in the spring. Of course, in the seasons with high rainfall the benefit of a short growing season in barley to avoid water deficit is minimized and yields of wheat increased to match those of barley.

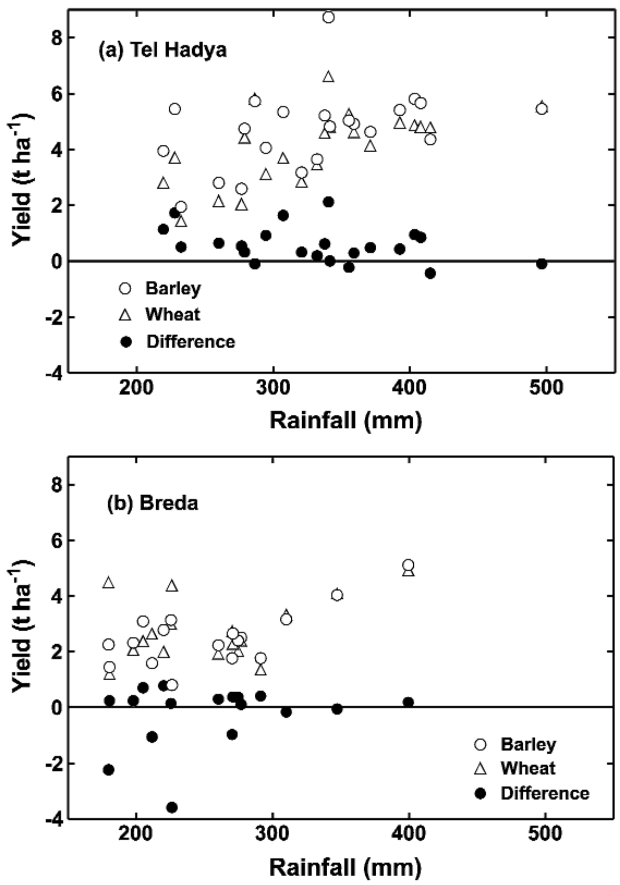

Fig. 6: Graph of simulated yield for a number of seasons at (a) Tel Hadya and (b) Breda of barley and wheat plotted against the total season rainfall. Differences between the grain yield of barley and wheat in each season are also plotted (Wahbi and Sinclair, 2005).

Simulations in the low rainfall environment of Breda also generally resulted in higher yields for barley as compared to wheat (Fig. 6b). However, low yields for both species in this dry environment did not result in large advantage for barley. In fact, there were a couple of years in which barley was simulated to be at a serious disadvantage. These years were unique in that there was late rainfall that could be used by wheat but not by barley due to its earlier maturity.

The results of these simulations highlighted the general advantage of barley in dry conditions. A number of development traits of barley caused it to have a simulated maturity substantially earlier than wheat. The simulation results at Tel Hadya (Fig. 6a), in particular, showed the advantage of barley under moderate rainfalls, between 250 and 350 mm. In seasons with rainfall greater than 350 mm, there was minimal yield advantage for barley. There were, however, a couple of unique rainfall seasons of lower rainfall at Breda in which wheat yields were distinctly greater than those of barley, indicating the importance of the timing of rainfall during the growing season. Overall, these simulation results are consistent with the long-term, conservative decisions of growers to generally favour barley over wheat in the dry areas.

Comparison of traditional 'barley-fallow' rotation with 'continuous barley': Traditional land use in Mediterranean climates, especially in areas with very low rainfall, is to keep the field fallow every second year in order to save some of the rain water for the next crop. This means, that the rain of two years is used for producing grain in one year, because of which the rain-use efficiency is rather low. Annual cropping would dramatically increase the water use efficiency but may not be feasible because of increased root pests. Amir and Sinclair (1996) showed that using straw mulches would enable continuous cropping of wheat without damage by root nematodes. The following example is the simulation of the long term yield of barley when cropped either in a 'barley-fallow' rotation or as 'continuous barley' at Breda, for the period 1980 – 2002, using the model SIMWASER. The simulation showed (Fig. 7) that by keeping the land fallow there was no much gain of water even during the winter month, when the evaporation from bare soil in total amounts to 80-90% of the evapotranspiration of a barley crop.

Therefore there is no advantage of the fallow period in terms of rain-use efficiency compared to continuous barley. Simulated mean total dry matter yield per year of continuous barley was nearly 6200 kg/ha compared to about 4100 kg/ha of the ‘barley-fallow’ system (Fig. 8) and mean grain yield per year in the ‘continuous barley’ system amounted to nearly 3100 kg/ha, while the ‘barley –fallow’ rotation yielded about 2400 kg/ha (Fig. 8). In this simulation it is assumed, that the continuous crop did not suffer from root nematodes because of chemical pest control.

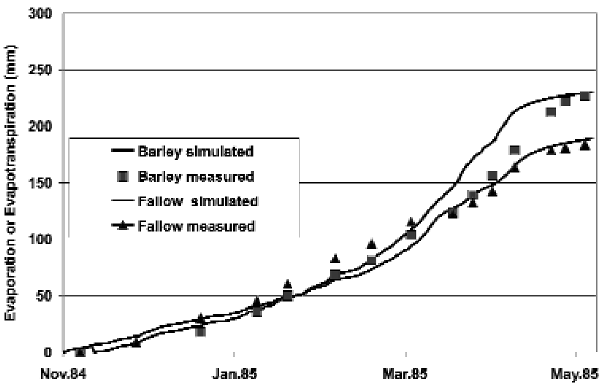

Fig. 7: Evaporation from bare soil compared to evapotranspiration from a barley crop simulated by the SIMWASER model. (Wahbi, unpublished data).

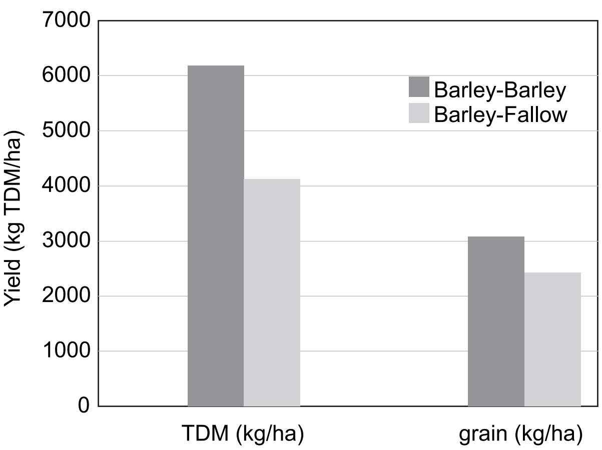

Fig. 8: Simulated total dry matter (TDM) and grain yields per year for 'continuous barley' and for 'barley- fallow' rotations, assuming that crops remained pest free and suffered no shortage of plant nutrients.

Conclusion

The tested models proved effective in simulating crop growth and yield development in relation to environmental conditions and cropping patterns. This is of great value in agricultural research as well as in extension and rural planning. Many of the other complex models can only be used by experienced and well trained experts. The models introduced in this paper are relatively simple so they can be used by plant breeders and agronomists who are generally not familiar with the manner in which the simulation models are to be written and run. Both models can be easily adapted to new varieties and different environments just by changing the respective plant and soil parameters.

The PGSGC and SIMWASER models complement each other, the first producing good results in the plant growth and development of different genotypes and species and the other providing good simulation in water use. Using the two models one could obtain satisfactory results on water use efficiency and transpiration efficiency which are key considerations in agriculture in our target environment where water is the most limiting growth factor. On the other hand, simulation can also indicate appropriate plant traits for the genotypes which use water in an efficient way, and this information could be used by plant breeders in their breeding programs. Getting the right plant traits, they can enable the agronomists to develop appropriate cropping systems in the target environments for sustainable production systems.

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Comparison of small-scale environment for three type biological crusts on longitudinal dune surface in Gurbantunggut Desert, China

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Abstract

Gurbantunggut Desert, the largest fixed and semi-fixed desert in China, is covered by well-developed biological 'crusts'. The distribution of biological crust has differential characteristics at different positions of longitudinal dune surface. The species composition, thickness, and extent of pressure vary a lot according to the type of biological crust. The specific distribution of biological crusts and their eco-environmental conditions on longitudinal dune surface were studied in 2002. The result showed that the moss crust was mainly distributed in the interdune area, where sand surface was stable and the dominant grain size was fine and very fine sand. The soil moisture in interdune could reach 5% during early spring and ephemeral plants grew well in this area. Lichen crust was mainly distributed from lower to middle parts of slopes, where the dominant grain size was fine sand and the soil moisture was about 4% in spring and ephemeral plants also grew well in this area. The algae crust was mainly distributed at the top of dune to upper part of the slope, where the sand surface was active and the soil moisture content was the lowest, which indicated that these species are adaptable to the harsh conditions.

Introduction

Biological crusts on desert area are organic complex formed by soil microorganisms, cryptogam population and soils. They occur extensively in arid and semiarid zones of the world (West, 1990). Owing to complex species composition and strong tolerance to harsh environments, they play a very important role in the landscape processes (Li et al., 2001), soil physicochemical characteristics (Belnap et al., 1993; Li et al., 2000) and ecological processes, and therefore have attracted widespread attention (Eldridge and Greene, 1994; Li et al., 2003). It is generally accepted that the distribution of biological crust is closely related to the environmental conditions. In a large territory, their distribution can be affected by soil properties, precipitation and its seasonal change (West, 1990; Rogers, 1971). In a small range, their distribution is related to soil physicochemical characteristics, soil moisture, structure of vascular plant communities, and other disturbing factors (Ponzetti and Mccune, 2001).

The Gurbantunggut Desert is the largest fixed and semi-fixed desert in China, where longitudinal dunes prevail. In addition to seed plants, the widespread occurrence of biological crust there is the most important factor affecting sand surface stabilization (Belnap, 1995; Williams et al., 1995). There exists a certain difference in the macroscopic distribution of biological crusts in the desert (Chen et al., 2005), and there is apparently a specific distribution on an individual dune surface (Zhang et al., 2004). The difference in material and available energy, caused by terrains, leads to a distinctive pattern of the relevant factors on individual dune surface (Tsoar, 1990) and different types of crusts also exhibit a corresponding selective distribution, essentially an ecological adaptation of organisms to environmental conditions (Stoddart et al., 1943; Kidron et al., 2000).

Owing to the lack of study on the small-scale environmental changes on the longitudinal dune surface, our understanding on the selective distribution of biological crusts is limited. In this study, the main type of microbial crust at different sites on longitudinal dune in Gurbantunggut Desert were identified, and material composition, soil physicochemical properties, soil moisture dynamics, vascular plant distribution and sand surface stabilization. at the corresponding sites were systematically monitored. The purpose was to investigate the environmental differentiation of microbial crusts on longitudinal dune surface, which would contribute to a better understanding of the environmental conditions for biological crust formation and distribution. It also has a certain importance in the field of transplantation in the light of local conditions for different types of microbial crusts.

Study area and method

Study area

Gurbantunggut Desert, with an area of 4.88×104 km^2, is located in the hinterland of the Junggar Basin in northwest China (44° 11´- 46° 20´ N, 84° 31´- 90° 00´ E) (Fig. 1). Main morphological dune types are longitudinal dunes with a few hundred meters to more than 10 km in length, 10 to 50 m in height and orientated north-south. Interdune and middle to lower part of slopes are stabilized but the crest often has 10~40 m wide mobile belt (Wang et al., 2005). Annual accumulated temperature varies between 3000-3500° and precipitation is about 70-150 mm, with pan evaporation exceeding 2000 mm.

There is about 20 cm thickness of snow cover in winter. Affected by the West Current, precipitation in spring and summer is higher than in autumn and winter (Fang et al., 2002). The rainfall from April to July accounts for 47.6% of whole year's amount. Such a temporal allocation pattern of water and heat creates a favorable environment for the germination and growth of ephemeral plants (Zhang and Chen, 2002). *Haloxylon persicum* is the dominant species of the desert and mainly appears at the middle to upper parts of dunes. Interdune and middle to lower slopes are covered by *Ephedra distachya* communities and beneath them are ephemeral plants and black microbial crusts.

Methods

One typical longitudinal dune (44°32´30´´N, 88°6´42´´E) was selected in the southern part of the desert (Fig. 2). Its orientation was NW 18°, relative height 20 m, and width 120m. The west slope was gentler than the east one. According to the distinctive differences in topography and microbial crust type, long-term monitoring quadrates were arranged in interdune depression, mid-slope and upslope. The thickness and compression strength of three types of crusts were measured. The compression strength was determined by hand force-measuring ring and thickness by steel ruler. More than 10 samples of each type of the crust were measured in the field and their mean values with standard deviation were calculated. Analysis of variance (ANOVA) was carried out to determine whether there were significant differences in the compression strength among the different crusts. The samples of undisturbed crusts

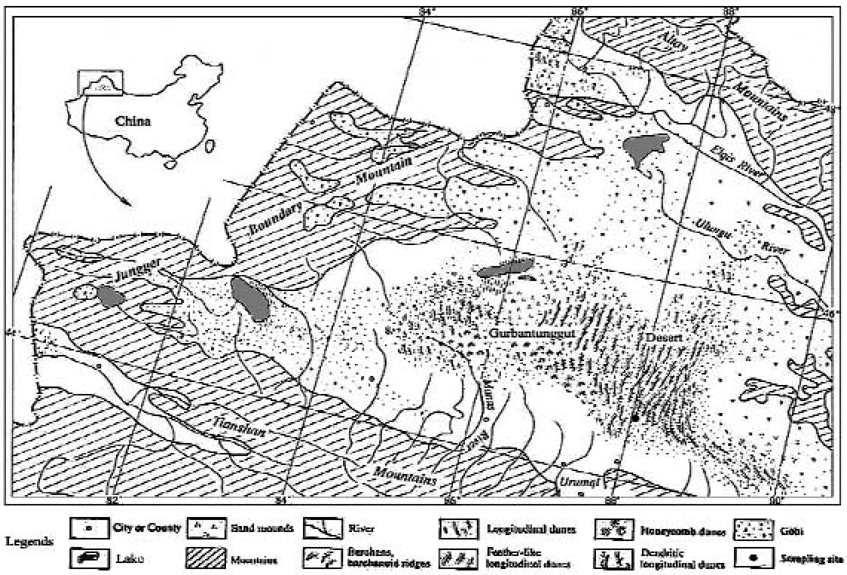

Figure 1. Location of Gurbantunggut Desert and study site

were collected by using cutting ring and transported to the laboratory for species identification.

Tree and shrub quadrates were 10 m×10 m and three small quadrates of 1 m×1 m were arranged in each large one for studying herbaceous species. Plant species, height, crown diameter and coverage, etc. were measured at about 15-20-day intervals from March to November, 2002. At the same time, soil samples in each quadrate were collected and their water contents were calculated after oven-dried at 105°C. Since the plant roots are mainly concentrated in 30 cm depth below ground surface, the soil samples were collected from 0-10cm, 10-20cm and 20-30 cm layers and average soil moisture was calculated. In addition, soil samples in different layer were collected in order to determine grain size composition and physico-chemical properties in laboratory.

Sand surface stability was observed in a strong synoptic process. A section perpendicular to the dune ridge was selected to monitor changes in wind velocity and direction at 2 m height on the Dune by using hand anemometers. The sand transport rates at typical sites of the dune were measured by using step sand trap (Wu, 1987). When the synoptic process ended, the collected sand in the traps were taken out and weighed. A total of 60 steel pins were uniformly arranged at the section and the variations in erosion-deposition of sand surface were measured.

Results

Composition and distribution of three types of biological crusts

The biological crusts in the study area were composed of microorganisms, algae, lichen, moss, etc. (Zhang et al., 2002). However, the species composition, thickness, surface features and mechanical resistance of them at different sites on longitudinal dune surface were not the same (Table 1). Moss-dominated crusts (moss crusts) mainly occurred in the interdune, where moss plants were densely distributed and grew in pulvinoid clump form. They looked black to dark brown in color and had concave-convex surface feature with certain flexibility; *Tortula* and *Bryum* were dominant genera. Lichen-dominated crusts (lichen crusts) were the most widespread in this desert. They occupied the middle to lower parts of dune slopes, were black in color, and had smaller convex-concave feature on their surface. The pressure-resistance strength of lichen crusts differed slightly as compared to the moss crust ($p<0.05$). Algae-dominated crusts (algae crusts) mainly occurred on the upper part of slopes, and they are gray to white in color, with smooth, thin and fragile surface feature. Their surface was easily crushed and the strength was significantly different as compared to moss crust ($p<0.05$). The filaments in cyanobacteria dominated crust can bind sand particles together and enhance soil resistance to erosion (Zhang, 2005).

Fig. 2. The longitudinal dune studied in the southern part of Gurbantunggut Desert.

Table.1 Species composition, thickness and compression strength of different biological crusts

Crust type	Main species composition	Thickness (cm) (Average±SE)	Compression strength (kPa) (Average±SE)
Moss crust	*Tortula desertorum, Crassidium chloronotos, Bryum argenteum, Tortula muralis Collema tenex* var. *diffrato-areolatum*	2.05±0.26	57.28±5.12
Lichen crusts	*Psora decipiens., Xanthoparmelia desertorum, Diploschistes muscorum, Peltula bolanderi, Heppia lutosa Microcoleus vaginatus, Microcoleus paludosus, Anabaena azotica,*	1.39±0.155	2.57±8.34
Algae crust	*Chroococcus turgidus* var. *solitarius, Lyngbya martensiana, Xenococcus lyngbyge*	0.29±0.06	32.53±3.08

Differentiation of small-scale environment

Physical and chemical properties of soil: For considering the relationship of microbial crusts with soil composition (Zhang, 2005), the particle size in surface layer (0-1cm) and subsurface layer (1-5cm) was analyzed (Fig. 3). The results showed that the particle size composition in subsurface layer tends to become coarse from interdune to the crest. The subsurface layer soil at upper slope is well-sorted, in which medium, fine and coarse sand account for 38.4%, 23.7% and 19.6% in weight, respectively. At the mid-slope fine sand accounts for 31.5%, and very fine and medium sand account for 25.6% and 24.6%, respectively. In the interdune both very fine and fine sand could reach about 29%, and the silt and clay contents are the highest on whole dune subsurface. Compared with the subsurface, the surface layer exhibits a certain change. In upslope area, where algae crust is mainly distributed, medium sand decreases to 27.8%, but the fine and very fine sand increase significantly. In the surface layer of the mid-slope area, where lichen crust is mainly distributed, the very fine sand and silt content also increased. However, compared with the subsurface layer, there was little change in sand component in the interdune where the moss crust is mainly distributed.

The analysis also showed that soil organic matter tended to decrease from the interdune to the crest (Table 2). The interdune had a small accumulation of organic matter (about 4 g/kg) in the upper layer of 0-5cm soil, while it decreased to about 1g/kg or so at the upslope. The pH value in the whole dune surface exhibited a weak alkalinity and it tended to increase slightly with soil depth, which indicates that soil leaching was limited in the desert but soil weathering and development continued. Soluble salt content in the surface layer of the whole dune was low and tended to decrease from lower slope to upper one.

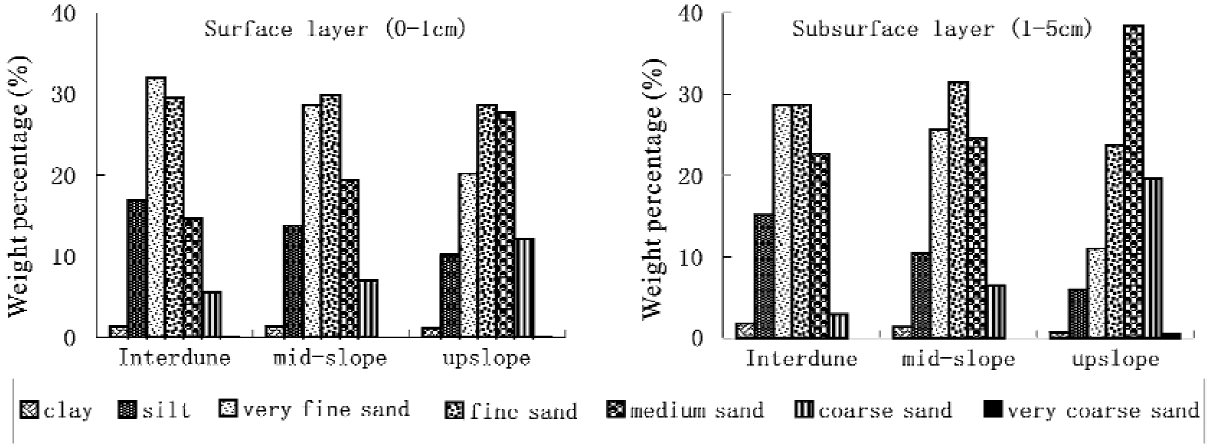

Fig. 3. Particle size distribution of soils on longitudinal dune.

Soil moisture regime: There were some temporal and spatial differences in soil moisture on the longitudinal dune. The whole dune was entirely covered by 20-30 cm thick snow cover from December to end of February. The snow cover melted in March. This coupled with high rainfall during this period resulted in the highest soil moisture content in spring out of whole year in the desert. Mean soil moisture in the upper 30cm layer reached 4.5% in April. In May it rapidly decreased to 1.86% and in late June it reached a low value of 0.66%, changing little afterwards. From December onwards air temperature fell below 0° and dune surface soil water froze. In early spring and late autumn, freezing and thawing alternately took place, and this coupled with the presence of an impervious frozen layer below, resulted in the flow of soil water in the dune surface from upslope towards the interdune causing spatial differentiation in the moisture content in the dune (Yair et al., 1997; Zhao et al., 2003). In the early to middle 10-day period of April soil moisture was 5.65% in the interdune and 3.83% in upslope area. In late April soil moisture in the interdune and mid-down slope area changed little with a value of more than 4%, but it decreased to 2.01% in upslope area, which may be related to the strong winds there. In the middle 10 days of May soil moisture in the mid-slope and interdune decreased to 2%, which is related to the widespread growth of ephemeral plants (Wang et al., 2004), while soil moisture in upslope changed a little, roughly ranging from 1.5% to 1.9%. From middle June onwards, soil moisture in different dune sites tended to become the same, generally ranging from 0.45% to 0.65%, and the crusts were generally in a dormant status in this period. By middle November the cycle of freezing and thawing started and the weak differentiation of soil water content in the dune surface took place again (Fig. 4).

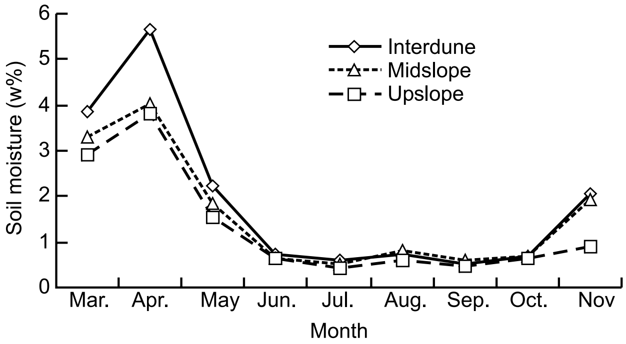

Fig. 4. Soil moisture of 0-30cm layer on longitudinal dune surface.

Vascular plants distribution: A total of 45 plant species were identified in the study region, including one dwarf tree species (*Haloxylon persicum*), four shrubs and sub-shrub species (*Ephedra distachya*, *Calligonum leucocladum*, *Artemisia arenaria*, and *Seriphidium terrae-albae*), 11 herbaceous plant species of long vegetative period, and 29 ephemeral plant species. The composition of plant community, vegetation cover and plant community structure were closely related to the position at the dune (Table 3). The interdune depression and middle to lower dune slopes occupied about 60% of total dune surface area, where the mean coverage of sub-shrubs varied from 8.9% to 10.0%. In the middle 10 days of May the coverage of ephemeral plants could reach 51.8%, out of which *Geraniaceae*, *Alyssum linifolium*, *Trigonella tenella* and *Carex physodes* contributed to 17.4%, 15.2%, 3.9% and 1.8%, respectively. The upper slope occupied about 25%-30% of its total area, where the coverage of tree-shrub, with *Haloxylon persicum* as dominant species, was 12.2%-21.4%, while the mean coverage of ephemeral plants in the middle to late May could reach 38.2%. The crest is the zone with strongest

Table.2 The physicochemical characteristics of soils on longitudinal dune

Site	Depth (cm)	Organic matter (%)	Total (%)		Available (mg·kg^{-1})		pH	Electric conductivity (mS·cm^{-1})	Total salinity (%)
			N	P	N	P			
Interdune	0-5	0.380	0.023	0.047	21.81	7.15	7.80	0.085	0.045
	5-10	0.140	0.010	0.037	12.35	3.84	7.90	0.066	0.038
	10-30	0.123	0.007	0.033	5.85	2.77	8.15	0.068	0.036
Mid-slope	0-5	0.239	0.022	0.043	12.60	6.08	7.65	0.068	0.035
	5-10	0.122	0.011	0.041	11.81	3.62	7.88	0.063	0.033
	10-30	0.102	0.006	0.037	9.51	3.62	8.10	0.067	0.040
Upslope	0-5	0.102	0.009	0.032	21.32	4.37	7.90	0.062	0.028
	5-10	0.089	0.006	0.028	11.95	3.92	7.58	0.047	0.025
	10-30	0.073	0.006	0.025	10.37	3.02	7.85	0.062	0.028

Table.3 Plant communities in different position on longitudinal dune

Sites	Sand surface activity	Community type	Vegetation cover (%)	Community height (cm)	Main associated species
Crest	Mobile	Aristida adscensionis	<15	20~35	*Corispermum lehmannianum, Horaninowia ulicina, Lappula rupestris, Salsola pestifer collina, Erysimum cheiranthoides Agriophyllum squarrosum, Soranthus meyeri, Ceratocarpus arenarius, Horaninowia ulicina,*
Midslope	Semi-fixed	Haloxylan persicum	15~30	50~250	*Arnebia* sp., *Carex physodes, Eremurus anisopteris, Chrozophora sabulosa Erodium oxyrrhynchum, Alyssum linifolium,*
Interdune	Fixed distachya	Ephedra	30~55	35~40	*Carex physodes, Eremopyrum orientale,* L. *semiglabra*

sand activity and it occupies 10%-15% of total dune area; the coverage here of shrubs, including *Calligonum leucocladum* and *Artemisia arenaria* etc., varied between 1.7% and 4.8%. The coverage of herbaceous plant of long vegetative period was less than 7.1%, while that of ephemeral plants was less than 4.4%. Out of all the plants the ephemerals showed a conspicuous seasonal variation. They initially sprouted in the end of March and their mean coverage could reach 5.3% in early April, with a relative height of less than 3 cm. Their mean coverage in late April was 20.8% and mean plant height was about 10 cm. The corresponding values in mid-May were 40.2% and 20cm, respectively. In mid-June most ephemeral plants gradually declined and by early July all ephemeral plants died away.

Sand surface stability: During the synoptic process the wind direction formed an intersection angle of more than 60° with dune orientation. Affected by dune topography, the airflow over windward slope was compressed and speeded up gradually. Wind velocity near the dune crest reached a maximum value, generally 1.2-1.8 times higher than that at the base of windward slope. Meanwhile, the sand surface of upper windward slope was generaly eroded. When the airflow blows over the dune crest, its separation takes place and thereby a dramatic reduction of wind velocity and the change of wind direction takes place, which shows that the airflow forms anti-spin eddy on the upper leeward slope (Tsoar et al., 2003). Meanwhile, sand deposition commonly takes place in this area, but the airflow below the leeward mid-slope gradually keeping its original direction. Generally speaking, the sand transport rates observed at different topographic sites differed greatly. Under the action of 10-hour long wind force, the quantity of sand

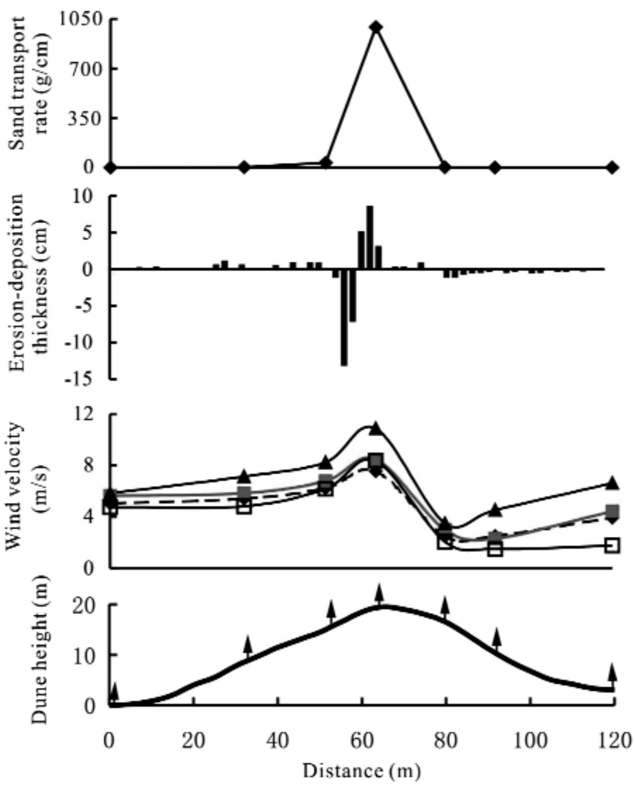

Fig. 5. Variation of wind velocity at 2m high and sand transport quantity on the longitudinal dune surface.

transport at the dune crest was nearly 1000 times larger than that in the interdune. The results of sand surface change in the same period showed that the strongest active area mainly occurred on the crest and upper part of dune, while the interdune and lower part of slopes nearly kept unchanged (Fig. 5).

Conclusions

The biological crusts in Gurbantunggut Desert exhibit a selective distribution on longitudinal dune surface. Moss crust, lichen crust and algal crust mainly occur in the interdune depression, mid-slope and upslope area respectively. From the interdune to the crest, the thickness of microbial crusts becomes thin and compression strength tends to weaken. The soil on the crest and upper part of longitudinal dune mainly consists of well-sorted medium sands and the soil profile differentiation is not evident. The interdune and middle to lower slopes mainly consist of poorly sorted fine sand and very fine sands and a certain amount of organic matter accumulates on the ground surface. The poorly sorted sands in the interdune depression can increase the contact area between particles, which form a barrier to hold water in surface soil layer effectively. The coarse particles with their good sorting at the crest and upper slopes are favorable to water penetration (Mckee, 1993), which have a certain influence on the vertical differentiation of soil water. Temporal and spatial variation of soil water in the dune surface is an important factor in affecting the selective distribution of biological crusts. The study indicated that the soil moisture was high in spring, low in summer and in a freezing status in winter. In early spring the soil moisture in interdune and downslope area was highest, followed by mid-slope and poorest in the dune crest. After full flowering of ephemeral plants in May, the soil moisture in interdune decreased rapidly while it decreased slightly in upslope area. From late June onwards soil moisture on whole dune surface was lower than 0.65% and no evident temporal-spatial variations were found, hence all biological crusts in the desert generally remained dormant. A total of 45 vascular plant species was recorded. *Haloxylon persicum* only occurred on the middle to upper slopes and *Ephedra distachya* and most ephemeral plants were confined to the interdune and lower dune slopes. Ephemeral plants showed seasonal variation and generally completed their life cycle within two to three months. The area occupied by the crusts was also densely covered by ephemeral plants and their interrelations need to be further studied. The sand surface activity on dune surface is determined by sand transport rate and erosion-deposition pattern (Livingstone, 1989). The existence of increasing wind velocity and decreasing roughness from the base to the crest of dune resulted in a high sand transport rate and strongest sand activity at the dune crest and upslope area, while at the lower slopes and interdune nearly no erosion and deposition occurred. It can be concluded that moss and lichen crusts developed well on the stable surface with better soil moisture, while algal crusts could tolerate a harsher environmental conditions.

Acknowledgments

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Sand stabilization and microhabitat effect of shrub belts on the top of the Mogao Grottoes

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Abstract

A blown sand control system is needed to protect the top of the Mogao Grottoes. In particular, a shrub shelter belt is an essential component of such a control system. Observations show that the airflow field near the shrub shelter belt is redistributed, and the near-surface sand stream is dramatically changed. The effective prevention range is 20-30 times of the height of shrub shelter belt, while wind velocity decreases from 68.1 to 40.7%, and sand transport rates at 2 m behind every shrub shelter belt are 1/38 and 1/138 as much as the sand transport rates at 30 m in front of the shrub shelter belt. Furthermore, the depth of sand accumulation in the shrub shelter belt reaches 0.7 m. The fine and very fine sand on surface layer (0-20cm) increases by 20.6 and 5.5%, respectively, and the organic content increases greatly in the area of vegetation roots development. Moreover, the shrub shelter belt also has an effect on micro-climate. The daily average temperature in dunes at 0.5, 1.0 and 1.5 m heights is 0.5, 0.9 and 0.2°C higher than in the shrub shelter belt, respectively. The relative humidity of the shrub shelter belt also increases at these heights by 0.4, 0.3 and 0.1% than in the shifting sand. The variation of daily and night temperature on the surface (0-20cm) layer is sinusoidal in distribution.

Introduction

The Mogao Grottoes were first built in Qian Qin Jian Yuan period (366 A.D.). It has been on UNESCO's World Heritage Sites list since 1987 and is one of the important nationally protected sites. There are 45,000 m^2 magnificent wall paintings and more than 2000 polychromed statues made from the 4th to the 14th century. They are also called as "World Art Gallery and Museum on the Wall". The largest, richest, and finest Buddhism art treasure of very high cultural value not only in China but also in the entire world (Fan, 2003).

The Mogao Grottoes are located in an extremely arid desert. The wall paintings have been well preserved for a long time because of dry climate, but they have long been threatened by blown sand from the Mingsha Mountain. Blown sand has been one of the major environmental issues impacting the remaining grotto relics, which has widely concerned the international community (Agnew et al., 1999; Jin, 1986; Li et al., 1997; Lin et al, 1996; Wang, 1990; Zhao, 1990). After better understanding the movement characteristics of the blown sand in this area and studying the practices to control blown sand during past decade it can be concluded that the key for solving the problem affecting the Mogao Grottoes is to cut down sand sources from the Mingsha Mountain and sandy-gravel desert by applying different control measures. The measures should be able to block sand stream being transported to the grottoes by westerly and southerly winds, but help the easterly wind to blow the deposited sand back to the Mingsha Mountain. The measures combining engineering, biological and chemical approaches are an integrated control system with multiple functions (Qu, et al., 2001; Wang et al., 2000; Wang et al., 2004 a,b; Xue et al., 2000; Zhang et al., 2004; Zhu, 1999). Among them, the shrub belts is one of the most important elements as they not only have

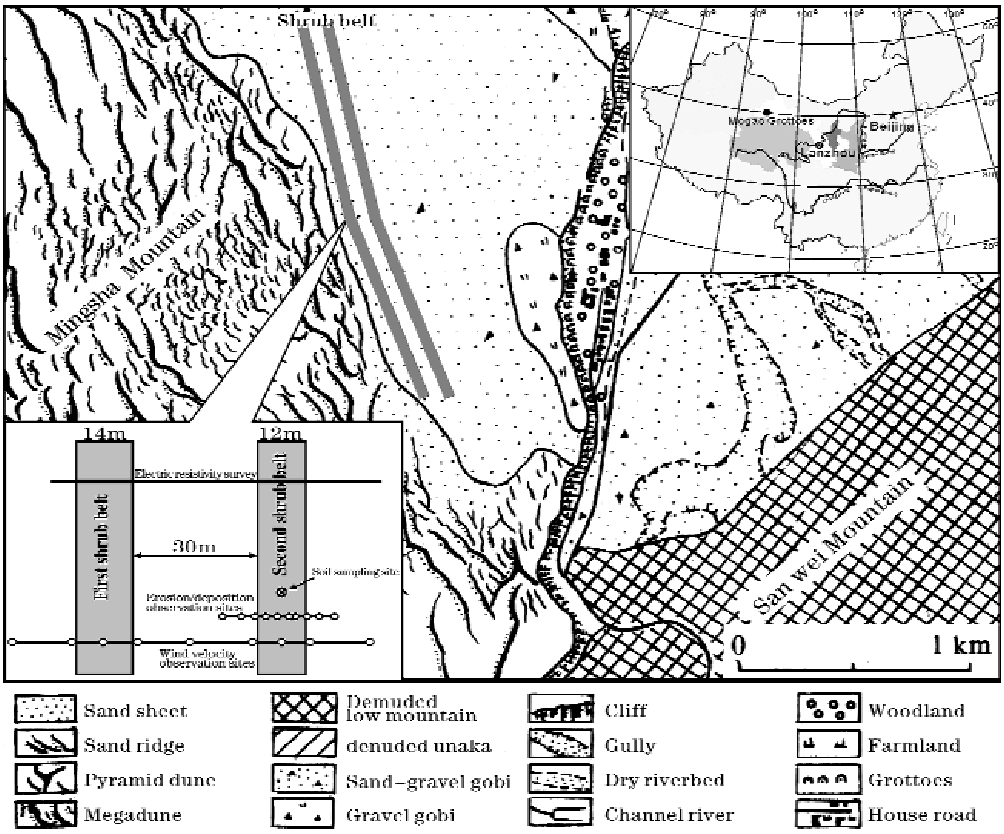

Fig.1. Geographic locations of the Mogao Grottoes and the shrub windbreak belts.

better capacity to lessen wind strength and stabilize sand, which can supplement the short term effects of the engineering measures, but also can regulate micro-climate and improve ecological environments (Wang et al., 2004b).

Many studies have been done on vegetative windbreak in the humid area, semi-arid area and arid desert area without irrigation (He and Zhou, 2002; He et al., 2002; Liu, 1987; Wang et al., 1989) but little has been studied in the extreme arid desert. A few studies probing indoor simulation were only on windbreak mainly for agricultural purposes (Oosterhoorn and Kappelle, 2000; Wang, 1997; Yu et al., 1991). Very limited research has been done on the effects of the shrub belt as windbreak on sand stabilization and regional environment improvement. Shrubs in the arid areas have the advantage of consuming less water and giving better control of soil erosion than trees. Hence, they can be used for projects for ecological environmental development and for enhancing ecotourism in arid areas.

The aim of this paper is to explain the changes in micro-habitat around the shrub belts through changes in sand transportation, and moisture content and chemical and physical properties of soil. The results of the research can be used as guidelines for improving the integrated approach for controlling the blown sand at the Mogao Grottoes as well as in other arid areas.

Methods and material

Brief information about the studied area

Mogao Grottoes are located at the southern edge of the Dunhuang Basin, 25 km south-east of Dunhuang City, bordered by the Sanwei Mountain to the east and the Mingsha Mountain to the west (Fig. 1). The grottoes were formed in a vertical cliff cut into the diluvial fan terrace of the west bank of the Daquan River. The surface of the cliff top (part of the Gobi Desert) stretches 700-1000 m westwards to the foot of Mingsha Mountain; a mega-dune complex. The surface material of the cliff top can be divided into four zones from east to west, namely, gravel gobi, sandy gobi, sand sheet and megadunes. The Mingsha Mountain, 60-

170 m in height, is composed of megadunes dominated by dune ridges, pyramid dunes and complex megadunes. The Mogao area is typical of desert climate influenced by Mongolia High pressure all the year-round. Meteorological data collected between 1990 and 2002 showed that the Mogao area was not only a high wind area but also characterized by multiple wind directions. The annual average wind speed was 3.5 m s^{-1}. In spring, between March and May, the average wind speed was 4.1m s^{-1} and the greatest wind speed was 20.2 m s^{-1}. About 48% of the yearly high wind days and about 47.5% of yearly dust storm days were in spring. The annual average rainfall was 23.3 mm and 58.0% of yearly rainfall was in June, July and August (Li and Qu, 1996). The evapo-transpiration was 4347.9 mm, which is 187 times of yearly rainfall. Dryness index was 32; average relative humidity was 32%; annual sunshine-hours were 2962.5; and annual average temperature was 10.6° C. The major natural plants in the studied area are *Calligonum mongolicum* Truce, *Haloxyion ammodendron (*Meg*)* Bunge, *Nitratria tangutorum* Bobr, *Artemisia arenaria* Dc, and *Aristida pennata* Trin. The vegetation coverage is about 1% of the studied area.

Two belts of shrub located at flat sandy field in the front edge of the Mingsha Mountain were planted in 1992, 1993 and 1999. The shrub belts are 1850 m long and oriented in the SE to NW direction. One is 12 m wide and another is 14 m wide. The spacing of plant was 2 m by 2 m. The average plant height is 1.5 m and the coverage is 40-60%. Planted shrubs are *Tamarix chinensis* Bgune, *Hedysarum scoparium* Fischet Mge, *Haloxyion ammodendron* (Meg) Bunge, *Calligonum mongolicum* Truce, and *Caragara korshinskii* Kom. Drip irrigation system was applied to the shrub using water from Daquan River, which has high content of Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} with 3.72 mg N/L total alkalinity, 509 mg/L ($CaCO_3$) total hardness, and pH value of 7.55. The brown desert soil contained 0.06% to 0.51% organic mater, below 0.01% N, 0.05 to 0.08% P_2O_5 and less than 2.0% K_2O. The pH was 7.22-8.94.

Research methodology

The goal of this study was to investigate the effects of the shrub belt as windbreak on sand stabilization and the environment. A data logger with 10 channels of wind speed and wind direction automatically recorded the average wind velocities every minute. Wind speeds were collected at 0.2, 0.5, 1.0, 1.5, and 2.0 m height above the ground surface (NW wind direction during data collection). The sand transport rate was observed by the staircase type sand collectors. The layout of the data collection points is shown in Fig. 1. Soil samples were collected on site and were analyzed in the Key Laboratory of Desert and Desertification, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences for mechanical composition (by sieve method), and chemical properties (pH, organic matter, nutrient and salt contents, using the routine procedures as outlined by Institute of Soil Sciences, Chinese Academy of Sciences, 1978.) in 1993 and 2002. Organic contents were determined by oxidizing and heating with potassium dichromate. Air temperature and relative humidity inside and outside the shrub belts were recorded by using HOBO automatic temperature and humidity meter during summer and winter at 0.5 and 1.0 m heights above the ground. Soil temperature at different depths (0, 5, 10, 15, and 20 cm) was recorded using model 2-30076 geo-thermometer manufactured by Shanghai Medical Equipment Factory. The profiles of soil deposition-erosion were dynamically monitored by a series of measuring rods in different windy seasons.

Results and analysis

The characteristics of the airflow around the shrub belts

The wind speed patterns around the shrub belts are shown in Fig. 2. The shrub belt greatly decreased airflow speed. When air flowed from the shifting sand approaching the first shrub belt its speed was slowed down and a backflow turbulent speed formed behind the shrub belt. The wind speed behind the first shrub belt at 0.2, 0.5, 1.0, 1.5, and 2.0 m heights was 22, 24, 32, 51, and 96%, respectively, 30 m away from the first shrub belt, which served as a reference point. Then, the wind speed increased a little bit at the open space between the two shrub belts. When wind speed continued to recover 90% of the reference wind speed the airflow encountered the second shrub belt which formed an area of decreasing wind

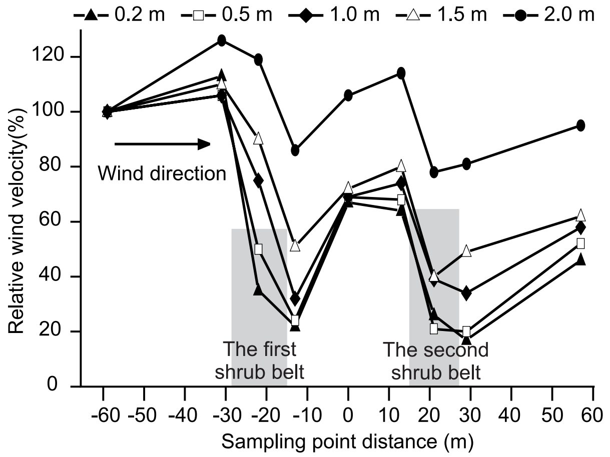

Fig. 2. Wind speed patterns around the shrub belts.

speed. The wind speed here reached its lowest values, about 17-30% of the reference wind speed. Thereafter, the wind speed started to increase and reached a value of 62 to 95% of the reference point. Airflow speed increased to form an increasing speed area at the top of shrub belts indicating the existence of an accumulated flow area at the top of shrub belts (Fig. 3). The result is similar to the result of wind tunnel test (Wang et al., 2004).

Sand blocking and stabilizing effect

Generally, sand deposition occurs in the area of decreasing wind speed, and sand erosion occurs in the area of increasing wind speed. One of the monitoring cross-sections (SE to NW orientation) was studied when the strong easterly and westerly wind were prevalent (Fig. 3). The surfaces included those undergoing constant erosion, deposition, and neither erosion nor deposition. A large amount of sand stream deposited inside the shrub belt because the shrub belt decreased the wind speed, but strong erosion occurred in the front and behind the shrub belt, and alternating deposition and erosion occurred with change in different wind directions. The greatest change in sand transport rate occurred in the front and behind the shrub belts. Under the action of 9.8 m s^{-1} of the northwest wind sand transport rates at shifting sand land, 2 m behind the first shrub belt and 2 m behind the second shrub belt were 59.34×10^{-4}, 1.54×10^{-4}, and 0.43×10^{-4} g/cm^2 min, respectively. The sand transport rate at the shifting sand area was 38 times of that at the first shrub belt and 138 times of that at the second shrub belt, indicating that the shrub belt was very effective in blocking sand movement (Table1).

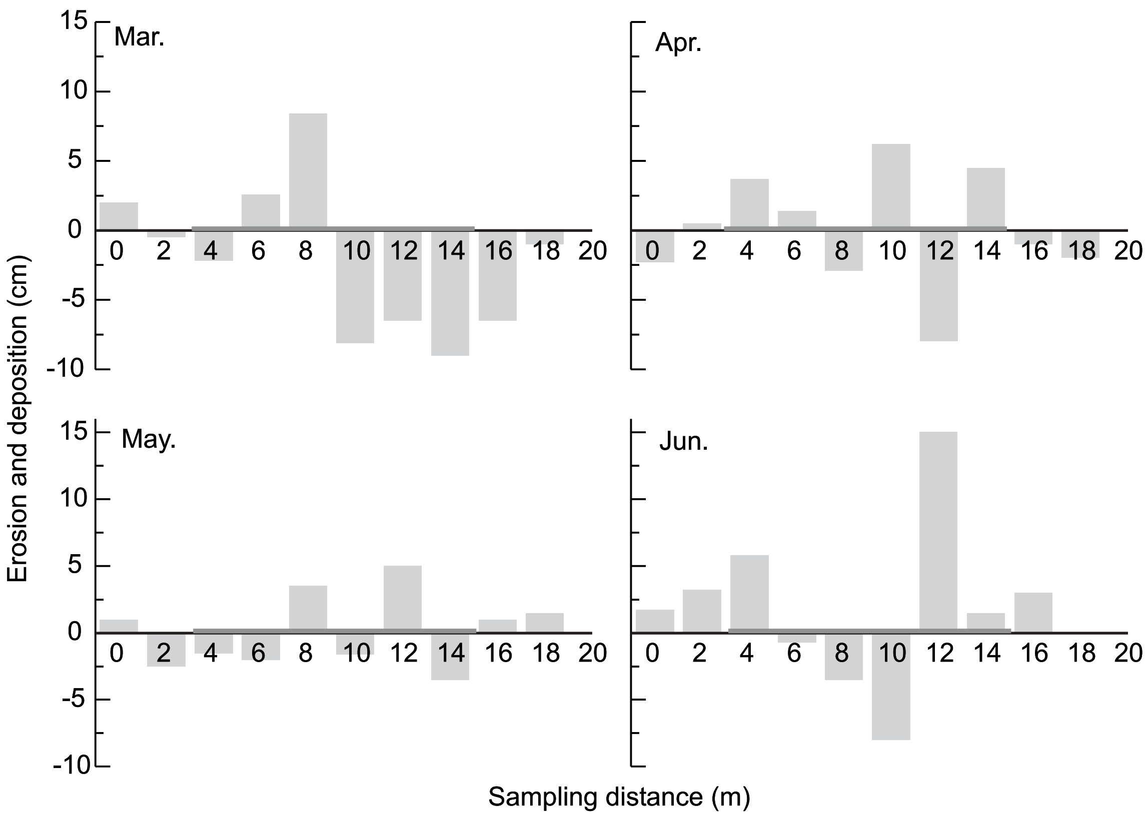

Fig. 3. The erosion and deposition in the shrub shelter belts in spring, 2001.

Table 1. The rate of transported sand in front of and behind the shrub shelter belt

Height (cm)	Sand dune	2m behind first shrub shelter belt	2m behind second shrub shelter belt
	Sand transport rates($\times 10^{-4} g \cdot cm^{-2} \cdot min^{-1}$)		
0~ 2	23.84	0.35	0.04
2~ 4	19.82	0.22	0.02
4~ 6	7.82	0.41	0.02
6~ 8	3.71	0.10	0.22
8~10	1.88	0.06	0.03
10~12	0.98	0.06	0.02
12~14	0.52	0.11	0.02
14~16	0.37	0.04	0.02
16~18	0.22	0.10	0.02
18~20	0.19	0.09	0.01
0~20	59.35	1.54	0.43

Moisture content of sandy soil

The monthly variation in soil moisture content at 0- 40 cm deep during 2000-2004 is shown in Fig. 4. Soil moisture content significantly increased under the drip irrigation system. The annual soil moisture content between the two shrub belts, grit gobi and shifting sand land were 2.22 %, 0.33 % and 0.39%, respectively. The average soil moisture content in the grit gobi and shifting sand land was 0.3-0.4%, which was one third of wilting percentage and therefore insufficient to meet the minimum moisture condition required for the growth of desert plants. The soil moisture content varied depending on the shrub growing season.

The precipitation from May to September was 26 mm, accounting for 67% of annual precipitation. The evapo-transpiration of shrubs and evaporation of soil increased and thus soil moisture content decreased in summer from June to August. However, in September, the average soil moisture content within the shrub belt was 3.54%, which was 4.5 and 3.6 times of that at the area of 5 m and 10 m in front of the shrub belt, and 2.8 times of that at the shifting sand land. That also indicates that at extreme arid desert area a small amount of precipitation will significantly impact soil moisture content. The monthly precipitation, evaporation and soil water content of dry layer in grit gobi and shifting sand land demonstrated that although a little precipitation was recorded during the period from October to next May, the soil water content was relatively stable because of lower evaporation.

Changes in physical and chemical properties of the soil

The physical and chemical properties of shrub land changed significantly due to the combined actions of irrigation, fertilization, vegetation rooting system, and the activities of soil microorganism (see Tables 2 to 4).

Table 2 shows that a large amount of fine grain materials got deposited in the shrub belts. After 10 years of establishment of the shrub belt, the grain size of sand in 0 to 20 cm layer changed from relatively coarse to fine grain. The fine sand (0.25-0.1 mm) and very fine sand (0.1-0.05 mm) increased by 70.2% and 9.4%, respectively.

When vegetation grew and irrigation continued the content of nutrients around the rooted area in soil redistributed and organic matter increased (Table3). The N and P contents also changed slightly but their change varied with soil depth because of absorption by roots of the shrubs. The irrigation water came from the Daquan River which has high alkalinity. When water evaporated, a ring of salt deposited on the ground surface. The pH value increased. In addition, salt content of soil between 0 and 60 cm depth increased generally (Table 4).

Micro-environmental effect of shrub belts

The impact on the air temperature of the shrub belts: The daily variation in temperatures at different heights on shifting sand land and shrub belts showed similar tendency (Fig. 5). The average daily temperatures at 0.5, 1 and 1.5 m heights at

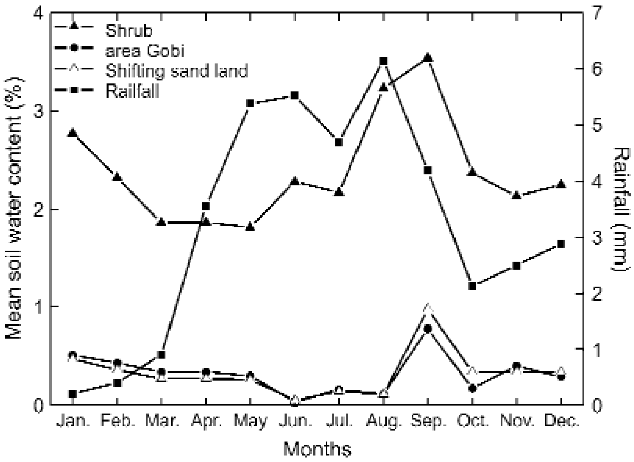

Fig. 4. Monthly variation in soil moisture content.

shifting sand land were 0.5, 0.9 and 0.2°C higher than in shrub belts, but the temperatures of the shrub belts were higher than at shifting sand land during the period of 1700-1800 hrs. This was because the heavy branches and leaves of shrubs blocked the airflow.

The impact of shrub belt on temperature at the shallow depth of soil: When the shrub belts were established the bio-geochemical cycling rate of soil increased changing its ground surface temperature and soil temperature of shallow depth. However, the changes were not obvious in the

Table 2. Mechanical composition of the soil particles in the profiles over the top of the Mogao Grottoes

Sampling time	Depth (cm)	Gravel >2 mm	Coarse 2~0.5	Moderate sand 0.5~0.25	Fine sand 0.25~0.1	Very fine sand 0.1~ 0.05	Coarse silt 0.05~ 0.01	Very fine silt 0.01~0.005
1933	0	0.37	32.53	5.90	29.46	28.77	2.96	0
	0~20	0.27	25.16	3.77	34.26	33.77	3.03	0
	20~ 60	0	21.20	6.17	35.20	32.20	5.27	0
	60~130	1.43	20.73	4.70	23.07	41.34	6.93	0
	130~200	42.17	9.81	8.58	19.95	10.67	0.70	0
2002	0	0	5.07	8.29	50.14	34.70	1.80	0
	0~20	5.04	8.83	5.60	37.47	35.63	7.43	0
	20~60	24.28	13.56	5.60	17.88	29.12	8.80	0.76
	60~130	0	0.60	3.46	78.74	11.20	0	0
	130~200	30.00	28.36	9.14	17.00	9.42	6.08	0

Table 3. Analysis results of nutrient in 2m depth layer over the top surface of the Mogao Grottoes(g/kg)

Sampling time	Depth (cm)	Organic C	Total nutrient			Available nutrient		
			N	P_2O_5	K_2O	Mineralized Nitrogen	P_2O_5	K_2O
1993	0	1.21	0.09	0.61	18.0	21.8	1.7	135
	0 ~ 20	0.80	0.08	0.60	18.0	20.6	0.1	96
	20 ~ 60	0.80	0.08	0.53	18.0	4.2	1.9	88
	60 ~ 130	0.83	0.01	0.54	18.0	12.1	2.6	80
	130 ~ 200	0.93	0.07	0.52	18.0	38.7	1.4	80
2002	0	1.55	0.09	0.63	17.5	21.6	3.0	150
	0 ~ 20	1.55	0.08	0.64	17.5	11.0	7.9	150
	20 ~ 60	1.27	0.09	0.64	17.5	17.9	15.9	140
	60 ~ 130	1.07	0.06	0.47	15.0	6.4	7.9	160
	130 ~ 200	1.29	0.06	0.87	17.5	6.4	6.9	130

Table 4. Analysis results of salinity in 2m depth layer over the top surface of the Mogao Grottoes (g/kg)

Sampling time	Depth (cm)	Anion				Cation				Amount of anion and cation	pH
		CO_3^{--2}	HCO_3^-	Cl^-	SO_4^{--2}	Ca^{++}	Mg^{++}	Na^+	K^+		
1993	0	0	0.12	1.59	3.10	0.54	0.28	1.40	0.07	7.10	7.26
	0~20	0	0.10	0.10	0.90	0.18	0.10	0.10	0.01	1.49	7.56
	20~60	0	0.09	0.13	3.02	0.84	0.23	0.15	0.03	4.49	7.32
	60~130	0	0.12	0.13	3.01	1.03	0.09	0.20	0.02	4.60	7.22
	130~200	0	0.13	0.12	1.19	0.16	0.21	0.10	0.02	1.93	7.32
2002	0	0	0.08	1.26	1.24	0.25	0.05	1.00	0.06	3.89	8.68
	0~20	0	0.11	0.65	1.46	0.29	0.03	0.71	0.06	3.31	7.74
	20~60	0	0.12	0.28	6.03	2.07	0.09	0.49	0.06	9.14	8.84
	60~130	0	0.12	0.06	0.26	0.04	0.02	0.11	0.02	0.63	8.76
	130~200	0	0.13	0.26	0.73	0.12	0.02	0.37	0.06	1.69	7.86

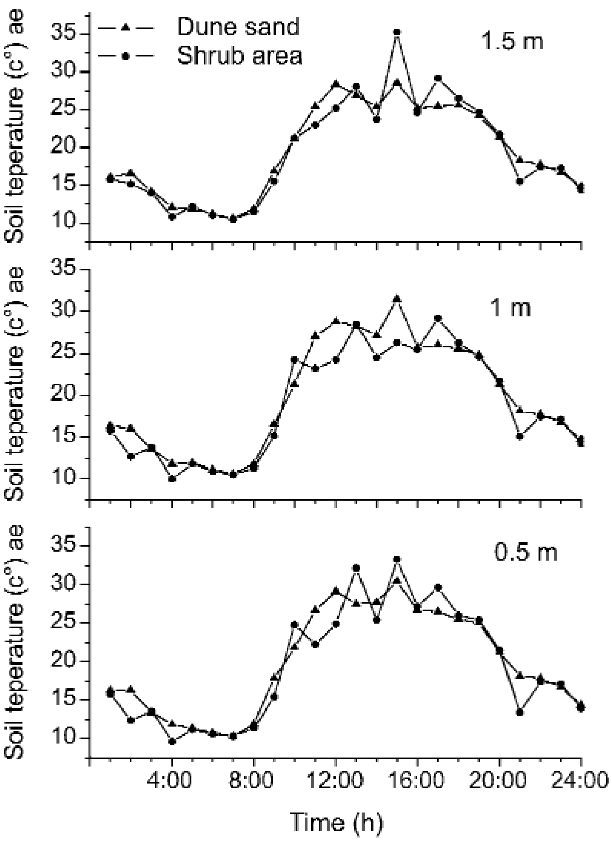

Fig. 5. Daily changes in air temperature in the shrub belt and on shifting sand land.

beginning of the shrub belt establishment. Fig 6 shows soil temperature changes at different depths of the shrub belt and the sand dune area on September 6, 1993. The pattern was very similar at two sites and formed a sine distribution curve. Soil temperature reached the lowest value at 7 a.m. and reached the highest value at 4 p.m. Deeper soil layer took longer time to reach the highest temperature. For instance, soil temperature at 20 cm depth reached its highest value at 9 p.m. Temperature at the ground surface, and at 5, 10, 15, and 20 cm depth in the shrub belt was respectively 1.6°C, 0.8°C, 0.3°C, 0.3°C, and 0.4°C higher than in the sand dune area. The temperature at the shrub belt was 0.7°C in average higher than that at the sand dune area. Sand is mainly constituted of quartz (SiO_2) which has high heat conductivity. Therefore, temperature increased rapidly when sun shined on sandy land. The highest temperature recorded was 70°C, at which the vegetation cannot survive. With drip irrigation of shrubs the temperature of ground surface dropped significantly, especially in the summer. The wetting of ground surface increased evaporation causing a temperature drop of up to 10°C, which benefited the growth of the vegetation.

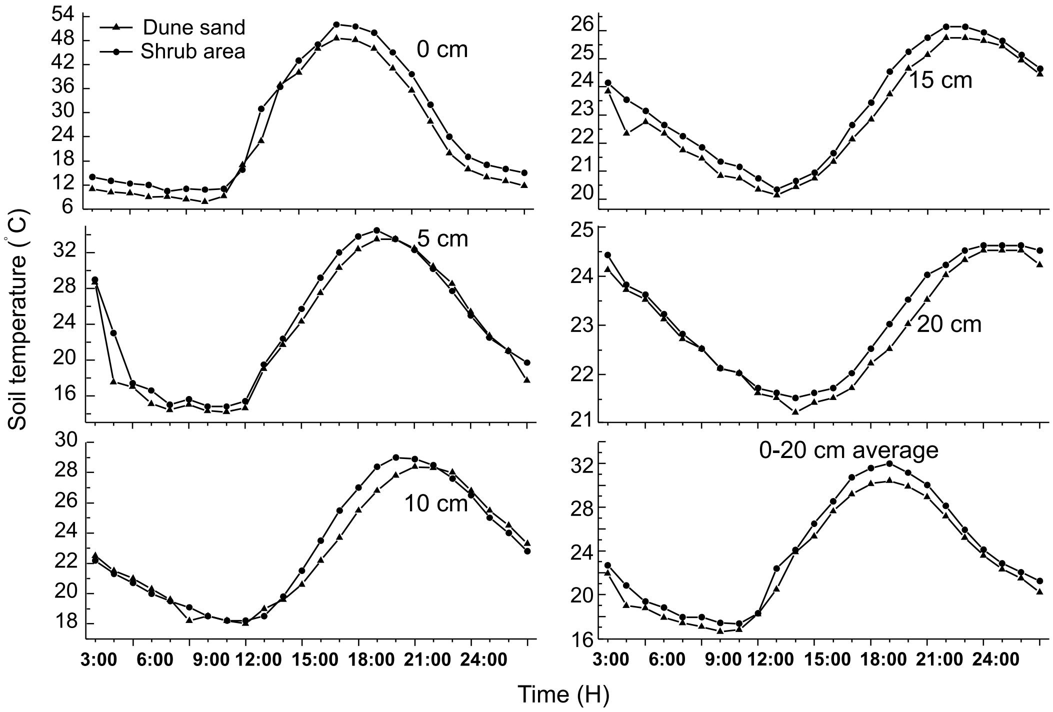

Fig. 6. Daily changes of soil temperature of shallow layer in the shrub belt and shifting sand land.

Soil temperature of shallow layer is directly impacted by solar radiation and the heat property of the ground surface. The soil temperature in the shrub area changed relatively fast and the change was higher than in the sand dune area. The pattern of temperature change at the shallow depth was consistent with that at the ground surface; however the intensity of change decreased at 20 cm depth.

Conclusion

The shrub windbreak is one of the essential elements for the integrated blown sand control system to protect Mogao Grottoes. Currently, two shrub belts control wind and stabilize sand. This has improved local micro-habitat and micro-ecology. The shrub belts redistribute airflow in their vicinity and change the structure of blown sand flow near the ground surface. The multi-shrub belts with narrow spacing would obviously have stronger effects in blocking and stabilizing shifting sand. The moisture content of soil inside the shrub belt increased and varied relatively significantly when season changed. Yearly average moisture content of soil inside the shrub belts in July, August and September was respectively 5.8, 1.1, and 2.8 times that of at the shifting sand area. Because of the combined effect of irrigation, fertilization, rooting system of shrub, and soil micro-organism, the soil physical and chemical properties showed some improvement in the surface layer in the shelter belt. Salt content of soil up to 60 cm depth increased a little bit in the belt area but decreased in the soil below 60 cm. The drip irrigation system did not cause salt accumulation in the shallow depth and washed salt into the area deeper than 60 cm. The shrub belts had a significant effect on sand stabilization and windbreak and they consumed small amount of water. Therefore, the shrub belt has proven to be a very important and practical means for blown sand control and rehabilitation of vegetation in the extreme arid desert and the practice should be promoted for the ecological environmental development in western China.

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Soil erodibility and PM10 emissions following tillage in a dryland wheat-fallow cropping system

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Abstract

Traditional agronomic practices in the conventional 'wheat-fallow' rotation employed in the Columbia Plateau of central Washington, USA include multiple passes with tillage implements during the fallow period, both to create a dust mulch layer to retard soil moisture losses and to manage weed populations. This dust mulch, in association with high winds and low rainfall during the summer and early autumn season, creates soil surface conditions optimal for wind erosion and emission of PM10 (particulate material ≤ 10µm in diameter regulated by the US EPA as an air pollutant). Therefore, less intensive tillage practices are sought that will reduce wind erosion and PM10 emissions from fallow fields. The objective of this study is to quantify PM10 emissions from a silt loam in the low rainfall area of the Columbia Plateau during a simulated wind event following various post harvest tillage operations. Experimental plots were established after harvest of winter wheat in August 2004 and were located near Lind, WA which has a mean annual precipitation of 244 mm. Treatments included conventional, moderate, minimum, and no tillage. Tillage operations were performed to a depth of 13 cm. A portable wind tunnel was used to generate air flow over a known surface area in the experimental field plots. Sediment flux and PM10 concentrations at various heights above the soil surface were measured within the working section of the wind tunnel. Soil physical properties were measured simultaneously with wind tunnel tests. Sediment flux and PM10 emissions were suppressed by a crust cover in no-till plots and were highest from plots that had the least residue biomass and cover. This study suggests that less intensive tillage in early autumn and spring will maximize the retention of residue biomass and reduce PM10 emissions from silt loams within the wheat-fallow region of the Columbia Plateau.

Introduction

The 50,000 square-mile Columbia Plateau region of north-central Oregon, south-central Washington State, and northern Idaho contains one of the driest as well as one of the most productive areas for dryland wheat in the world. Mean annual precipitation on the Columbia Plateau ranges from as little as 150 mm near the confluence of the Snake and Columbia Rivers in central Washington State to as much as 710 mm near the Washington-Idaho border (Phillips, 1965). In drier areas of the Columbia Plateau wind erosion is of particular concern; windblown dust generated as a result of some agronomic practices poses a hazard to motorists, pollutes the air in downwind communities, and degrades soil resources by removing nutrient-rich topsoil. In recent years, air quality has become a societal concern in the Western United States, primarily due to the effect of particulate matter in windblown dust on human health. Small airborne particulates known as PM10, or particulate material ≤10 µm in aerodynamic diameter, are small enough to be taken into the body's respiratory system. Epidemiological studies indicate that human exposure to airborne particulate matter is associated with increased mortality and morbidity, primarily by causing or exacerbating existing respiratory problems (Schwartz, 1994; Liao et al., 1999).

Traditional agricultural practices in the 'winter wheat-summer fallow' system that is employed on 1.5 million ha of the Columbia Plateau include multiple passes with tillage implements during the fallow cycle, both to create a 10-15 cm dust mulch layer designed to minimize soil moisture losses due to capillary action and to manage weed populations (Schillinger and Young, 2004; Stetler and Saxton, 1996). Emission of PM10 from landscapes depends both upon the physio-chemical characteristics of soil as well as those environmental factors that affect particle entrainment, e.g. wind speed, topography, vegetative cover, surface roughness. High winds and low rainfall during summer and early autumn create conditions optimal for wind erosion. On the Columbia Plateau, this combination of tillage-intensive fallow practices and dry, windy conditions contributes to wind erosion.

The objective of this research is to quantify sediment loss and PM10 emissions from a silt loam in a low rainfall area of the Columbia Plateau during a simulated wind event following various tillage operations throughout a fallow cycle. Our goal is to provide quantitative information regarding the potential to reduce soil and PM10 loss from fallow fields through the adoption of less intensive tillage practices that can offer crop yields similar to or greater than those obtained from traditional farming techniques.

Materials and methods

Experimental plots were established after harvest of winter wheat in August 2004 at the Washington State University Dryland Agricultural Research Station near Lind, WA. Annual precipitation at this station averages 244 mm. The soil at the experimental site, Shano silt loam (coarse-silty, mixed, mesic, Calciorthidic Haploxeroll), is moderately deep with a 1-5% slope. The experimental design was a randomized complete block with four tillage treatments, each replicated four times. Tillage treatments included: 1) conventional tillage using a sweep implement with overlapping 36-cm wide V-sweeps on 30-cm spacing in August 2004, a chisel implement in October 2004, and two passes with a cultivator with overlapping 20-cm wide V-sweeps on 15 cm spacing in May 2005; 2) moderate tillage using an undercutter with overlapping 80-cm wide V-blades on 75-cm spacing in August 2004 and May 2005; 3) minimum tillage with no autumn tillage and using an undercutter in May 2005; and 4) no tillage in which the plots were undisturbed throughout the fallow period (Table 1). All tillage operations were performed to a depth of 13 cm.

A portable wind tunnel was used to generate air flow over a known surface area in field plots. It is 13.4 m long and has a working section 7.3 m long, 1.2 m high and 1.0 m wide. Power is supplied by a 40 hp Ford industrial gas engine which drives a 1.4 m Joy axivane fan. Detailed information about the wind tunnel can be found in Pietersma et al. (1996).

PM10, saltation, and suspension were measured immediately after tillage operations in August 2004 and May 2005. Measurements were made inside the working section of the wind tunnel and approximately 5.4 m downwind of the leading edge of the tunnel. PM10 was measured using DustTrak™ laser- photometer aerosol monitors at heights between 10 and 60 cm above the soil surface. Saltation and suspension were measured using a 0.75 m high, 0.003 m wide isokinetic slot sampler. Eroded soil collected in the vertical slot sampler for each wind tunnel test was converted to a flux by dividing the mass of soil collected in the slot sampler by the width of the sampler. Each test with the wind tunnel was comprised of a 10-minute sampling interval during which no abrader was added to the air flow and followed by a second 10-minute sampling interval during which abrader (quartz sand 250-500 µm in diameter) was introduced into the air flow at a rate of 90 g m^{-1} min^{-1}. Fan-generated wind speeds were maintained at approximately 15.0 m s^{-1} at 60 cm above the soil surface throughout each trial.

Results and discussion

Dispersed particle size distribution analysis using a Malvern Mastersizer particle size analyzer indi-

Table 1. Description of tillage operations performed in autumn 2004 and spring 2005 in each of the four tillage treatments.

	No tillage	Minimum	Moderate	Conventional
August 2004			Undercut	Sweep
November 2004				Chisel
May 2005		Undercut	Undercut	Cultivate

cated that approximately 26% of the Shano silt loam was less than 10 µm in diameter. The amount of PM10 in the field soil, as determined by dry sieving samples collected throughout the fallow cycle, was approximately 5%. This disparity indicates the ability of fine Shano silt loam particles to aggregate. Aggregation can be caused by several factors including the presence of organic matter, volcanic glass, and carbonates in soil. Organic matter enhances the formation and stabilization of soil aggregates. The Shano silt loam contained less than 1% organic carbon. Thus, organic matter likely contributed little to the aggregation of the fine particles in our study. Layer silicate minerals in soils with low organic matter, however, comprise the bulk of the reactive solid phase and will have the greatest contribution to soil structure. Soils with high volcanic glass content are sometimes considered more susceptible to wind erosion due to poor aggregate stability. Results of a previous study indicated that soils near Lind, WA exhibited more than 15% volcanic glass content in the very fine sand (53 – 106 µm) and coarse silt (20-53 µm) fractions (Marks, 1996). The same study, however, determined that the volcanic glass content of soils on the Columbia Plateau was not directly proportional to wind erosion susceptibility. Calcium carbonates can cause cementation of primary soil particles by forming coatings over or between other soil particles and iron oxides. No carbonates were detected in Shano silt loam samples collected at the experimental site. Thus, the ability of fine Shano silt loam particles to aggregate appears to be due to the physio-chemical bonding of layered silicates that comprise the soil.

Saltation and suspension appeared to be suppressed following post harvest tillage in August 2004 in the no-tillage and undercut plots as compared to conventional tillage plots; however, differences in sediment flux between tillage treatments were not significant (Fig. 1). Differences in sediment flux resulting from various tillage practices were more apparent following primary tillage in the spring (Fig. 2). For example, sediment flux from no tillage plots in spring was significantly lower than flux from all other tillage plots when abrader was added to the air stream. Differences in sediment flux in the absence of abrader were less conclusive, likely due to the absence of suspension-sized particles on the soil surface as a result of a thin soil crust. The formation of the soil crust occurred in response to 8 precipitation events totalling 24 mm between the time of spring tillage and wind tunnel tests in May 2005.

Measured PM10 concentrations were lower in May 2005 than in August 2004 across all tillage treatments (Fig. 3, Fig. 4); most likely due to the presence of a thin crust on the soil surface in May 2005. As expected, in both autumn 2004 and spring 2005, PM10 concentrations were greatest in

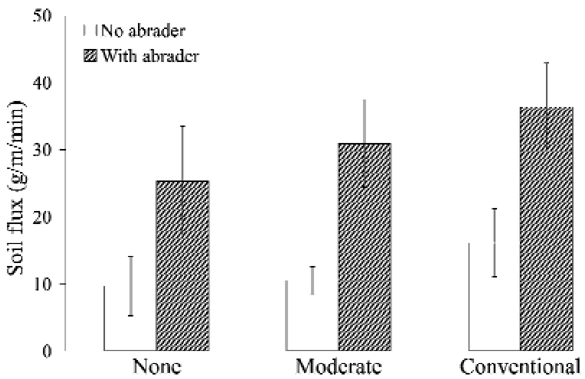

Fig. 1. Mean total suspended particulate emissions and standard deviations for plots with no autumn tillage, moderate and conventional tillage operations as measured in August 2004 using an isokinetic slot sampler inside the wind tunnel.

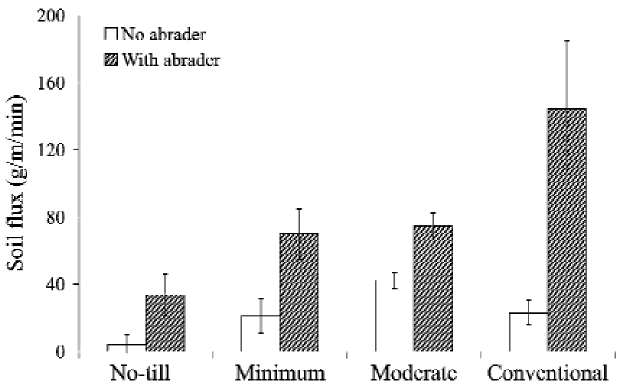

Fig. 2. Mean total suspended particulate emissions and standard deviations for plots with no autumn or spring tillage (no-till), no autumn tillage followed by spring undercut (minimum), autumn undercut followed by spring undercut (moderate), and autumn sweep and chisel followed by spring cultivator (conventional) as measured in May 2005 using an isokinetic slot sampler inside the wind tunnel.

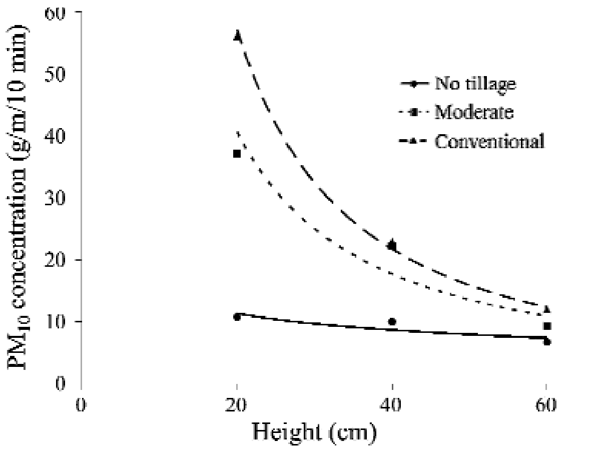

Fig. 3. PM10 concentrations to a height of 60 cm above the soil surface for plots with no autumn tillage (no tillage and minimum tillage plots), moderate and conventional tillage operations as measured in August 2004 using aerosol monitors inside the wind tunnel.

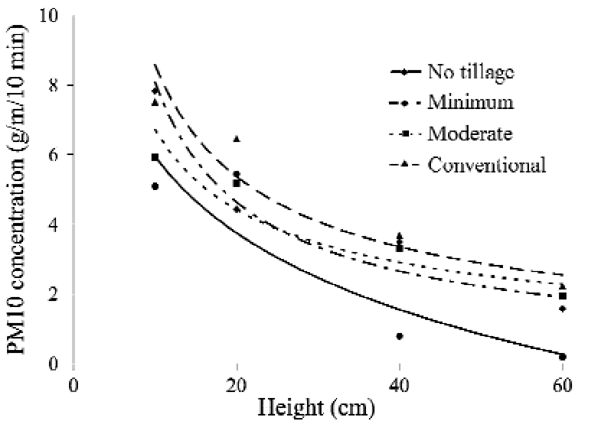

Fig. 4. PM10 concentrations to a height of 60 cm above the soil surface for no tillage, minimum, moderate and conventional tillage operations as measured in May 2005 using aerosol monitors inside the wind tunnel.

plots subjected to the most intensive tillage. More aggressive tillage practices reduced the quantity of standing stubble from the previous year's wheat crop thus increasing the susceptibility of the soil surface to wind erosion (data not shown). Further analyses are necessary to quantify particulate emissions from specific tillage practices; however the PM10 concentration profiles indicate that less intensive tillage practices reduce PM10 emissions from fallow lands.

The percentage of soil aggregates < 840 µm in diameter based on dry sieving with a compact rotary sieve is currently the primary soil parameter used to define wind-erodibility of agricultural soils (Merrill et al., 1999). Field soil samples collected after tillage in August 2004 (Fig. 5) and May 2005 (Fig. 6) were separated into aggregates that were non-erodible (> 0.85 mm mean diameter) and susceptible to creep (0.50 – 0.85 mm), saltation (0.10 – 0.50 mm), and suspension (< 0.10 mm). Analyses of variance indicated no significant difference in aggregate distribution among tillage treatments either in August 2004 or in May 2005.

Soil loss ratio (SLR) was used in this study to describe the relative difference in soil loss among tillage treatments. Soil loss ratio was determined by dividing mean sediment flux from conventional, moderate, or minimum tillage treatments by the mean flux for the no tillage treatment using the equation SLR = Ftillage/Fnotillage, where Ftillage = sediment flux from conventional, moderate, minimum, or no tillage (g/m/min), and Fnotillage = sediment flux from no tillage treatment (g/m/min). The SLR exhibited similar trends across tillage treatments in August 2004 and May 2005 (Table 2). For example, the SLR was highest for conventional tillage as compared to other tillage treatments. Conventional tillage exhibited the highest SLR in May 2005, but only when abrader was introduced into the air stream. When abrader was not introduced into the air stream, the SLR was highest for the moderate tillage treatment (autumn undercut followed by spring undercut).

Table 2. Calculated soil loss ratio (SLR) for Shano silt loam soils following tillage in August 2004 and May 2005.

	No abrader	With abrader
August 2004		
No tillage	1.00	1.00
Minimum	1.00	1.00
Moderate	1.09	1.22
Conventional	1.67	1.44
May 2005		
No tillage	1.00	1.00
Minimum	5.79	2.08
Moderate	7.82	2.23
Conventional	6.30	4.29

It is well-documented that tillage practices have a large impact on soil loss from agricultural lands.

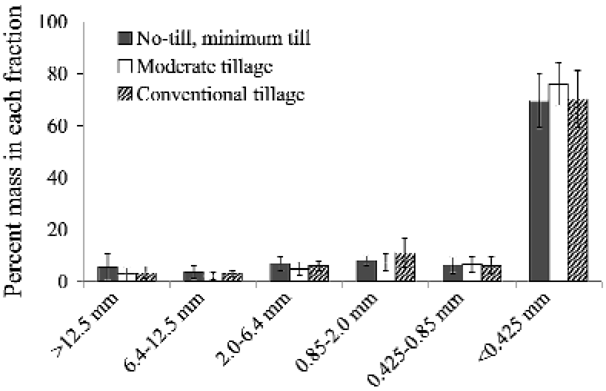

Fig. 5. Mean aggregate size distribution for plots with no autumn tillage (no tillage and minimum tillage), autumn undercut (moderate tillage), and autumn sweep (conventional tillage) tillage operations as measured in August 2004 by dry sieving using a Gilson sieve apparatus.

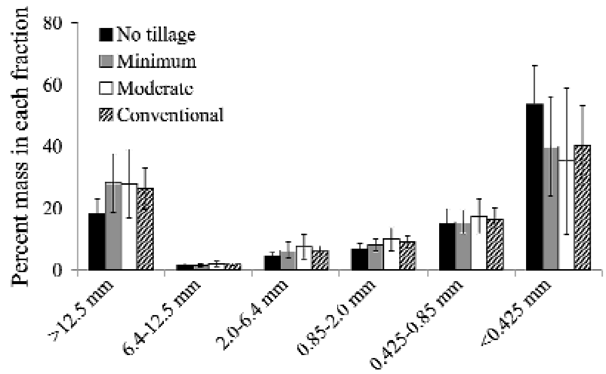

Fig. 6. Mean aggregate size distribution for plots with no autumn or spring tillage, no autumn tillage followed by spring undercut (minimum), autumn undercut followed by spring undercut (moderate), and autumn sweep and chisel followed by spring cultivator (conventional) tillage operations as measured in May 2005 by dry sieving using a rotary sieve apparatus.

Further study is required to quantify differences in PM10 emissions associated with tillage sequences. Our results indicate that less intensive tillage practices, such as the use of a non-inversion undercutter implement rather than a conventional sweep or cultivator implement, may reduce PM10 emissions from tilled fields and improve air quality in agricultural regions.

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Effect of saline water management on rice production and soil improvements in salt accumulated rice field

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Abstract

Possibilities of using poor quality water for the rice growing in salt accumulated fields were examined in two experimental fields of the Agricultural Research Station, El-Sirw, Damietta Province, Egypt in 2003 and 2004 seasons. Rice cultivar 'Giza178' was used in this study. Water quality treatments were: applying mixed water (MW) with salinity level of 1.4 – 1.62 dS m^{-1} throughout each season (T1), applying drainage water (DW) with EC of 4.69 - 5.2 dS m^{-1} throughout each season (T2), applying MW up to the panicle initiation (PI) and then DW up to the end of each season (T3), and applying DW up to PI then MW up to the end of each season (T4). Water-management treatments were: water-saturated condition (0 cm water depth), and 3 and 6 cm standing water depth with a watering interval of four days. The observed parameters were: Na^+, Ca^{+2}, K^+ contents in rice leaves, leaf area index , dry matter production per m2, grain yield, soil EC, soluble cations Ca^{+2}, K^+ and Na^{+2} at the end of each season. All the parameters studied were significantly affected by both water management and water quality treatments. The soil chemical condition and rice productivity were better under the treatment of 6 cm water depth at four-day intervals. The treatment T1 with 6 cm standing water depth, gave the best results from the viewpoint of rice production and soil traits. Treatment T3 scored the second rank, followed by the treatment T4. Treatment T2 stood at the last rank. The water-management treatment of 6 cm standing water depth reduced Na^+ and salinity level of saline paddy soil with the treatments T1 and T3

Introduction

Out of about 1500 million ha cultivated area in the world, approximately 18% is under irrigation (Schultz, 2001). It is estimated that land degradation due to secondary salinization is of the order of 15~30% of the irrigated areas (Ghassemi et al., 1995). In the arid zones, such as in Egypt, there are parts which have limited supplies of good quality waters, so it becomes necessary to irrigate with saline water. Growing rice crop under salt-affected soils using poor quality irrigation water such as drainage or mixed water leads to secondary salinization. Obviously, the poor quality and inadequate drainage facilities contribute largely to salinity problem in rice paddies. Soil salinity is a major environmental factor that adversely affects plant growth and yield of rice crop in Egypt.

Biswas (1987) indicated that plant height, panicle number, 100-grain weight and grain yield of rice significantly increased with increasing soil submergence level up to 10 cm. Also, he found that EC values and panicle sterility decreased with increasing submergence levels. Hangoven et al. (1987) reported that applying 5 cm water per week was necessary for good yields. Interestingly, rice crop had reasonably good growth and yield attributes under soil submergence with saline water. The EC values at all growth stages were reduced as irrigation intervals were narrowed with an irrigation depth of 7 cm (Zayed, 1997). However, continuous irrigation with saline water resulted in a decrease in growth, grain yield and yield attributes of rice (Soliman et al, 1993; Mohaiudden et al., 1997 and 1998; Sultana et al., 2001; Shehata, 2004). Na^+ content of soil was significantly increased when poor quality water was continuously used; while the effect on K^+ and

Ca^{2+} content was inconsistent under such circumstances (Abd-alla, 1995; Al-Nabulsi, 1998; Atwa, 1999). Use of mixed water, instead of only the poor quality or saline water, was found to be satisfactory to reduce salt accumulation and produce reasonable grain yield under salt-affected soils.

Regarding the sensitivity of rice plants at different growth stages it was found that the effect of saline water was more pronounced at the early growth stages (Leland et al., 1994; Atwa, 1999). The effect was less hazardous at late growth stages, as the plants become more tolerant (Mohaiudden et al., 1998). However, the information on the benefits of the alternate applications of poor and good quality water for irrigating paddy rice on the salty clay soils of Nile Delta is scanty and not well documented. The objectives of this study were to (a) find out the best way of using poor quality water for irrigation to increase water use efficiency of rice and reduce the hazardous effects on soil and (b) provide technical information to the farmers for better management of the poor quality water on the farm level.

Materials and methods

Two field experiments were conducted during 2003 and 2004 with salt-tolerant rice cultivar (*Oryza sativa* L.) 'Giza 178' at the agriculture research station, El-sirw, Damitta province, Egypt (Fig. 1**)**. The station is located at the 31° 33´ N latitude and 31° 72´ E longitudes. The soil was clayey with salinity level of 9.0 and 8.0 dS m^{-1} in 2003 and 2004, respectively. The experiments were arranged in split-plot design with four replications. The main treatments (ponded water depth) were: R0-irrigation to get continuous saturation of the profile (0 cm depth of standing water), R3-irrigation to get 3 cm standing water depth and R6-irrigation to get 6 cm standing water depth. Watering was done after every four days. The subtreatments related to water quality and were: T1-mixed water (MW) with salinity levels ranging between 1.9 and 1.92 dS m^{-1} used throughout the season, T2-drainage water (DW) with salinity range of 4.69 - 5.2 dS m^{-1} used throughout the season, T3-MW up to panicle initiation (PI) + DW from panicle initiation up to the end of season, and T4-DWup to PI + MW from panicle initiation up to the end of the season..

The meteorological data of the studied site during the growing seasons are shown in Table 1. The chemical analysis for the irrigation water is presented in Table 2.

Standard agricultural operations such as land preparation, fertilizer application, weeding and planting date were adopted for all treatments. Nitrogen was applied at the rate of 150 kg ha^{-1} as urea in splits doses; phosphorus at 36 kg ha^{-1} as calcium mono-phosphate, and Zinc sulphate at 50 kg Zn ha^{-1} before transplanting. One month old seedlings were transplanted at 20 × 20 cm spacing in each treatment. Each plot was completely isolated from the other using wide borders and a plastic sheet to prevent lateral movement of water.

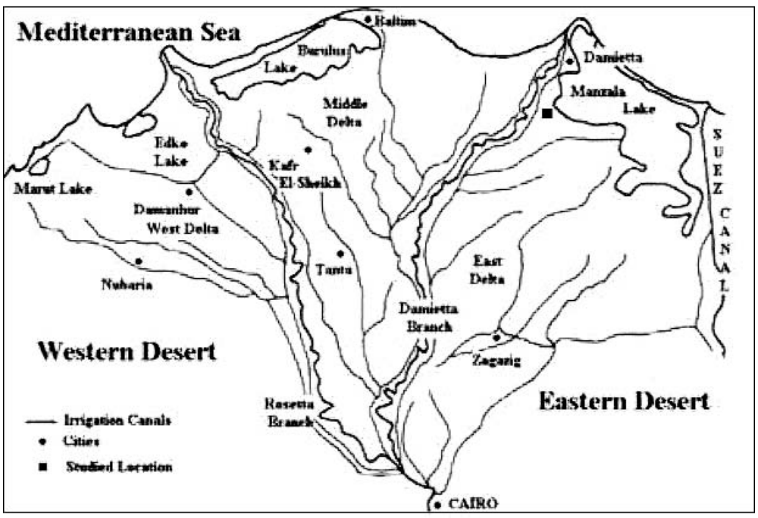

Fig. 1. Map of Nile Delta showing the location of the study area.

Table 1. Metrological data, ETa, ETp (mm d^{-1}) and crop coefficient (Kc) at El-Sirw during the study period

Season month	Ave. temp. (°C)	Ave. humidity (%)	Wind velocity (km d^{-1})	Sunshine hours	Duration (Day)	ETa[(1)] mm d^{-1}	ETp[(2)] (mm d^{-1})	Kc
				May 17 – Sept. 30, 2003				
May	23.6	60.45	106.7	12.0	14	7.60	5.49	1.384
June	26.1	64.95	89.3	12.1	30	8.20	5.75	1.426
July	26.3	68.50	100.0	12.3	31	8.40	5.77	1.456
Aug.	26.8	73.15	85.3	11.6	31	7.50	5.38	1.394
Sept.	25.5	68.60	99.0	10.5	30	6.50	4.70	1.383
Average	25.7	67.1	96.1	11.7	27.2	7.6	5.4	1.407
Season				May 16 – Sept. 30, 2004				
May	20.5	58.0	108.0	12.0	15	7.01	5.03	1.394
June	24.3	65.3	119.0	12.0	30	7.80	5.61	1.390
July	25.8	67.0	103.0	12.4	31	8.10	5.74	1.411
Aug.	26.8	67.7	86.3	10.5	31	7.20	5.13	1.404
Sept.	25.1	67.8	99.6	9.5	30	6.40	4.70	1.362
Average	24.5	65.2	103.2	11.3	27.4	7.3	5.2	1.404

[(1)] ETa: Actual evapotranspiration, [(2)] ETp: Potential evapotranspiration using Penman-Monteith method

Table 2. Chemical analysis of mixed and drainage water as an average over two seasons

Water status	$pH_{1:5}$	$EC_{1:5}$ (dS m^{-1})	Cation (meq L^{-1})				Anion (meq L^{-1})			$SAR_{1:5}$
			Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	
Mixed water	8.1	1.90	9.0	0.50	4.0	6.0	4.0	7.63	9.26	4.03
Drainage water	8.0	5.52	36.0	0.33	11.3	12.6	7.3	16.9	36.0	10.41

For determining leaf area index (LAI) and dry matter accumulation (DM), five random plants were cut just at the soil surface at 85 days after transplanting (DAT). They were carefully washed with deionized water, and used for leaf area measurement and DM determination. For estimation of mineral concentration, oven dry samples of 85 days old plants were digested by HNO_3-$HClO_4$ and Na^+, Ca^{2+}, K^+ were analyzed by atomic absorption spectrometry (Mitusui et al., 1999). Fifteen random plants were selected from each plot at harvest to determine the plant height, tiller number, panicle number per hill, panicle length, filled grains per panicle, sterility percentage and 100-grains weight. Rice grain yield was determined from the produce of a 25 m2 area from the center of each plot. The plants were air-dried for about 3 days, threshed and the weight of grains recorded at 14% moisture content basis as described by Wang et al. (1997). EC was determined in the field using portable EC-meter. The methods employed for chemical analyses were as per Jackson (1967).

The amount of water applied (mm) was measured by parshall flume (20 ×90 cm). Water use efficiency (WUE) was determined as the grain yield weight (kg) produced per unit volume of applied water (m^3) as per Michael (1978). The consumptive use of water was determined using a tank of 60 cm diameter and 110 cm length, placed in the center of the experimental field surrounded by a buffer area of paddy, representing the actual microclimate. Three tanks were used for the measurement of consumptive use of water for each treatment. First tank had a closed bottom, and rice plants were grown on soils in the tank to measure the evapotranspiration. Second tank also had a closed bottom but without plants to measure evaporation. Third tank had open bottom and rice plants were grown in it to measure both evapotranspiration and water percolation. At the start of experiment, the water level in each tank was set at 10 cm above the soil surface. It was then measured daily to determine water losses, and brought back to original level. Rice plants were transplanted in the two tanks on the same day as the transplanting in the field (Abou El Hassan et al., 2005).

The data were statically analyzed using the MSTAT software (1989) and the mean differences were compared using LSD test according to Gomez and Gomez (1984).

Results and discussion

Effect of depth of water and quality treatments on growth characters

Leaf area index (LAI), dry matter production (DM), number of tiller m^{-2} and days to heading showed significant variation because of the treatments (Table 3). The LAI, DM and number of tillers increased as flooding depth increased. As the soil was saline, under low water input, the salinity hazard and water stress might have inhibited the production of growth regulators, which resulted in smaller leaf area, reduced photosynthesis and thus less dry matter production (Kashem et al., 2000). A submergence level of 6 cm resulted in the earliest heading. Lower submergence levels delayed the phonological development and flowering perhaps by accentuating salinity stress as has also been reported by Zayed (2002).

Irrigation water quality treatments also affected the rice growth significantly (Table 3). The crop growth under mixed water treatment (T1) was better than with drainage water applied through out the season (T2). Leaf area index, DM and number of tillers m^{-2} reduced by 16.6, 18.1 and 32.7% respectively, by T2 as compared to T1. Mixed water up to PI + DW till maturity (T3) showed a little decrease in rice growth and dry matter production, followed by T4 (DW up to PI + MW up to the end of the season) treatment. This may be due to high salinity level and Na^+ content in the DW at the beginning of the season.

Effect of water depth and quality treatments on yield components

All the yield components (Table 4) were significantly affected by ponded water depths except panicle length during 2004 season. All yield components increased with increasing ponded water depth except sterility %. The results are in agreement with those reported by Biswas (1987) and Hangovan et al. (1987).

Water quality treatments also affected the yield components significantly. T1 gave best results followed by T3 and T4. Using DW over all the season (T2) sharply decreased all the yield components. For example, the average reduction in number of panicles was 36.5, 14.1 and 30.2%, while reduction in filled grains was 29.71, 7.67 and 24.12% for T2, T3 and T4, respectively as compared to T1. The number of panicles also reduced severely under poor quality water. It can be inferred that irrigation with drainage water might have created unfavourable condition for plant growths by enhancing Na+ accumulation and increasing salt stress. Saline water irrigation has been reported to reduce dry matter accumulation by lowering assimilate production and its transfer from stem or sheath to grains, restrict panicle formation and grain filling; and promote the early senescence leading to a decrease in rice grain yield (Zayed, 2002).

Table 3. Leaf area index (LAI), dry matter production (DM), tiller number and heading date as affected by water depth and quality treatments under salt-affected soil

Treatments	LAI		DM (g m^{-1})		Tillers number per m^2		Days to heading	
	2003	2004	2003	2004	2003	2004	2003	2004
Water depth (R)								
0 cm	3.73	4.19	496.3	505.6	382.8	329.0	91.9	92.3
3 cm	4.18	4.58	527.8	525.6	409.5	359.4	91.8	92.5
6 cm	4.94	5.17	595.1	599.9	448.5	451.5	90.3	90.2
LSD (0.05)	0.19	0.17	13.8	16.7	17.0	33.0	1.0	1.2
Water quality (T*)								
T1	4.73	5.04	588.3	596.9	481.3	481.0	89.8	90.3
T 2	3.88	4.27	481.7	489.3	362.5	285.5	93.3	92.6
T 3	4.53	4.79	563.6	565.0	431.3	410.4	90.0	91.4
T 4	3.99	4.49	525.4	523.7	379.3	343.8	92.3	92.5
LSD (0.05)	0.17	0.16	13.3	17.1	41.5	37.5	1.2	1.0
R×T interaction	ns	ns	**	ns	ns	ns	ns	ns

**T1=Mixed water overall season (MW), T2=Drainage water overall season (DW), T3=MW to panicle initiation + DW to harvest and T4=DW to panicle initiation + MW to harvest.*

Effect of water depth and quality treatments on Na^+, Ca^{2+} and K^+ content in rice leaves

Na^+, Ca^{2+} and K^+ content (Table 5) in rice leaves was significantly affected by ponded water depths in both seasons. Increasing submergence level significantly increased Ca^{2+} and K^+ contents and reduced Na^+ contents. It seems that lack of ponding of water allowed more Na^+ accumulation in soil and resulted in higher external Na^+ concentration in contrast to Ca^{2+} and K^+ concentration leading to more Na^+ uptake. Mohamed et al. (1987) stated that high external Na+ in soil reduced Ca^{2+} uptake and more Ca^{2+} and K^+ content in rice leaves enhanced salinity tolerance. The content of Na^+, Ca^{2+} and K^+ in rice leaves was also markedly affected by the water quality treatments in both the seasons. The use of mixed water through out the season (T1) restricted Na^+ uptake, while Ca^{2+} and K^+ uptake increased in contrast to the drainage water treatment (T2). Also, the irrigation with DW up to PI + MW up to the end of season did not improve Ca^{2+} and K^+ content in leaves against Na^+ content. High Na^+ content in rice leaves reduced photosynthesis rate, lowered growth and decreased the grain yield. Reducing Na^+ content is very important way to enhance the tolerance of rice to salt hazard (Mohamed *et al.*, 1987).

Effect of water depth and quality on chemical composition of soil

Table 6 showed that ponded water depths had significant effect on soil Na^+, Ca^{2+} and K^+ concentrations as well as salinity levels. Increasing flooding

Table 4. Yield components as affected by water depth and quality treatments under salt- affected soil

Treatments	Plant height (cm)		Panicles number/m^2		Panicle length (cm)		Filled grains/panicle		Sterility (%)		100-grain weight (g)	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Water depth (R)												
0 cm	82.6	76.4	339	283	17.0	18.8	79.3	81.3	18.4	19.3	18.1	18.2
3 cm	86.2	80.8	364	339	18.0	19.1	89.1	93.7	16.8	18.1	18.8	18.8
6 cm	90.5	84.5	406	419	20.0	19.2	115.9	119.3	12.2	14.0	20.1	19.9
LSD (0.05)	2.54	2.45	28.8	49.3	1.0	1.0	4.95	3.87	1.56	1.15	0.40	0.7
Water quality (T*)												
T1	90.5	83.5	440	458	20.0	19.8	114.7	110.8	12.8	13.3	19.9	20.1
T 2	81.6	77.5	310	260	16.0	18.2	76.8	81.7	21.6	22.9	18.1	18.0
T 3	90.4	80.3	394	377	18.0	19.5	104.8	103.4	12.8	13.7	19.2	19.1
T 4	83.2	81.0	335	292	18.0	19.3	82.8	88.3	15.9	18.6	18.8	18.7
LSD (0.05)	2.44	2.29	31.9	40.0	1.0	0.7	6.59	3.32	1.07	1.08	0.62	0.6
R×T interaction	ns	ns	ns	ns	ns	ns	**	ns	**	**	ns	ns

**T1=Mixed water overall season (MW), T2=Drainage water overall season (DW), T3=MW to panicle initiation + DW to harvest and T4=DW to panicle initiation + MW to harvest.*

Table 5. Na^+, K^+ and Ca^{2+} in leaves of rice crop as affected by water depth and quality treatments under salt-affected soil

Treatments	Na^+ (mg g^{-1})		K^+ (mg g^{-1})		Ca^{2+} (mg g^{-1})	
	2003	2004	2003	2004	2003	2004
Water depth (R)						
0 cm	3.41	3.28	5.58	5.95	1.02	1.08
3 cm	2.98	3.22	6.05	6.10	1.09	1.38
6 cm	2.42	2.87	6.57	6.72	1.36	1.63
LSD (0.05)	0.29	0.12	0.23	0.07	0.08	0.06
Water quality (T*)						
T1	1.34	1.98	6.74	6.92	1.04	1.74
T 2	4.04	4.19	5.48	5.69	1.00	1.13
T 3	2.51	2.61	6.25	6.51	1.19	1.30
T 4	3.35	3.75	5.79	5.91	1.06	1.27
LSD (0.05)	0.38	0.14	0.17	0.12	0.04	0.08
R×T interaction	ns	ns	ns	ns	ns	ns

Table 6. EC, Na^+, K^+ and Ca^{2+} in soil as affected by water depth and quality treatments under salt-affected soil

Treatments	Na^+ (mg g^{-1})		K^+ (mg g^{-1})		Ca^{2+} (mg g^{-1})		$EC_{1:5}$ (dS m^{-1})	
	2003	2004	2003	2004	2003	2004	2003	2004
Water depth (R)								
0 cm	57.2	57.0	0.61	0.44	7.53	7.03	6.6	6.0
3 cm	49.0	49.4	0.67	0.50	7.93	7.59	5.9	5.5
6 cm	37.9	39.7	0.74	0.56	10.3	9.16	4.9	4.9
LSD (0.05)	4.90	3.27	0.03	0.03	0.39	0.32	0.27	0.30
Water quality (T*)								
T1	34.1	33.7	0.76	0.62	9.97	9.50	4.2	4.1
T 2	68.6	67.8	0.57	0.42	7.34	6.23	7.4	7.3
T 3	38.4	41.1	0.70	0.49	8.99	8.54	5.0	4.6
T 4	51.1	52.5	0.64	0.47	7.98	7.43	6.6	5.9
LSD (0.05)	3.45	6.60	0.03	0.03	0.54	0.32	0.41	0.5
R×T interaction	ns	ns	ns	ns	ns	ns	ns	ns

**T1=Mixed water overall season (MW), T2=Drainage water overall season (DW), T3=MW to panicle initiation + DW to harvest and T4=DW to panicle initiation + MW to harvest.*

depth consistently reduced Na+ concentration in soil, while Ca^{2+} and K^+ content increased. The results are in agreement with those obtained by Biswas (1987) and Zayed (1997). Water quality treatments affected the mean values of Ca^{2+}, K^+, Na^+ contents and EC level in order; T2< T4< T3< T1 irrespective of irrigation treatments. T1 gave lowest values of Na^+, while maintaining higher content of Ca^{2+} and K^+. It shows that the salinity level in the soil can be reduced either by intermittent irrigation with fresh and saline water or by using water with low level of salinity instead of poor water. Drainage water increased Na+ accumulation and reduced available Ca^{2+} and K^+ content in soil. High Na+ contents in soil produced more Na^+ uptake, less Ca^{2+} and K^+ uptake, less growth and low grain yield. It can be concluded from the data that submergence level of irrigation under salt affected soil has to be increased up to 6 cm as maintaining saturation level is not sufficient under such circumstances. The substitution of DW to MW at late growth is possible with little yield reduction.

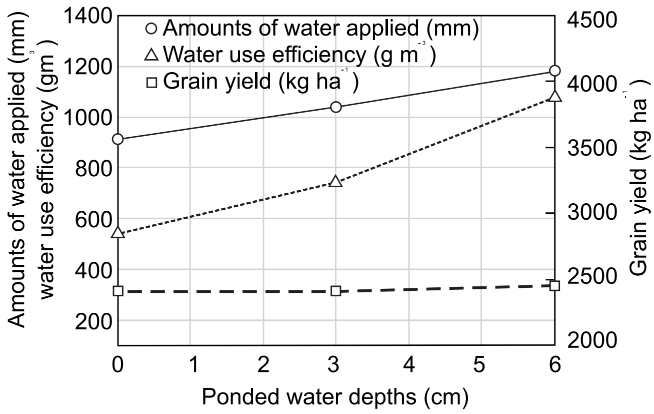

Fig. 2. The effect of ponded water depth on amounts of applied water , water use efficiency and rice yield in 2003 experimental season.

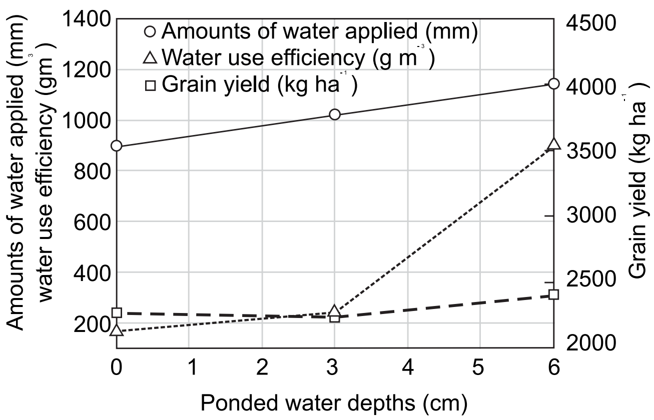

Fig. 3. The effect of ponded water depth on amounts of applied water , water use efficiency and rice yield in 2004 experimental season.

Effect of water depth and quality treatments on yield and water use efficiency

The depth of ponded water and its quality affected significantly the grain yield and WUE. The mean values for amount of applied water (mm) in both seasons increased with increasing levels of ponded water depth (Figs. 2 and 3**).** The ponded water depth increased rice grain yield (Figs. 2 and 3) with all quality treatments during both the seasons. WUE values were also higher under 6 cm ponded water depth than under 0 or 3 cm water depth. The variations in the mean grain yield affected the WUE more than the amount of water applied. The effect of water quality on grain yield is illustrated in Figs. 4 and 5**.** The yield was in the order: T1 > T3 > T4 > T2, in both the seasons.

Crop coefficient values

As shown in Table 1, the monthly average values of crop coefficient (Kc) for rice calculated during 2003 seasonal, based on Modified Penman method, were 1.384 (May), 1.426 (June), 1.456 (July), 1.394 (August) and 1.383 (September). While, for 2004 seasonal Kc values were 1.394 (May), 1.390 (June), 1.411 (July), 1.404 (August) and 1.362 (September). These results indicated that the value of Kc was lowest at early stage of growth and increased gradually up to the maximum in mid of season (grain filling stage) and then decreased at maturing stage.

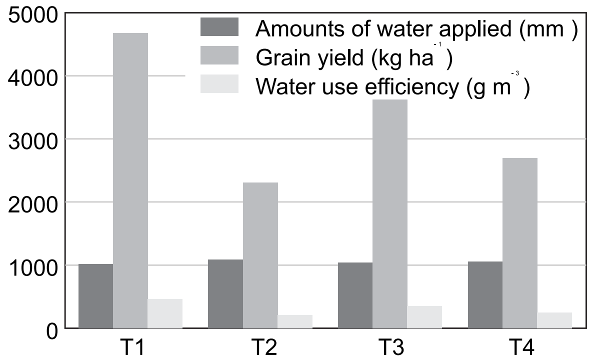

Fig. 4. The effect of water quality treatments on amounts of applied water, water use efficiency and rice yield in 2003 experimental season.

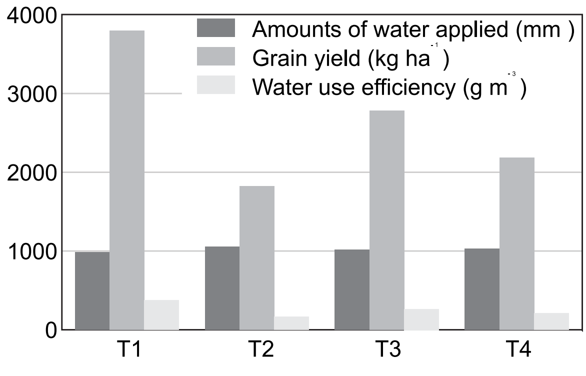

Fig. 5. The effect of water quality treatments on amounts of applied water, water use efficiency and rice yield in 2004 experimental season.

Conclusions

a) The use of MW at early growth stage and its substitution by DW at late growth stage is preferred for rice growth under saline soil condition. Also, a flooding depth of 6 cm is recommended when poor quality water is to be used for irrigation under salt affected soils, which helps to affect better leaching of salts. Maximum grain yield (4.68 and 3.90 t ha^{-1}) was obtained when submergence level of 6 cm was applied with MW through out the growing season.

b) High sodium and low Ca^{2+} and K^{+} contents in rice leaves negatively affected rice growth, dry matter production, yield components and grain yield. It is recommended that more water should be used for irrigation under saline soil or while using saline water to improve Ca^{2+} and K^{+} content in rice leaves.

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Terracing, an effective solution to the problem of soil erosion and food deficiency in the hilly area of Loess Plateau

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Abstract

Severe soil erosion and absolute poverty have been the most significant problems threatening sustainable development of the Loess Plateau in China. These two factors are always interlinked and usually reinforce each other. The situation in the hilly areas, which cover a major part of the Loess Plateau, has been even more unfavorable. In order to protect land resource and obtain securer harvest, farmers here have developed an effective terracing system, which remarkably alleviates soil erosion, food deficiency and poverty. The case of Zhuang-Lang County, Gansu province, located in the hinterland of the Loess Plateau, well demonstrates the success of this system. Recognizing that the traditional agricultural practices on its wide-spread sloping land could not produce enough food for its people, the county authorities launched a terrace-construction movement since 1960s, which has run for nearly four decades. The Zhuang-Lang people have converted all of their sloping land into high standard terraces, which greatly reduced soil erosion and also built up a secure base for agricultural production. This paper documents the unique achievements of terrace building at such a large scale, and also analyses its costs, benefits and functions in ecological, economic and social context. A future prospect and some of the underlying implication of terrace building are briefly discussed.

Introduction

China's Loess Plateau has the most severe soil erosion in the world, which poses significant threat to sustainable development of the region. The situation in the hilly part, which constitutes most of the Loess Plateau, has been particularly unfavorable. Massive topsoil loss often results in not only local environmental degradation and more fragmentized landscape, but also gives rise to heavy load of sediment in the distributaries of the Yellow River. The annual total sediment load of the river is 1.6 billion tons, 90 percent of which comes as soil erosion from the Loess Plateau (Kleine, 1997). In additional to this environmental problem, the people of this area have been suffering from food insecurity and chronic poverty. The Plateau is considered to be one of the least-developed regions in China. Malnutrition was once very common among local rural inhabitants due to food shortage. The environmental degradation and socio-economic problem are always interlinked and usually reinforce each other. Continued degradation of farmlands and water resources can only deteriorate local living standards and economic conditions, while poor economic status will not allow further input for environmental improvement. In order to protect land resources and obtain securer harvest, people here have developed an effective terracing system, which has remarkably alleviated soil erosion, food deficiency and poverty. The case of Zhuang-Lang County, Gansu province, PRC, presented here, demonstrates the success of this system.

This paper analyses the ecological, economic and social impact of the practice and discusses the prospect and some of the underlying implication of terrace building as a means for water and soil conservation and food security.

The Loess Plateau and its challenges

The Loess Plateau takes its name from the thick deposits of windblown dust and silt, called loess, that originate thousands of kilometers away on the steppes of Central Asia. Although Loess is distributed throughout many areas of northern China, the greatest concentration of loessal soils are in north-central part, covering most of Gansu, Shaanxi, Ningxia, Shanxi, and parts of Qinghai, Inner Mongolia, and Henan, which are all along upper and middle reaches of the Yellow River. This highland, the Loess Plateau, averages 1000 m in elevation and encompasses an area of 0.62 million km^2 with the typical loess area of 0.42 million km^2 (Luk, 1990-1991; Liu, 1999).

The loess soil is a geologically recently-deposited, fine-grained yellowish material that is loosely cemented by calcium carbonate. It has depths of 50-200m, extending to 330 m near Lanzhou. The soil is usually homogeneous and highly porous, and is traversed by vertical capillaries. The infiltration rate is high, over 1 mm min^{-1}(Liu, 1999). The unique nature of loess soil provides not only favored conditions for high agricultural productivity, but also potential threat of severe environmental degradation if the land were managed in an unwise manner.

Human factors accelerate the erosion process. The Loess Plateau region is acknowledged as the cradle of Chinese civilization. For over 2,000 years, human activities have been both chronically and commonly damaging the environment of the Plateau (Veeck et al., 1995). Population increase is one of the most important factors in the land degradation process. Since small proportion of flat area of the region usually could not yield enough food for its increasing population, more and more marginal slopes were exploited for production (Fig. 1). With the traditional neglect and abuse of the fragile slopy lands, erosion on hilly areas of the Plateau became more severe.

The rainfall of the area had an extremely important role in affecting erosion pattern and the farming practices in the Loess Plateau region. Although the Plateau has a low rainfall, an average of 250-550 mm a year, up to 40% could fall in a single storm. Concentrated rainstorms hitting the erodible loessal soil cause tremendous erosion. According to a survey by Chinese Academy of Sciences, erosion covers 45% of the area of the plateau and the average soil loss is 3720 ton km^2 yr^{-1} (Liu, 1999). Moreover, approximately 60% of the annual precipitation occurs between July and September, which is not the period when crops need water the most (Yang, 1990). Farmers here have to find solutions to cope with these problems of moisture deficit by employing cultivation techniques that may promote infiltration and conservation of the rainwater in the soil profile for better crop production.

Erosion on the plateau affects both the local area and the surrounding region. Locally, as these areas erode, nutrients in topsoil are washed away, soil

Fig. 1. Sloping land in Qing'an County. July 2005. (Photo: D.W. Zhang)

structure is broken up, and water retention is low, which together lead to poor and unreliable harvests. Erosion also gradually reshapes the flat terrain and helps the formation of deep gullies and steep slopes on the Plateau. Furthermore, heavy load of sediment discharged into tributaries of the Yellow River has been causing the riverbed to rise by more than 10 cm every year and exceeding the banks' land elevation by more than 10 m in certain areas. This is badly threatening property and life safety in the lower reaches of the river.

To mitigate this environmental degradation, the Chinese government started promoting soil conservation and rural development measures since the 1949 revolution. The main conservation practices recommended included afforestation for creating permanent ground cover, contour farming, mulching with different materials, and terrace building. However, the implementation of a strategy to deal with erosion problem is complicated by the conflicting demands for environmental stability and economic improvement. Despite the fact that the government has been tirelessly advocating soil and water conservation, implementation is still far from satisfactory. One of the ambitious strategies launched by the Chinese Government in late 1990s of converting all of steep sloping cropland (> 25°) into forestry and grassland in western China did not succeed, at least in mid-Gansu in 2004.

Terracing as a viable solution to prevent soil erosion and increase crop production on sloping lands

Although many options are available to reduce soil losses, terracing is the most popular (Chen et al., 2001). Growing perennial forage instead of crops on sloping lands was clearly unrealistic for traditional farming system prevailing in northern China. In an area where even simple vegetarian diets were not securely available, forage became a luxury because of its high energy loss through animal husbandry. Retaining stubble on the soil surface is one of the best methods of conserving soil in these areas. But it alone is often not adequate. Any attempts of sparing sloping lands from grain production have proven unfeasible, as they go against the traditional farming techniques in the area. The issue, therefore is how to grow crops on slopy lands in a sustainable way. Terracing provides this possibility.

Terracing, which is basically grading steep land, such as hillsides, into a series of level benches, was practiced thousands of years ago in such divergent areas as the Philippines, Peru, and Central Africa. Today, terracing is of major importance in Japan, Mexico, and parts of the United States, while many other nations use this method to alleviate water and soil loss in some of their areas (Ramos and Porta, 1997). However, in China it is more common than anywhere else in the world. Terraced fields can be seen north and south China. Evidence has shown that agricultural terracing in the northern region has been continually practiced for at least 3,000 years (Kleine, 1997).

Many research results have shown the effectiveness of terraces on soil and water conservation and in increasing agricultural production. Using bench terraces increased water storage by about 5 cm at Akron, Colorado, and sorghum yields increased by about 112 kg/ha (Brengle, 1982). A later study in St Lucia also indicated that the terraced system was effective in minimizing runoff and soil loss on hillside lands (Madramootoo and Norville, 1993).

A ten-year study on the sloping fields at Suide Soil and Water Conservation Station in the Loess Plateau has proven that the level terraces reduce soil loss by 87.6%-95.0% and runoff by over 92.4% of that occurring from non-terraced land (Zhao, 1996). Scientists in the Gansu Academy of Agricultural Sciences (GAAS) observed remarkable crop yield increases in a small watershed, called Gaoquan (9.2km^2) in Dingxi, Gansu province by monitoring harvests from both terraced lands and non-terraced slope lands (Table 1). However, almost all of the available literature about the effect of terracing has been based on either experiments or on surveys on a relatively small scale. Promising experimental results in a limited area can not always ensure instantaneous successes in a rather large region considering the complexity of natural conditions and, especially, management factors, which are often not a big concern in the small-scale trials. Very little information was available in the literature on the impact of large-scale terracing on the regional environment and economic development until the Zhang-Lang case study was made.

Table 1. Average yields of main crops grown on terraced and non-terraced sloping lands, based on a five-year (1996 and 2000) survey in Gaoquan Watershed (long-term mean annual rainfall 415 mm) of the Loess Plateau, mid-Gansu.

Crops	Yields from terraced lands (kg/hm²)	Yields from non-terraced slope lands (kg/hm²)	Yield increase by terracing %
Spring wheat	2187.5	1125.3	94.3
Pea	1947.5	1131.5	72.1
Flax	917.3	547.7	67.5
Potato	3317.4	2141.6	54.9
Naked oat	2586.0	1699.5	52.1
Buckwheat	2286.0	1199.5	90.5
Millet	4219.5	2971.0	42.0

Terrace construction in Zhang-Lang County of mid-Gansu

Located in the central part of Gansu Province, Zhuang-Lang County is a typical representative of hilly regions on the Loess Plateau (Fig. 2). Similar to many other places of the Plateau, most of Zhuang-Lang's territory was historically covered by woods, bushes, and grasses. Due to human activities, such as military conflicts, and irrational land use, a majority of vegetation was destroyed. Since ecologically damaged hilly region could not yield enough food for its people, more and more slopes had to be reclaimed for farming purpose. In spite of that, famine occurred in the wake of drought years. Several times, the government had to resort to shipping grain by truck during severe dry spells.

Fig. 2. Location of the study area, Zhang-Lang County, Gansu Province, People's Republic of China.

Although Zhuang-Lang County has an arable land area of 76,000 hm², over 90% is on the hillsides (Table 2). As one of the most populous county on the Plateau, with a population of 409,800 (264 per km2 in 2000), it had to rely on effective management of sloping lands to have a self-sufficient food supply. Recognizing that the traditional agricultural practices could not achieve this goal, the county authorities launched a terracing movement since middle 1960s, which has run for nearly 40 years now and has enabled the Zhuang-Lang people to reshape 97% (67,000 hm²) of their sloping land into level terraces. This has greatly reduced soil erosion and built up a much securer base for agricultural production. This unique work on such a large scale has also changed regional landscape (Fig.3). To acknowledge the extraordinary achievements made, the Zhang-Lang County was honored as "China's Model County in Terrace Construction" by the central government.

Table 2. Classification of land gradient in Zhang-Lang County. (Sources: Zhang-Lang County Bureau of Soil and Water Conservation)

Land gradient	Percentage
< 5°	8.6 %
5°-15°	14.9 %
15°-25°	46.6 %
25°-35°	16.6 %
>35°	13.3 %

The whole course of terrace building in Zhuang-Lang County can be divided into two stages. Each period was featured by different organizing and management methods, as well as styles of construction. The first stage started in 1963, after despairing crop failures in three consecutive years (1960-1962) that caused perishing famine. The wide-spread starvation stimulated people’s determination for terrace construction. About 31,000 people were mobilized for a large-scale terracing project in the winter of 1963. Next year, even larger number of people (58% of the total labor force) worked for the project, because of the centralized social structure, the commune, which made this massive collective work possible. In this period, the terraces were constructed almost entirely by human labor with simple tools, such as shovels, baskets, and small carts as means for soil excavation and displacement. Till the end of 1977, a total area of 18,100 hm^2 sloping lands had been terraced.

The second stage started in 1979 as China launched its rural reform. A new land policy called “household responsibility system” was implemented, which entitled rural farmers long-term land tenure; therefore, they could manage their land individually. Although, this fundamental change advanced China's agriculture, it created new circumstances for terracing and other conservation projects, especially where teamwork is needed. To accommodate this change, the organizing system was then adjusted. Therefore, a 4-U terracing approach was developed, which included unified design, unified implementation, unified standard, and unified appraising. Regulations for collecting labor were also made by the county authorities, which required each working adult to contribute 20 to 40 working days a year for the construction work. A small amount of government subsidy (150 to 450 Yuan, or 18.5 to 55.5 US$, per hm^2) was given to terrace builders as an incentive. Another remarkable progress in this stage was the introduction of machines, mainly bulldozers, which greatly increased the pace and efficiency of terrace construction. By the end of the year 2000, another 49,000 hm^2 of terraces were constructed.

Several distinct characteristics make the huge landscape-changing effort unique:

1) *Maximized terrace adjacency:* Expanded area of terraces can be seen not only on a regional scale, but also on a localized scale such as a valley or a hill. To maximize the effectiveness of terrace system, spatially conjunctive or neighboring slopes need to be leveled simultaneously. Otherwise, runoff from unmanaged

Fig. 3. Terraced landscape in Zhuang-Lang, July 2005. (Photo: D.W. Zhang)

upper slopes can easily damage the newly-constructed, loose terraces below. Rather than having a fragmentally scattered pattern, the size of the most of the localized terrace systems is over 100 *mu*, or 6.7 hm^2.

2) *High standard:* Although different types of terraces are available, such as graded channel terraces, level-ridge terraces, conservation-bench terraces, etc., level-bench terraces are the most effective in terms of water retention and soil protection. This type of terrace consists of a series of level benches without sloping space in between. Almost all the newly-constructed terraces in Zhuang-Lang County are level-bench terraces. Maintenance works, like regular leveling of bench terraces, bund or riser protection, have been done to keep terraces in sound condition.

3) *Continuity:* For nearly four decades, continuous effort has been made by the County and township officials and local farmers in Zhuang-Lang, while in many other regions on the Loess Plateau, construction work halted intermittently for various reasons.

Supporting farming measures on Zhuang-Lang's terrace land

Conversion of sloping lands into terraces requires updated agricultural practices to optimize productivity. A series of improved farming measure has been adopted in the County.

1) *Nutrient management*: Soil disturbances during construction work inevitably redistribute nutrients across profile. As rich topsoil is turned down, less nutrient is available to crops, which usually causes yield reduction. Zhang-Lang's farmers were encouraged to apply more organic fertilizers and commercial phosphate into their newly-built fields to improve soil quality.

2) *Water management*: Soil moisture tends to drop on new terraces due to accelerated evaporation with excavation, displacement, and filling operations. But moisture contents can be recovered and increased in the subsequent period by adopting adequate farming technique. One of the most common water conservation practices on terraced land is mulching. A traditional sand-stone mulching system (Gale et al., 1993) has expanded over a larger area in Zhuang-Lang County, while modern plastic mulching has also been adopted by local farmers. All these mulching measures prevent evaporation, and promote infiltration. Furthermore, a recently developed rainwater harvesting system has also been introduced. The system consists of a synergistic combination of techniques centering on the capture and storage of rainfall from roads, courtyards and artificial catchments for use in dry periods (Cook et al., 2000). All methods together have improved water availability and crop yields. Another development has been to introduce new crops (the first crop on new terraces). Potato is recommended primarily because of its main growing period overlaps with local rainy season. This can partly offset the influence of moisture deficits.

Cost and benefit of terraces

The cost of constructing terrace varies with the way it is built, manually or mechanically. It is also directly associated with the slope. The steeper the slope, the greater the volume of soil to be excavated and redistributed and thus greater the cost of construction. In general, the cost for human-built terraces averaged 1500 working days, or 6000Yaun (750$), based on the payment of market wages for labor in early 1990s. The cost for machine-built terraces was about 6000-7600 Yuan (750-900$). However, when corvee labor is used, as is generally the case, the monetary cost of human-built terraces declines considerably. It is justified on the basis that such contribution will result in better welfare for the local residents. Continuous effort of terrace construction in Zhuang-Lang County has changed regional landscape. Large-scale terrace system has also brought evident environmental and economic benefits to local area and beyond. A survey by Zhang-Lang County Bureau of Soil and Water Conservation indicated that, as more and more terraces were built, both soil erosion and runoff reduced remarkably since 1960s (Fig. 4).

Long-standing problem of food shortage has been eased. Owning to increased available moisture and nutrients on terraced land, as well as the improved farming practices, average grain yield increased 4.2 times, from 600kg/hm^2 in early 1960s (1960-1962) to 2540kg/hm^2 in early 2000s (2000-2004). In spite of the doubling of the population in the

County in last 40 years (from 128 persons per km^2 in 1960 to 276 persons in 2004), the per capita grain availability has doubled, from 160 kg to over 320 kg (Fig. 5), which ensures food security in the County. One may argue that the region is not densely populated when compared to many areas in eastern China. But when the County's population juxtaposed with its limited productivity, the levels of population and population growth are excessive. Therefore, food self-sufficiency in Zhuang-Lang is an extraordinary achievement considering its fragile farmlands.

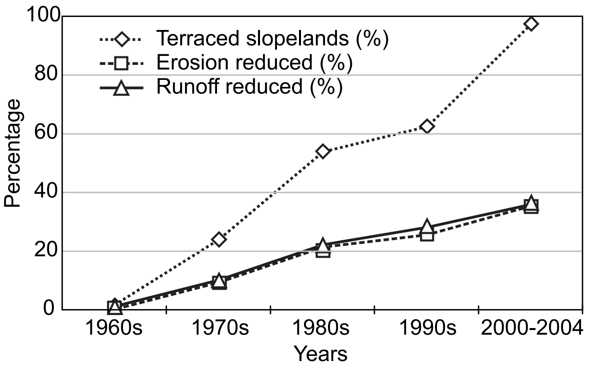

Fig. 4. Environmental effects of terracing project in Zhuang-Lang since 1960s. Terraced sloped lands % is the average terraced area as percentage of the original slope area (68.7 thousand hm^2 in 1960). Runoff reduced % is terrace captured runoff expressed as percentage of baseline runoff; erosion reduced % is terrace reduced erosion as percentage of baseline erosion. Data source: Zhang-Lang County Bureau of Soil and Water Conservation.

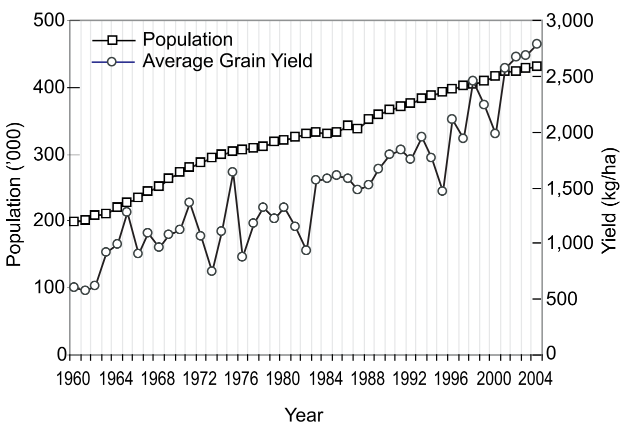

Fig. 5. Average grain yield and population growth in Zhang-Lang during 1960-2004. Data source: Zhang-Lang County Statistics Bureau.

Discussion and future prospect

Success of terrace system in Zhuang-Lang County has confirmed its effectiveness in reducing erosion and improving crop yields on a large scale. However, the income of rural households has not shown commensurate increase with the terrace expansion. This is mainly because of the prevailing subsistence agriculture in the region. As it is a state-designated poor County, the decision-makers here at different levels, as well as the local farmers have a huge challenge to use the terrace land efficiently to generate more income. Instead of growing grain crops, more market-targeted vegetables and fruits can be planted on terraces—as is the case in some townships like Wanquan and Zhudian in the County now. In a long run, policies are needed to create alternative industries for off-farm employment and income in order to offset the pressure of much intensive farming and over-use of natural resources.

The national and regional debate over economic and environmental goals and strategies is no less complex when translated to the local level (Veeck et al., 1995). When it comes to land management, policymakers mainly focus on erosion control for ecological reasons, while local farmers emphasize agricultural productivity and short-run income. It should be noted that terracing is an environment-friendly land-use practice. This explains why farmers prefer terrace construction to many other conservation measures. Terraces are not merely a soil conservation practice, they also serve as improved "soil reservoir" that retains valuable rainwater for better harvest. In general, it is important that a method to achieve soil loss control is compatible with improved efficiency of agricultural production. Otherwise, policy incentives would be necessary to stimulate efficient resource use for promoting sustainable development on the Loess Plateau.

The terracing option may not be adoptable for similar areas else where in China and other parts of the world because it is highly location-dependent. Terrace construction is closely associated with topography, nature of soil, availability of labor, management factors and, most importantly, the economic benefits. For sustainable development of other most eroded and poverty-stricken regions, it would be desirable to develop solutions that are compatible with the prevailing physical and socio-economic conditions.

Acknowledgments

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Global overview of desertification: Perspective from the Millennium Ecosystem Assessment

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Abstract

Desertification is driven by an imbalance between human demand and the supply of benefits by natural systems. It is understood that population growth, inappropriate policies, and some aspects of globalization lead to unsustainable stresses on drylands. A new global evaluation report on desertification developed by the Millennium Ecosystem Assessment (2005) has determined that growing desertification in drylands – which occupy over 40 percent of the world's land area and are home to over two billion people – threatens the homes and livelihoods of millions of poor.

Environmental impacts of desertification are further exacerbated by political marginalization of the dryland poor and the slow growth of health and education infrastructures. This is manifested in poor wellbeing indicators. For example, infant mortality in drylands in developing countries averages about 54 children per 1,000 live births, 10 times higher than that in industrial countries. Income per capita and statistics for nutrient-deficient populations also show similar disparities.

The MA report also highlights the global nature of the desertification challenge. The impacts on the global environment – increasing dust storms, floods and global warming – are well known and documented. There are also alarming impacts of desertification on societies and economies, notably those related to human migration and economic refugees.

The MA report points to a variety of integrated policy options to reverse the decline of drylands while optimizing economic output. These include integrated land use management policies that prevent overgrazing, over-exploitation and unsustainable irrigation practices. Stresses on degraded and at-risk lands can also be reduced by creating new and sustainable livelihood options for dryland populations. These alternative livelihoods – like solar-energy production, ecotourism and saline aquaculture – take advantage of the unique dryland attributes. Inclusion of these approaches in the mainstream national strategies for poverty reduction and combating desertification is essential to success in combating desertification.

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Study on the rainwater outflow of small basin in Loess Plateau

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Abstract

Desertification is becoming a serious problem in the Loess Plateau and requires urgent measures. Tree planting is an important measure for preventing desert encroachment in the Loess Plateau, but it requires dependable water resources. Rain water is a major resource, but much of it is lost as runoff. Capturing the runoff and using it is important for desert prevention programs. This paper aims to clarify the relationship between rainfall and the outflow characteristic. For this purpose, we observed the water level in gully and the rainfall intensity in the chosen small basin. The results helped in clarifying the runoff characteristic of the basin. In addition, we developed a numerical computation model that may reproduce the outflow characteristic of the local basin, and examined its applicability by numerical comparison with the results observed in the field.

Introduction

The Chinese Loess Plateau is a semiarid region. The annual rainfall here ranges from 200mm to 650mm and it gradually decreases from southeast to northwest (Wu et al., 2002). The rainfall distribution is non-uniform within a year, about 60% rain occurs in the wet season, from July to September (Huang and Tang. 1999). Loess Plateau is prone to erosion caused by rain and wind due to poor vegetation cover. Therefore, there is an urgent need to take preventive measures. A tree planting program has been considered as a possible measure to control erosion. For successful implementation of such a program, dependable natural water resources are needed. Estimation of these resources can help in implementing the tree-planting strategy. Therefore, this study was undertaken to clarify the runoff characteristics and to estimate the quantity of water resources on a small basin named Liudaogou, which is located in the northern part of Loess Plateau, as shown in Figure 1. Then the runoff simulation was done for outflow process by using the method of artificial stream networks.

Characteristics of the study location

Loudaogou is located between 110°21′ to 110°23′ E longitude, and 38°46′ to 38°51′ N latitude and at an elevation ranging from 1094.0m to 1273.9m. This basin is located in the Shenmu County, in the western part of Shaanxi, 12km from Shenmu city (Fig.1) (Jiang et al., 2005; Tang et al., 1993).

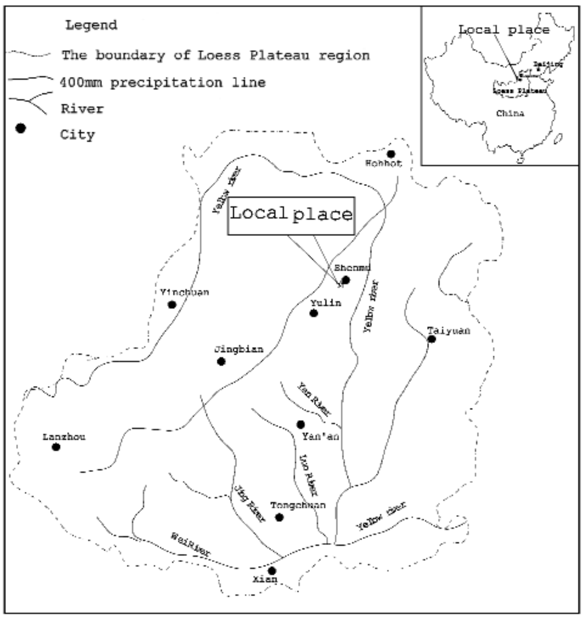


Fig. 1.The position of the study location in Loess Plateau (Liudaogou basin).

The basin is very dry with very little rainfall, but strong winds and clouds of dust are common during the spring and winter seasons. In contrast, there is heavy rain in summer and autumn. Average annual rainfall from 1956 to 1978 was 437.4mm. The subsurface situation is such that the outer layer (15cm) is covered with loose sand yellow ocher, the subsequent layer is thick delicate yellow ocher (Zheng, 2004). The topography of the local basin is complicated and many small gullies of different scale are distributed around the main river channel. Therefore, the Liudaogou basin can really reflect the topographical characteristic of Loess Plateau (Qiao et al., 2001).

Our study in the local basin focuses on the following four issues: (1) gully erosion, (2) ground and soil property, (3) weather condition and the rain characteristic, and (4) the water income and expenditure of small stream area. Many researchers and students from the Chinese Water and Soil Conservation Institute and the Arid Land Research Center, Tottori University, Japan, have studied various local problems in this area and have contributed to the study reported here.

Relationship between rainfall intensity and the runoff

The rainfall intensity was recorded by rain gauge installed at the site used for the study. A water level recorder was installed in the river channel to observe the water level. The catchment area of this basin is about 0.093km^2. From 11 to 22 August 2004, the total rainfall in the local basin was 202.6mm (Fig. 2). The intensive rainfall occurred several times and we chose these intensive rainfall data to perform the runoff calculation. The total precipitation, the greatest flow quantity, the total outflow quantity and the outflow rate are shown in Table 1.

The rain events on 14 and 22 August 2004 were chosen as the typical examples that were separated into long-lasted light rain and short-lasted heavy rain. The relation between the rainfall and the runoff is shown in Fig. 3. In the rain event on 14 August the rainfall period was 25 hours 50 minutes, the average rainfall intensity was 0.14mm/5min and the highest rainfall intensity was 0.8mm/5min. This event can be looked at as an example of long-lasting light rain, compared with the event on 22 August 2004. The total precipitation was more, but because of the low rainfall intensity, the outflow rate was very low, only 3.2%.

The runoff occurred after the rain had fallen for 14 hours 50 minutes. During this period the topsoil was unsaturated and rainfall of 26.2mm had infiltrated into the topsoil. Assuming that the mean porosity of the topsoil was 0.15 and the infiltration rate from the topsoil to the subsequent layer was approximately zero, the depth of the topsoil could be estimated as less than 17.5cm. Based on this result, we adopted the depth of the topsoil as 15cm. The infiltration rate of the topsoil could be calculated, which was more than 0.8mm/5min

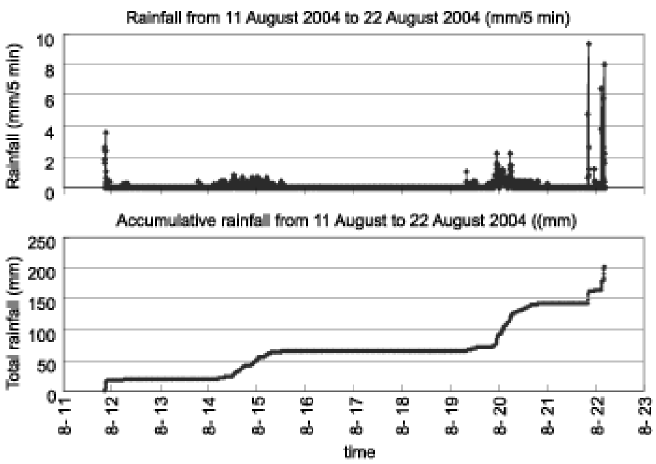


Fig. 2. Rainfall curves.

Table 1: Relation between rainfall and outflow quantity

August 2004 (date)	Rain lasted time	Total rainfall (mm)	Total precipitation (m^3)	The highest rainfall intensity (mm/5min)	The greatest flow quantity (m^3/s)	Total outflow quantity (m^3)	Outflow rate (%)
11	1h	18.4	1705	3.6	0.366	306.7	18.0
14	25h 50min	42	3891	0.8	0.0147	125.5	3.2
21	25min	19.4	1797	9.4	1.075	500.7	27.8
22	1h15min	38	3521	6.4	1.33	965.6	27.4

(2.7×10^{-6}m/s). After the overland flow occurred the runoff curve varied with the rainfall intensity as shown in Figure 3.a.

The rainfall period on 22 August 2004 was only 1 hour 15 minutes, the average rainfall intensity was 2.53mm/5min and the highest rainfall intensity attained was 6.4mm/5min. This is an example for short-lasting heavy rain. Due to the high rainfall intensity, the outflow rate attained 27.4%. The runoff occurred immediately after the rain started. The rainfall intensity of this time was much higher than the infiltration rate so that the time of runoff process lasted that long as the rainfall period (Fig3.b).

In summary we can infer that: 1) Generally, the outflow rate of the short lasted heavy rain is higher than that of the long lasted light rain; 2) The depth of the topsoil is less than 17.5cm. Based on this result, we adopted the depth of topsoil which was equal to 15cm to perform the runoff simulation calculations; and 3) The infiltration velocity of the topsoil is over 0.8mm/5min (2.7×10^{-6}m/s). So we adopted the infiltration velocity of topsoil which equals to 3.0×10^{-6}m/s to perform the runoff simulation calculation.

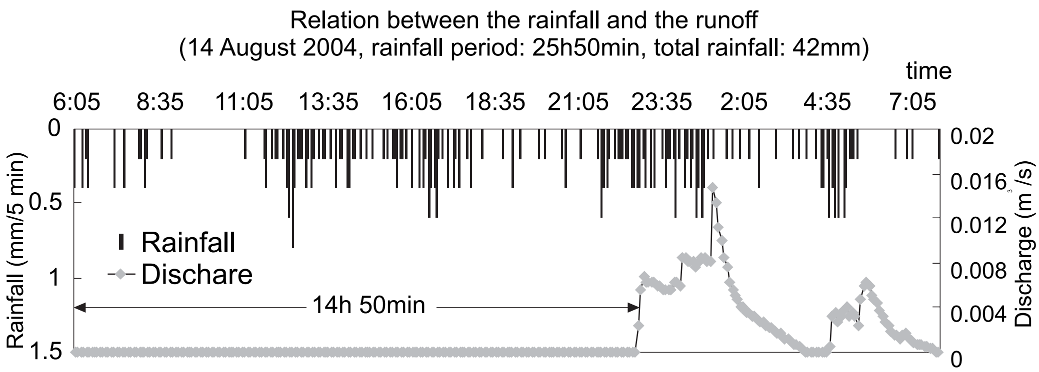
Construction of the runoff analysis technique

Artificial stream networks of the local basin: The construction of the artificial stream networks of this local basin consists of three main steps as given below:

(a) *Digital elevation map (DEM):* To generate the water fall line and the artificial stream networks, a digital elevation map of 5m mesh of the study basin was created by using the old data of the local topography of 1981. However, a certain portion of the data was updated by the GPS (geographical positioning system) and level survey done by the end of August 2005. Then the digital elevation map of the local basin was generated by using the GIS (geographical information system) software.

(b) *Water fall line:* The water fall line was constructed by inserting the mesh in the digital elevation map, and then the water fall line was made by the most steep grade method. (Yamamoto, et al., 2004).

(c) *Artificial stream network:* Based on the digital elevation map and the water fall line, the artificial stream network was constructed by the water fall line.



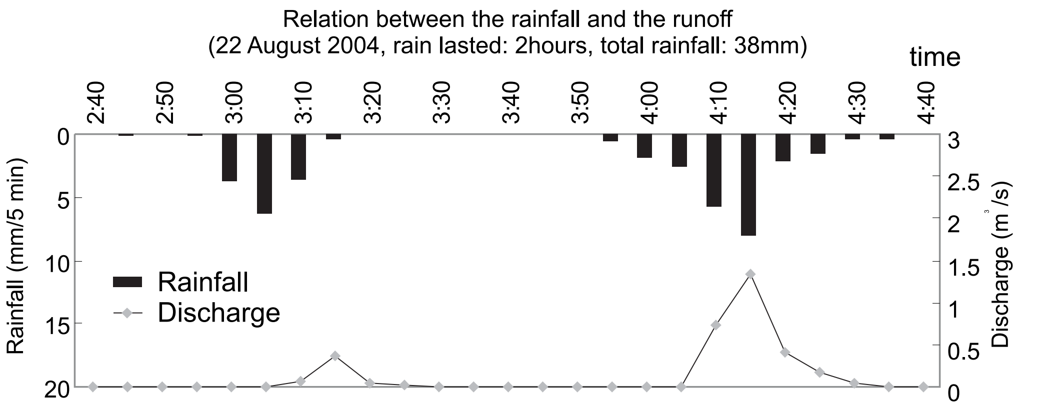


Fig.3. Relation between the rainfall and the runoff.

The digital elevation map together with the water fall line and the artificial stream networks are shown in Figure 4.a.

Runoff simulation

Runoff simulation model: We constructed the runoff simulation model as shown in Figure 5. In this model, study basin was separated into the slope and the river channel, using the basic equations shown below. The surface flow and the ground water flow were calculated separately.

Continuity equation of surface flow:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q'+(r-f_1)b \quad ;$$

Manning's average velocity equation of surface flow:

$$Q=\frac{1}{n}AR^{\frac{2}{3}}I^{\frac{1}{2}} \quad ;$$

Continuity equation of ground water flow of topsoil:

$$\lambda\frac{\partial \overline{A}}{\partial t}+\frac{\partial \overline{Q}}{\partial x}=q_s^{'}+f_1-f_2 \quad ;$$

and Darcy's law of ground water flow: $\overline{Q}=kI\overline{A}$; where: *A:* flow section area, *t*: time, *Q*: surface flow discharge, *x*: distance of flowing down, *q*': overland inflow to the river channel from per slope unit width, *r*: the effective rainfall, *f1*, *f2*: infiltration velocity, *b*: river channel width, *n*: Manning's coefficient of roughness, *R*: hydraulic radius, *I*: river channel gradient, λ : effective porosity in infiltration layer, $q_s^{'}$: ground water inflow to the river channel from per slope unit width, $\overline{A}$: ground water section area, $\overline{Q}$: ground water discharge

Modeling of the local basin: According to the artificial stream networks, we constructed the local basin model by dividing the study basin into nine small distributed basins (Fig.4.b). While formulating the method, we paid attention to the junction of the branches and confirmed the water inflow relation of each small basin.

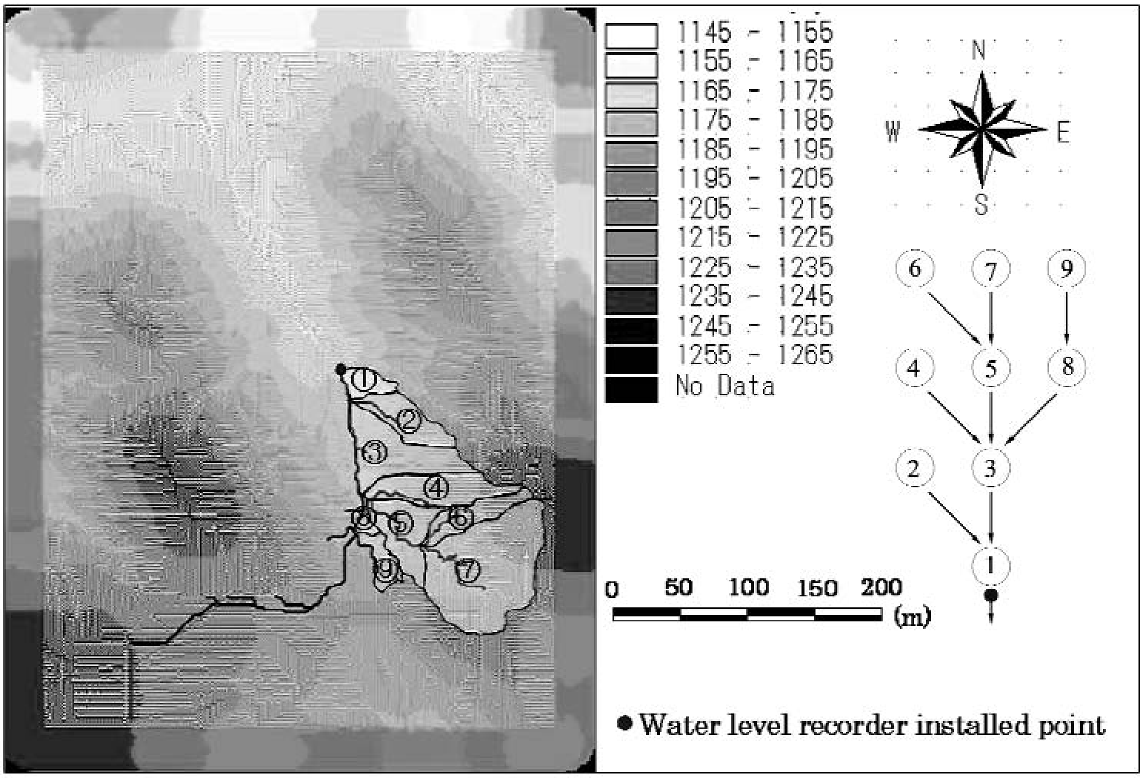


Fig. 4. Artificial stream networks and the modeling of the local basin.

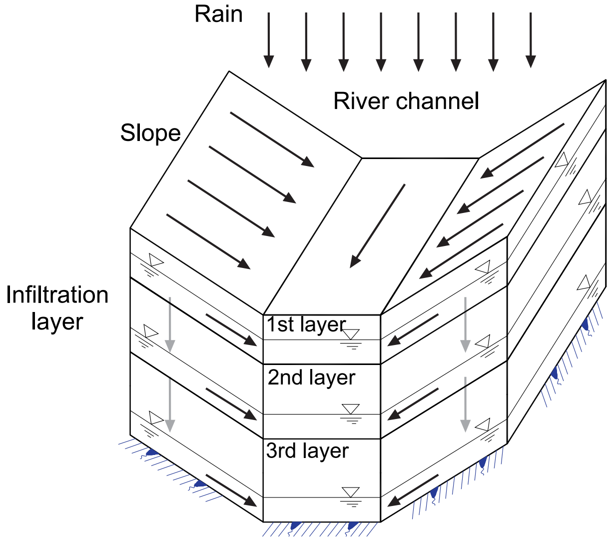


Fig.5. The constructed outflow simulation model.

Runoff simulation results and applicability

Based on surveying and defining each parameter (Table 2), the runoff calculation from August 11 to August 22 was performed (Fig. 6). Figure 6.a (August 13~August 15) shows the water depth of the topsoil of right slope of the No. 3 small basin, the calculated discharge and the observed discharge. The figure shows that the rainfall intensity was lower than the infiltration velocity and the topsoil did not attain saturation, but the runoff occurred. This was because of the long period of the rainfall that allowed the ground water of the slope to flow into the subsequent layer of the river channel. When the subsequent layer of the river channel was saturated, the runoff occurred. According to this result we can understand that the ground water of the subsequent layer could affect the surface flow.

Figure.6.b (August 19~August 21) shows that large runoff occurred around 06:00 hr on August 20. As the topsoil attained saturation and the rainfall intensity was higher than the infiltration velocity, the runoff was quite large.

Figure.6.c (August 21~August 22) shows that the runoff occurred when the topsoil was unsaturated. The rainfall intensity was much higher than the infiltration velocity so that the runoff occurred immediately after the rain started.

The simulation results show that the two flow curves are much similar in shape and process.

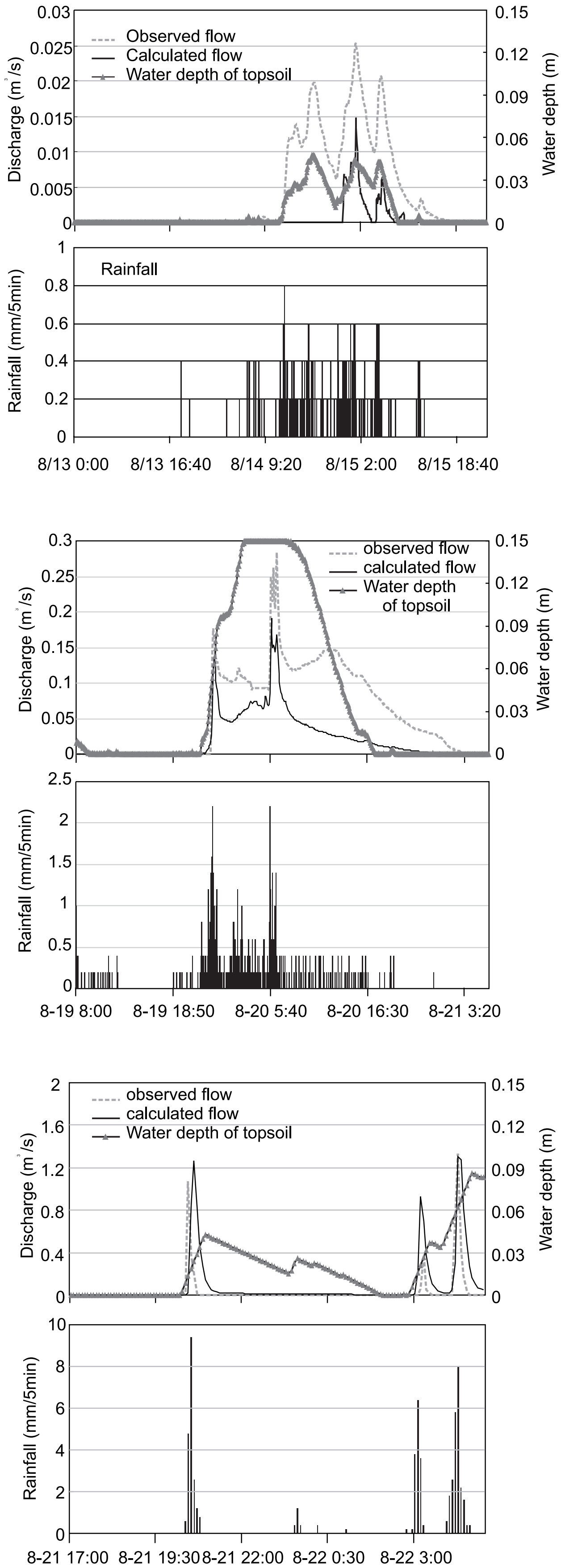


Fig. 6. Runoff simulation.

Table2: Parameters for the runoff calculation

Parameter	Object	Numerical value	Unit
Manning's coefficient of roughness	Slope	0.20	$sm^{-1/3}$
	River channe	l0.10	$sm^{-1/3}$
Coefficient permeability	1st layer	2.0×10^{-3}	m/s
	2nd layer	0.60×10^{-4}	m/s
	3rd layer	4.0×10^{-6}	m/s
Coefficient of infiltration	1st layer	3.0×10^{-6}	m/s
	2nd layer	4.0×10^{-7}	m/s
	3rd layer	1.20×10^{-8}	m/s
Loss coefficient	……..	1.0×10^{-8}	m/s
Layer thickness	1st layer	0.15(topsoil)	m
	2nd layer	5.0(loess)	m
	3rd layer	10.0(red soil)	m
Initial water depth	……..	0	m
Porosity	……..	0.15	……..

Thus the runoff simulation model could reproduce the runoff process well, although there was a little difference between the observed flow and the calculated value. The results imply that the constructed runoff simulation technique and its calculation program could apply to the study basin.

Future perspective

There is a need to undertake more local observations over a long period of time to improve the accuracy of the runoff simulation model. There is also a need to construct the long-term runoff simulation model by considering evaporation.

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The impact of irrigation technology development on land salinization in Manas River Valley, Xinjiang, northwest China

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Abstract

The irrigated area of Manas River Valley represents a successful example for the reclamation of land affected by soil salinization. Before the beginning of reclamation, the irrigated area was characterized by inappropriate irrigation method (flood irrigation) and inefficient irrigation management. As the irrigated area increased, particularly since the early 1950s, large-scale secondary salinization of irrigated land occurred. This resulted by 1980 in a sizeable land area to move out of cultivation. To reverse the declining trend in soil quality, a series of modern irrigation technologies based on the seepage control in irrigation canals, exploitation of groundwater and application of water-saving irrigation techniques such as drip irrigation have been applied, which have greatly improved land condition. This study analyzed the historical impact of irrigation technology on land salinization over four key periods of irrigation development in Manas River Valley. The results revealed a lowering of the ground water levels and reduction of area of salinized land. The cropping pattern also changed in favour of more remunerative crops and crop yields and water use efficiency increased. Of course, the control of land salinization in the area still remains a problem. For example, continuous salt accumulation is still occurring in parts of the irrigated area and long-term monoculture of crops has replaced the previous crop rotations used for controlling soil salinization. The use of drip irrigation could bring a potential threat of secondary soil salinization because no salt is being leached out from the irrigated area. Therefore, regular leaching of salts is required to reduce the salinity hazards.

Introduction

Irrigation plays a major role in ensuring food security and improving the livelihoods of people in the Xinjiang Uygur Autonomous Region of northwest China. Although irrigation is known to increase food production, it also results in serious problems of soil salinity in the irrigation command areas (O'Hara, 1997; Sharma et al., 2000; Mondal et al., 2001). Tian and Zhou (2000) estimated that about 31.1% of the total cultivated lands in Xinjiang was affected by varying degrees of soil salinity; 18% lands suffered from strong soil salinity, 33% suffered from medium soil salinity and 49% had weak salinity.

This study was conducted at Manas River Valley, which is situated in the north part of Xinjiang. Before the beginning of reclamation, different degrees of soil salinity were widespread in the alluvial-proluvial fan edge, alluvial-proluvial plain and alluvial delta. Although the irrigated area was characterized by inappropriate irrigation method (flood irrigation) and inefficient irrigation management, salinization of irrigated land was not very severe because the percentage of area under agriculture was relatively low and most of the water lost from the conveyance and field irrigation system was discharged in the lowland (Lai et al., 2004). Since the early 1950s, with the massive expansion in the cultivated area, however, these low efficient irrigation methods continued to be used. Most of the irrigation canals were unlined and, more importantly, the drainage system to control ground water levels did not exist. Moreover, considerable amount of water seeped out from the irrigation reservoirs. Therefore, these inefficient irrigation technologies resulted in a marked increase in ground water levels and a distortion in the natural salt balances in the soil-water system (Yuan, 1995). Although since then clearance and extension of drainage channels has become more efficient because of the use of digging machines, the amount of land affected by salinization has continued to expand due to the excessively high ground water levels.

It is estimated that until 1980 the total area of abandoned farmland caused by soil salinization and secondary soil salinization in this region varied roughly between 35 and 40 thousand ha (Lai et al., 2004). Since 1980, some progress has been made in the improvement of soil conditions, mainly because of the introduction of modern irrigation technologies based on the seepage control of irrigation canals, exploitation of groundwater, and application of water-saving irrigation techniques (Lai et al., 2004). For example, the connection of main-, secondary- and tertiary-drainage canals in this area has mostly been completed and conveyance systems have been lined with cement or plastic film. The amount of groundwater use has also significantly increased. By 2000, for example, the total amount of groundwater pumped in Shihezi region amounted to 3.16×108 m^{-3}, which was 70% of permissible exploitation volume (Fig. 1).

Additionally, water-saving irrigation techniques such as drip irrigation under mulch have been adopted since 1998. For example, by 2004, the area of water-saving irrigation in Shihezi region rose to 10 million ha accounting for 62% of the total irrigated land while the percentage of drip irrigation was nearly 50% (Fig. 2).

The reclamation of this region represents a successful example for the redevelopment of soil affected by high ground water table and salinization. Currently, not enough historical information is available on impact of irrigation technology on land salinization over last several decades. An analysis of effectiveness of irrigation technologies was therefore undertaken over the following four periods when major new techniques were used: (a) period of flood irrigation and before development of drainage system(1950-1960); (b) after start of the drainage system but continued low efficiency irrigation (1961-1980); (c) after the stoppage of seepage from irrigation canals and start of exploitation of groundwater (1981-1997); and (d) finally, since 1998 when the application of

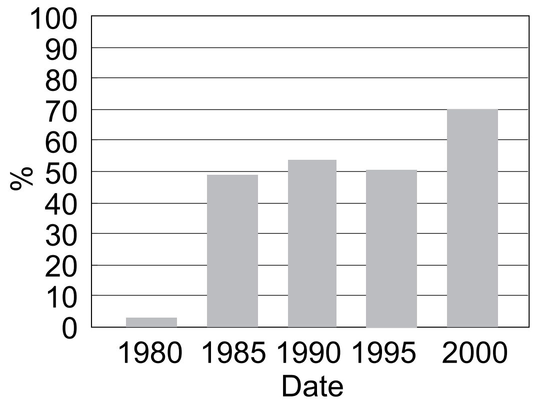

Fig.1. Variation in the percentage of exploited ground water in Shihezi region, 1980-2000. Source: Bureau of Water Conservancy in Shihezi region.

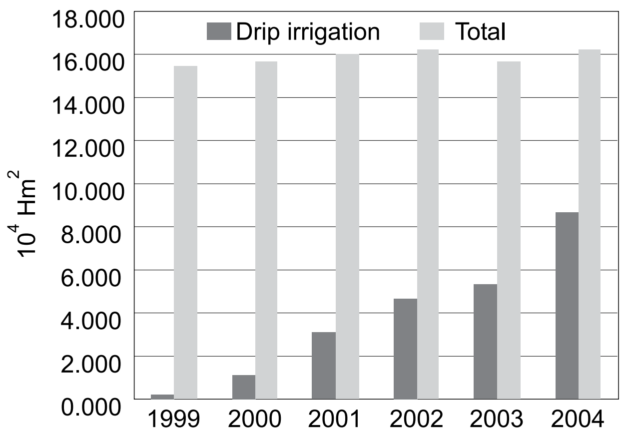

Fig.2. Variations in the area of drip irrigation in Shihezi region, 1999-2004. Source: Bureau of Statistics in Shihezi.

water-saving irrigation techniques were introduced. In addition, an attempt was made to predict the trend in the development of salinization up to 2010 and 2020 on the basis of the relationship between the irrigation level and land silinization.

Materials and methods

Location of the study area

Manas River Valley (84°43´-86°35´E and 43°21´-45°20´N) is situated alongside the southern margin of Junggar Basin. The study area is bordered in the west by the Bayingou River, in the south by the Tianshan Mountains, in the east by Taxi River, and in the north by the Gurbantonggut Desert (Fig. 3).

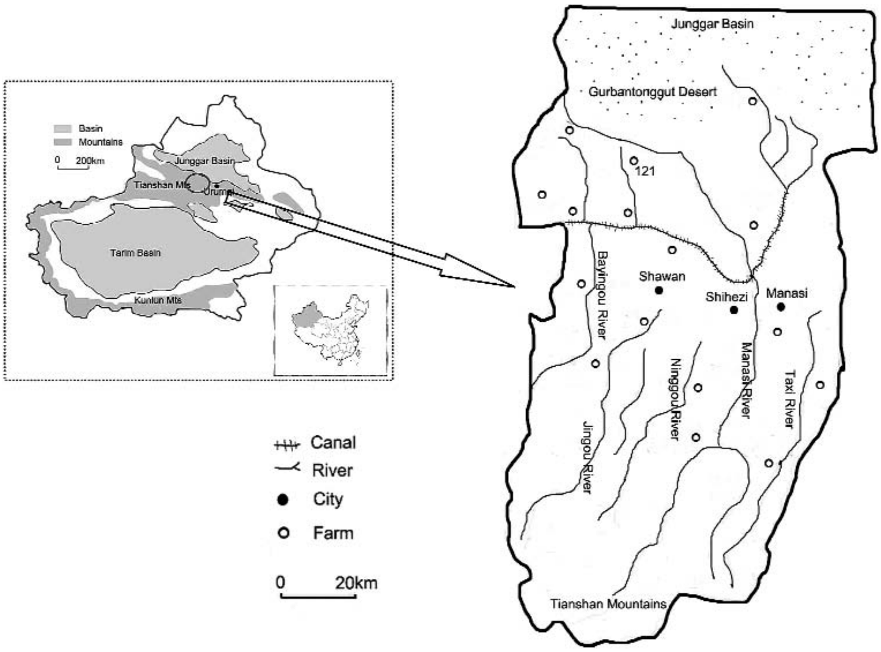

Fig. 3. Location of Manas River Valley, with five main rivers, the regions of Shihezi, Shawan and Manasi highlighted.

It covers an area of approximately 22.9 thousand km^2, of which 48% comprises the mountain zone being confined to the south of the valley, 42% oasis plain, and 10% desert zone. It is characterized by a flat to a very gently-sloping terrain.

The total population has reached 0.95 million (Cheng, 2000) and is mostly concentrated in the oasis plain zone. Manas River Valley is divided into three main administrative regions: the City of Shihezi, Manasi County and Shawan County. The largest and longest river in the valley is Manas River (with a surface flow of 1400 million cubic meters) that shows increased discharge during spring when snow and ice in Tianshan Mountains melt. Other rivers, the Taxi, Bayingou, Jingou and Ninggou, all arise in the mountain and move to the middle oasis plains. The Manas and other four rivers have a dominant influence on the local hydrological system.

Climate

The typical continental climate prevails in the area with hot summers and cool winters. Over a 50-year period, average annual rainfall ranged from 450 mm in the south highlands to nearly 115 mm in the desert edge, but in much of the area annual rainfall is less than 200 mm. About 67% of rainfall occurs during spring and summer, 33% during autumn and winter. Mean annual pan evaporation is high, varying from 1500 mm to 2000 mm. Average temperature is relatively low, varying from 3°C to 7°C. The coldest months are December to February with temperatures frequently falling below -10°C, and the hottest months are June to August when temperatures often exceed 40°C (Yuan, 1995).

Soil characteristics

Lai et al. (2004) reported that the soils in the study area developed from old river alluvial materials and had salinity. Annually 0.38 million tones of salts are removed from the tertiary sediments passing through the Manas River and deposited over this enormous area, causing considerable damage to farmland (Luo, 1985). Soil texture varies from sandy to sandy loam, to desert grey. Approximately half of the total cultivated land is characterized by a very low organic matter content ($<10 g\ kg^{-1}$) in the soil.

Crop production, irrigation and soil salinity data

The data from 1950 to 2004 on crop production, irrigation application, and irrigation network were obtained from the bureaus of agriculture, hydroelectricity and statistics in the study area. Information on soil salinity levels from 1957 to 1999 was mostly obtained from statistical yearbooks.

Results

Impact of irrigation technology on land salinization

Dynamics of soil salinity and ground water depth in the irrigated land: The results on the changes in soil salinity and ground water levels in irrigated land between 1957 and 1999 are presented in Figures 4 and 5. The soil salinity level was categorized in three classes: weak, medium, and strong, depending on the total salt and Cl^- concentration in dry soils. It is evident that the total area of irrigated land affected by soil salinization was comparatively higher during the period of flood irrigation without drainage, and it rapidly increased in early 1970s and then reached a maximum in early 1980s. Over the period, the amount of irrigated land with strong salinity increased by nearly 3200 ha accounting for over 47% of the total salinized land up to 1982, the area of land where soils were moderately saline rose by 1900 ha, while the area of weakly-saline land varied little. This indicates that low efficient irrigation technologies had little effect on the development of land salinization. However, there was a general reduction of soil salinity in the irrigated land since 1980. The area of irrigated land that was strongly saline declined from about 11,000 ha in 1982 to only 1005 ha in 1999. Over the same period, despite a little change in the percentage of land classified as moderately saline, the actual amount of salinized land in this category decreased by about 5,000 ha, while weakly-saline land increased slightly, by about 730 ha.

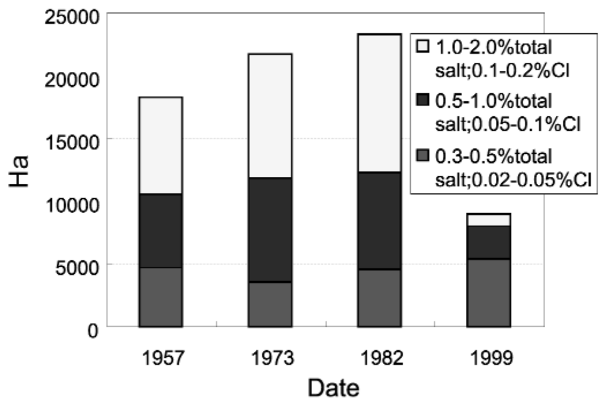

Fig. 4. Variations in soil salinity of irrigated land in Shihezi Region between 1957 and 1999. Source: 121st state farm in Shihezi Region.

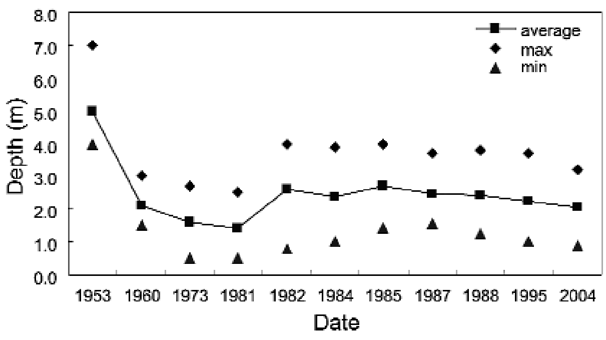

Fig. 5. Variations in the average ground water depth in Shihezi region between 1957 and 1999. Source: 121st State Farm in Shihezi region.

A similar trend was noted for the ground water levels. Most of the irrigated land experienced increasing ground-water levels before 1980. The ground water rose from about 4-7 m in the early 1950s to 1-2 m in 1980. Since then, there was an apparent decrease compared to the previous years. At present, ground water levels of the irrigated land vary between 2 m and 3.5 m.

From the above findings, it is clear that modern irrigation technologies, based on seepage control of irrigation canals, exploitation of groundwater and application of water-saving irrigation techniques such as drip irrigation under mulch, had significantly improved soils by lowering of ground water levels.

Cropping patterns, crop yields and water use efficiency (WUE): Improved soil conditions in the irrigated land allowed farmers to gradually grow more remunerative crops. For example, in Shihezi region, a significant change in the cropping pattern was observed. In the early 1950s, it mainly included wheat and oil crops. Wheat accounted for approximately 20% of the total cultivated area, and oil crops 14%, while cotton as a cash crop covered only 7%. By 2004, 78% of the cropped area was planted with remunerative crops of which cotton was 71% while the wheat area declined to about 6%, and oil crops became as low as only 1%. The increased importance of cotton in the area was because of favorable market conditions.

Besides a shift in the cropping pattern towards more remunerative crops, the improved irrigation technologies also resulted in a general increase in crop production (Table 1). Over the 50-year period, the area of irrigated land in Shihezi region increased 2 times. The effect of irrigation technologies on crop yields and WUE was substantial. For example, the yield of lint cotton in Shihezi region was only 350 kg ha^{-1} during the period of flood irrigation without drainage. Now it is about 1750 kg ha^{-1} under the drip irrigation system. The WUE of cotton increased by 0.25 kg m^{-3} over this period. It is interesting to note that the most significant increase in crop yields and WUE occurred since 1980. All these indicate that the adoption of modern irrigation technologies improved the general soil conditions around that area.

Prediction of developing trends of land salinization in Manas River Valley

Low-efficiency irrigation technologies are considered to be one of the main causes of salinization (Hachicha et al., 2000; Darwish et al., 2005). Fan et al. (2002) concluded that nearly 80% of the total saline land in this area occurred due to secondary soil salinization caused by irrigation, and the developing trend of land salinization in the future will to a great extent depend on irrigation technology. For the above reasons, an analogistic method was used to evaluate land salinization trends to 2010 and 2020 by considering the relationship between percent of salinized land and the level of development of irrigation. Five indices determining irrigation development levels were chosen: volume of groundwater exploited, percent of canal network lined, coefficient of irrigation water use, irrigation applications, and water use efficiency of crops. The results were as follows:

The period for reasonable use of irrigation water in most of the irrigated area (2010): As was the case in Shihezi region, which was subjected to higher irrigation levels and relatively low land salinity (Table 2), measures must be taken to achieve the improvement in irrigation efficiencies in other parts of the area. According to the local water conservation department, planning and developing trends of irrigation technologies by 2010 are that the amount of groundwater pumped is estimated to range between 60% and 70% of permissible exploitation volume in most of the irrigated area; percentage of irrigation canals lined to vary from 25% to 30%; coverage of land by water-saving irrigation techniques to vary from 20 to 30% of the total irrigated land in both Manasi and Shawan Counties; gross irrigation application of crops might decline to 7500 m^3 hm^{-2}; and water use efficiency for cotton might vary between 0.25 and 0.30 kg m^{-3}. The total coefficients of irrigation water use in the irrigated area could be up to 0.70. Based on these anticipated changes in the level of development of irrigation, it is estimated that the percentage of total salinized land could be reduced to 35-40% in this area.

Table 1. Variations in average area of irrigated land, crop yield and water use efficiency at different stages of irrigation technology development in Shihezi region

Period	Area of land irrigated (10^3 hm^2)	Yield of cotton (kg hm^{-2})	Increase in yield (kg hm^{-2})	Water use efficiency of cotton (kg m^{-3})
Flood irrigation and before drainage	73.83	352.60	-	0.04
After drainage but low efficient irrigation	143.33	607.80	255.2	0.07
Exploitation of groundwater and anti-seepage of irrigation canals	152.96	1141.2	0533.4	0.15
Since the application of water-saving irrigation techniques	162.59	1736.80	595.6	0.29

Table 2. Relationship between salinized land and irrigation levels in Manas River Valley

Region	Percent of salinized land	Percent of groundwater exploited	Percent of canal network lined	Irrigation water use coefficient	Irrigation requirement (m^3 hm^{-2})	Water use efficiency (kg m^{-3})
Shihezi	38.1	59.7	25.9	0.68	7500	0.27
Manasi	47.2	48.5	19.0	0.62	8825	0.16
Shawan	66.8	35.9	14.7	0.59	9250	0.12

The period for high efficiency of irrigation water use (2020): High efficiency of irrigation technologies must be combined with modern irrigation technologies. For 2020, estimates are that the percentage of groundwater pumped might range from 80% to 90% of the permissible exploitation volume; about 40-50% of irrigation canals could be lined; modern water-saving techniques such as drip irrigation could be applied to 40-50% of total irrigated land; the gross irrigation application of crops could be stabilized between 7500 and 5000 m^3 hm^{-2} ; WUE for cotton could remain between 0.30 and 0.45 kg m^{-3}; and total coefficient of irrigation water use in this area could rise to 0.80. On these presumptions the percentage of total salinized land is estimated to remain below 30%.

However, it is necessary to indicate that as an inland enclosed area, salts are not exported from the irrigated area. It is conceivable that in the long-term, with the expansion of oasis, soil salinization could still occur in the newly cultivated land taking into account the rise of the ground water levels. All in all, although the irrigation efficiency in the future appears to become quite high, it is not sufficient to ensure that the development of secondary soil salinization would be completely controlled.

Discussion and conclusion

The study shows that the direct and indirect effect of irrigation technologies over a period of 50 years has been immense in the area. It has contributed to lowering of the water table and decrease of the salinized land area. The crop production has been significantly affected; cropping pattern has changed in favour of more remunerative crops and crop yields and water use efficiency have increased. However, the problem of land salinization in this area continues to exist. For example, continuous salt accumulation might occur in part of the irrigated area where the ground water levels fluctuate between 1m and 3m. Hence, unless irrigation technologies are efficient, salinity could rise to concentrations that will interfere with cropping. Additionally, long term monoculture of cotton is common in this area, which has replaced the previous crop rotations known to control salinization (e.g. rice-wheat with succession of green manure-cotton-alfalfa). For example, the area of cotton has reached nearly 70% of the total cropland in Shihezi region. Currently, the problem of salt accumulation in continuous cropping land has not been observed, but it could emerge after 5-10 years (Ji et al., 1998). Because of water shortage, farmers are implementing water-saving irrigation techniques such as drip irrigation under mulch despite higher investment cost. However, the use of drip irrigation could bring potential threat of secondary soil salinization because no salt is leached out from soil profile and salt build-up on the soil surface could increasingly occur after several years of irrigation (Tian et al., 2000; Zhou and Ma, 2005). Hence, the yearly leaching of salts is required to reduce the salinity hazards.

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Study on temporal variation of sediment yield and determination of factors affecting it, a case study of Taleghan watershed

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Abstract

Estimation of sediment yield and temporal variation is very critical for appropriate management of watershed. For this purpose a research study was undertaken in Taleghan watershed, located in northwest of Tehran, Iran. The study area is about 80,428 ha and has annual average precipitation of 697.2 mm. Three temporal periods were considered to estimate sediment yield in the outlet. Then the factors most influencing the sediment yield in each period were estimated using multivariate regression and stepwise approach. The results showed that annual suspended sediment increased from 1969-1971 to 1971-1978 period while it showed a decrease in the period from 1971-1978 to 1979-200. The statistical analysis showed that sediment increase for first period was related to climatic parameters while sediment yield decrease in the second period was because of the change in the land use in the study area.

Introduction

Soil erosion is one of the most serious environmental problems in many countries in the world. The sediment loss affects the ecologic balance of the watershed. The knowledge of the amount of soil erosion occurring in a watershed and its temporal changes is important for devising control measures. Bray and Xie (1993) using multiple regression analysis showed that the amount of sediment yield correlated with land use changes, drainage and hydrological parameters at 14 stations in Canada. Kalteh (2002), analyzing the data from the northern and southern Alborz watershed in Iran, showed that the amount of sediment yield depended on watershed area and annual discharge. The aim of this study was to find out the factors affecting the sediment yield in different period in Taleghan Watershed, located in north-west of Tehran, Iran.

Materials and methods

Site description

This watershed is one of the sub-watersheds of Sefidroud River and is located between 36° 5' 17" and 36° 20' 45" northern latitudes and between 50° 39' 33" and 51° 11' 26" eastern longitudes. The area is 80428 ha and includes 19 sub catchments. The mean annual precipitation is 697.2 mm and means annual temperature is 4.48°C. This watershed has mean slope of 42%. This region is located in Alborz geologic zone with diverse formations (Shabani, 2003).

Methods

In this study three time periods were included: 1969-1970, 1971-1987 and 1987-2001. The amount of annual sediment yield in the outlet was obtained from the hydrometric station data. The sediment changes in the above periods were studied. Finally, by utilizing a multiple regression, the factors affecting the sediment yield in these periods were investigated

Results and discussion

The results show that the mean annual sediment increased from 712,574 ton per year in 1969-1970 to 944,583 ton per year in 1971-1987, and then decreased to 586,772 ton per year in1987-2001 (Fig.1).

The sediment yield was related to such independent variables as discharge, change in coverage of

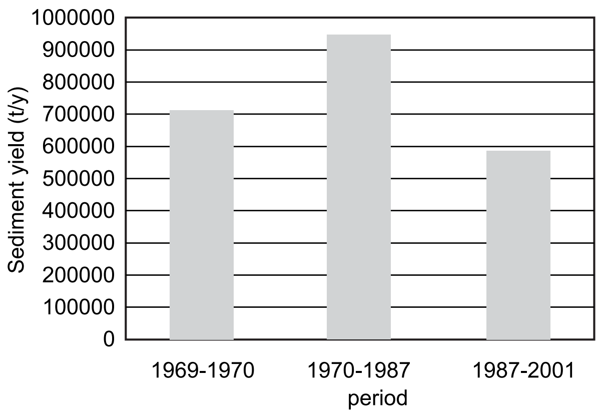

Fig. 1. The comparison of annual sediment yield in study periods in Taleghan watershed.

land by range and rainfall. The data in Table1 shows that the amount of sediment yield is controlled by discharge and dry land variables (R^2=78%) in sub watersheds in the period of 1969-1987 and by rainfall and range land variables in the period of 1987-2001 (R^2=76.3%).

The land use changes were also studied for the three time periods. These are shown in Table 2 along with the data on discharge, rainfall and sediment yield. The results showed that the % sediment yield increased from 1969-1970 period to 1971-1987 period and then decreased during the 1987-2001 period (Table 2).

The increase in the sediment yield in 1971-1987 period is accompanied by an increase of range land area and decrease of agricultural land area. This association does not agree with reports of Selby (1994) and Chappy (1999). There was a substantially higher rainfall in the 1971-1987 period than in 1969-1970. Therefore the increase in sediment yield should be related to increased precipitation. In this period, the discharge variable has a higher standard â then dry land variable, so it plays a more important role in sediment yield (Table1). The percent sediment yield decreased from 42.1% in 1971-1987 period to 27% in 1987-2001 (Table 2). In this period there was a decrease in the agricultural land area (irrigated and dry land) and an increase in rangeland area. These results agree with the observations of Selby (1994) and Chappy (1999). Besides this land use change, there was also a decrease in the mean annual precipitation in 1987-2001 as compared to 1971-1987. In the1987-2001 period rangeland variable had a higher standard â then rainfall variable (Table 1), so the land use plays a more important role in sediment yield.

In conclusion, it can be said that the increase in sediment yield in the 1969-1987 period is related to the climate parameters and the decrease of sediment yield in the1987-2001 period is related to the human factor in the form of land use.

Table 1. Regression relationship between sediment yield (dependent variable) and different independent variables (discharge, range land area change, rainfall) during the study period.

Regression equation	Standard ß	R^2 (%)	Independent variable (X)	Depend variable (Y)	Period
$Y= 29313.8\ X_1+30.56X_2\ +3191.43$	0.856	78.0	Discharge (x_1)	Sediment	1969-1987
	0.651		Range land (x_2)	yield	
$Y=-5.47X_1+\ 99.68X_2+79998.8$	0.917	76.3	Range land (x_1)	Sediment	1987-2001
	-0.608		Rainfall (x_2)	yield	

Table 2. The amounts of rainfall, discharge, sediment yield and land use area in study periods.

Area of land use (%)				Mean discharge (m^3/s)	Mean rainfall (mm)	Sediment yield		Period
Unusable	Irrigated land	Dry land	Range land			%	ton/y	
4.3	5.93	15.6	74.0	16.8	693.3	31.7	713574	1969-1970
4.3	2.72	10.1	83.2	12.9	734.2	42.1	944582	1971-1987
4.3	2.12	4.5	89.0	12.3	701.0	27.0	586771	1987-2001

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Status, development and trend of desertification in North China

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Abstract

According to the results from the remote sensing and field surveys, the area of desertified land in North China was about 385 686 km² in 2000. The desertified area has increased by 46,740 km² as compared with the mid-1980s, and the annual rate of increase was 3 600 km² in 13 years. Based on the rate of expansion and causes, the desertified land of North China can be divided into three kinds: the lands where reversal of desertification was occurring, distributed in the agro-pastoral mixed region; the stable desertified lands distributed in the lower reaches of inland rivers; and the lands where desertification was increasing, mostly distributed in the pure nomad pastoral areas.

Introduction

Desertification affects an estimated 70 per cent of all of the dry lands of the world, amounting to about 3.5 billion hectares. About one-sixth of the world population, living in these areas is affected by desertification process (Hare, 1993). Similar to other countries and regions of the world, desertification plagues almost all areas of the North China and some 35 million people are affected (Zhu and Wang, 1993). Although the research on desertification has a history of more than fifty years in China (Zhu, 1959, 1961; Hou, 1973), the Chinese scholars started to systematically study the desertification process, mechanism and rehabilitation following the United Nations Conference on Desertification in Nairobi in 1977.

Judging the situation in China, Zhu (1993) considered that desertification is a process of environmental degradation under fragile ecological conditions and intensive human activities. This process of degradation leads to the development of a desert-like landscape and a reduction in land productivity. The desertified lands are mainly distributed in the arid, semi-arid and part of sub-humid regions of North China.

By comparing and interpreting aerial photographs taken at the end of 1950s and the mid-1970s, the desertified land in North China expanded at a rate of 1 560 km² per year (Zhu and Wang, 1993). These newly desertified lands could be divided into two. One set of desertified lands are from arid agricultural lands where the steppe and desert steppe had been reclaimed to develop farmland. The other newly desertified lands are the ones resulting from the reactivation of the fixed sand dunes and sand lands due to overgrazing and over-woodcutting (Wang et al., 1999).

From 1975 to 1987, the rate of expansion of desertified land in North China was 2100 km² per year and the desertified area reached 338 950 km² (Wang et al., 2003). According to Wang (1999), these areas are mainly distributed in: 1) Bashang area of Hebei province, as a result of over-cultivation in Ulanqab Steppe and Chahaer Steppe of Inner Mongolia; 2) Horqin sand land located in the east of Inner Mongolia, representing the fixed sand dunes activation due to the overgrazing, over-cultivation and over-woodcutting; 3) areas used for mining for energy source (for example Shenfu coal field) because of their over-exploitation.

The Chinese government, having obtained a clear understanding of the desertification situation in recent years, has formulated some corrective policies to readjust the structure of land use and enlarge the area of forest and grassland, especially in the mixed agro-pastoral regions. As a result, a majority of farming land in such areas has been converted into forest and grassland. Some studies in typical areas have shown that the situation of desertification has now changed a great deal as compared with the previous two stages (between 1950s to1970s, and between 1970s to1980s). For getting better picture of desertification status, studying the development trends, and assessing the achievement of controlling desertification in some regions in North China in the recent years the remote sensing and field survey have been conducted since July 2001. This paper presents some results based on this and the previous research.

Study area and methods

The study area was located in North China and covered about 2 560 000 km^2, consisting of Hulun Buir sand land, Songnen sand land, Horqin sand land, Xilinguole steppe, Ulanqab steppe, Bashang area of Hebei province, Kubuqi sand land, Mu Us sand land, Shiyang river basin, Heihe river basin, Kumutage desert, the north, middle and south part of Xinjiang province, the source area of Yellow river, and the Chaidamu area of Qinghai province (Fig. 1). The area covers 177 counties of 10 provinces and includes agro-pastoral mixed area, arid rainfed agricultural area, and irrigated agricultural area of oasis and nomad pastoral area in sub-humid steppe, arid and semi arid steppe, desert steppe and alpine meadow, respectively.

The study has been conducted since July 2001, and is composed of remote sensing, monitoring, and field survey of desertification. Band 2, 3 and 4 of Landsat TM images in July, August and September 2000 were used in this study to monitor desertification of study area, because they can readily reflect the information of vegetation and water of earth surface. Firstly, several typical desertified areas (trail areas) were selected on the images of study area, and then preliminary interpretation was done of the status of desertification. For verifying, evaluating and assessing the result of remote sensing investigation, the field studies in the trail areas were conducted in September 2002.

During the fieldwork, the ground places in the trial areas corresponding to those in the image were first located using Global Position System and then desertification information of these areas was recorded. The information collected mainly included coverage and component of vegetation; component, content and distribution of gravel and sand; size and height of shrubs on the dunes; the erosion and sedimentation of sand and activity of dunes. Most of this information could not be obtained from the images because of the low spatial resolution (30 m) of TM data.

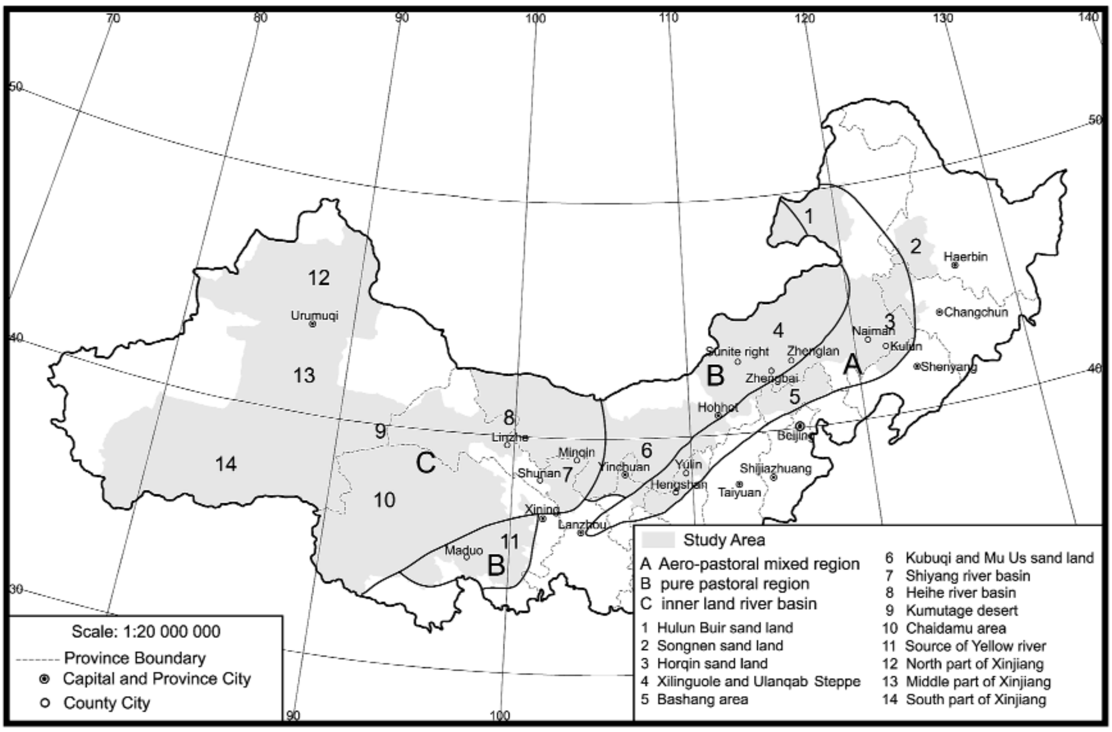

Fig. 1. Location and distribution of study areas.

Table 1. The desertification classification system of the study area

Class of desertification	Different kind of manifestation of desertification				
	Sand dunes and sheets activation	**Shrub-coppice dunes**	**Coarse gravel surface**	**Wind erosion land**	**Arid farmland desertification**
Primitive landscape	Fixed dunes or steppe, farmland	Steppe, desert steppe or steppe-desert	Desert steppe or steppe-desert	Desert steppe or steppe-desert	Dry farmland
Slight desertification	Wind erosion pits emerge on the windward slope of dunes; shifting sand emerge on the spot; and P=5-25%, $C=90\%C_p$	Shrub flourish; Sand begin to deposit under the shrub	Gravels emerge and gather on the surface	Wind erosion shallow furrows without evident steep bank emerge on the surface	A little sand deposit and evident wind erosion marks emerge on the ridges of the farmland in spring
Moderate desertification	Erosion and deposit slopes apparently emerge on dunes; P=25-50%, $C=50\text{-}90\%C_p$	Shrub can not cover sand deposit wholly; shifting sands emerge on the windward side of the shrub	More coarse gravels distribute on the surface, vegetation scatter, $C>25\%\ C_p$	Wind erosion furrows naked and evident steep bank emerge on the furrows	Shifting sand emerge on the loess farmland; the thickness of humus being eroded surpass 50%
Severe desertification	Sand land become semi shifting and P>50%, $C<50\%C_p$	Large area of shrub dies; P>50%, $C<25\%C_p$	Gravel cover the whole earth surface, seldom sand particles emerge among the gravels, $C=10\text{-}25\%\ C_p$	Wind-eroded hills and hollows emerge on the surface, and scattered vegetation grow on the flat land between the hills	The humus of farmland is eroded out, calcareous crust, bedrock and parent material crop out; the area of shifting sand surpass 25%, and farmland is abandoned
Very severe desertification	Shifting sand lands emerge and $C<10\%C_p$	Shifting and undulate sand lands emerge, and $C<10\%C_p$	Gobi emerge, $C<10\%\ C_p$	Yadang emerge	Sand sheets and gravel land emerge; $C<10\%\ C_p$

C=coverage of vegetation; C_p=coverage of primitive vegetation; P=the proportion between sifting sand area and total area

Table 2. TM image characteristics of desertified land

Land type	Image characteristics	Others
Sand dunes (sheets)	Crescent, reticulate, and undulated patterns, the color is light yellow or grayish white	Distinct boundary and homogeneous tone
Slight desertification	Massive and irregularity patterns; light red	Red spots emerge on the light red background
Moderate desertification	Massive and irregularity patterns; pale red	Micro-fluctuation earth surface, and scattered small dunes
Severe desertification	Irregular patch patterns; brown-yellow	Distinct dunes and spotted shrub coppice
Very severe desertification	A large area of brown-yellow	Distinct sand dunes and ridges

Based on the information of typical desertified areas, the desertification classification system and the image characters of desertified land of the study area were established (Table 1 and 2). Comparing the field desertification patterns and image characters reflecting actual landscape of the same typical area, an interpreting index system was established for applying remote sensing to study desertification. Based on this interpreting index and desertification classification system, the desertification status of the whole study area was interpreted. The ARC/INFO and ARCVIEW software was used to help completing interpretation and estimating the area of desertification.

The concept of latent desertification of land was used for developing a clear understanding of the desertification process. Latent desertification mainly occurs in pastoral areas and can also be called grassland degradation. Grassland degradation is mainly manifested in the of form degradation of vegetation species and reduction of productivity of the land; for example the edible fodder grasses being gradually substituted by poisonous species due to drought and over-trampling of animal. Degraded grassland cannot provide enough fodder to maintain the numbers of livestock that used to graze before because of low carrying capacity. After the edible vegetation is grazed, these lands become vulnerable to wind erosion. So, this can be called latent desertification. This change cannot be monitored by TM imaging because the change in vegetation coverage is little. In this study, the data on latent desertification were obtained mainly by field survey of typical areas.

Results and discussion

The desertification status of North China

Only preliminary results have become available so far from the remote sensing and field surveys. The desertified areas in different monitoring regions in North China are shown in Table 3. The result indicates that the total desertified area in North China is 385, 687 km^2, of which an area of 139, 268 km^2 shows latent and slight desertification, 99, 769 km^2 moderate desertification, 79, 091 km^2 severe desertification, and 67, 559 km^2 very severe desertification. The four classes of desertified lands occupy 36.1%, 25.9%, 20.5% and 17.5% respectively of the total desertified area.

Table 3. Area (km^2) of desertified land in North China in 2000

Region	Monitoring area	Latent and slight desertification	Moderate desertification	Severe desertification	Very severe desertification area	The total desertified	A_d/A_m (%)*
Hulun Buir sand land	83615.0	17890.00	852.00	1990.00	161.00	20893.00	25.0
Songnen sand land	51588.0	1909.76	1386.25	460.43	8.94	3765.00	7.3
Horqin sand land	105603.8	30669.32	9008.79	5815.42	4673.99	50167.52	47.5
Xilinguole steppe	181309.8	20999.21	11300.09	7274.83	5595.37	45169.49	24.9
Ulanqab Steppe	60967.9	9079.36	3782.65	278.44	41.57	13182.02	21.6
Bashang area	46013.0	7824.30	3680.73	1302.42	243.87	13051.33	28.4
Kubuqi sand land	87158.5	5214.02	13025.43	5705.72	2338.44	26283.59	30.2
Mu Us sand land	97352.0	20509.82	14333.78	7949.56	10679.33	53472.49	54.9
Shiyang river basin1	20172.0	2243.32	3692.43	16704.70	10005.36	32645.81	27.2
Heihe river basin	202946.0	352.72	1568.20	2852.47	10090.82	14864.20	7.3
Kumutage desert	172731.0	2594.94	4341.53	1823.95	325.14	9085.56	5.3
Yellow river source area	89996.0	7728.00	2586.00	1314.00	1377.00	13005.00	14.5
Chaidamu area	446562.7	3008.38	11170.07	2835.49	2606.50	19620.44	4.4
North Xinjiang	272552.0	5715.39	13609.29	12948.15	9046.60	41319.43	15.2
Middle Xinjiang	158843.0	2238.78	2502.04	4397.90	6552.30	15691.02	9.9
South Xinjiang	386651.0	1290.28	2929.70	5437.88	3813.08	13470.94	3.0
The whole study area	2564062.0	139267.60	99768.98	79091.36	67559.31	385686.80	15.0

** Ad is the area of desertified land, Am is the monitoring area.*

The desertification development in North China

Compared with 338, 950 km^2 of 1987, the desertified area in North China increased by 46, 740 km^2 during last 13 years showing a rate of expansion of about 3, 600 km^2 per year. The annual rate of rise was higher than 1, 560 km^2 in 1970s and 2, 100 km^2 in1980s. The desertified area was mainly divided into three types (Fig 1) (Zhu and Wang,1993): a) the agro-pastoral mixed region in the sub-humid and semi-arid zone; b) the undulating steppe and desert steppe (pastoral region) in the semi-arid zone; and c) the margins of oases and inland river basins in the arid zone. According to Zhu and Wang (1993) the percentage of the desertified area of each type was respectively 40.5%, 36.5% and 23% of the total desertified area of North China in 1987 (Table 4). In contrast to this, the situation in 2000 has undergone a great change. It can be seen from Table 4 that the contribution of the desertified area in the agro-pastoral mixed region to the total desertified area has dropped by a big margin, while the contribution of the desertified lands in nomad pastoral regions and inland river basins and marginal oases has shown a distinct increase, especially the nomad pastoral regions.

For understanding further the desertification development of the three above mentioned regions, we selected several counties in different regions to study the change in desertified area (Table 5). Naiman Banner County and Kulun Banner County, located in the south of Horqin sand land, and Yulin County and Hengshan County, located in the south of Mu Us sand land (Fig. 1), belong to the typical agro-pastoral mixed area. From Table 5, the desertified area in the four counties showed a continuous decrease since 1975, but showed a reversal in the trend during the 1980s to 1990s. For example, the average annual rate of desertification was 19.04 km^2 during the 1970s-1980s, while it was 69.52 km^2 during the1980s-1990s in Naiman Banner County.

Table 4. The desertified land in different regions as percentage of the total desertified area

Region	1987	2000
Agro-pastoral mixed regions	40.5%	25.9%
Nomad pastoral regions	36.5%	44.4%
Inland river basins and marginal oases	23.0%	29.7%

In Minqin County, Linzhe County and Shunan County, located in the inner river basin of arid zone (Table 5), little remote sensing monitoring of desertification was conducted before the 1990s. Thus, for this area there is a lack of continuous and long time data about the magnitude of desertified land. We could collect desertification data for this region only during the 1990s, and analyzed the development situation at this stage. The results show that the increase in desertified area in the three counties was same during the 1990s, but the rate of increase was distinctly different. The annual average increase in desertified area in Minqin County (lower reach of river) was 1074.5 km^2, in Linzhe County (middle reach of river) it was 44.7 km^2 and in Shunan County (upper reach of river) it was 2.7 km^2.

Zhengbai Banner County, Zhenglan Banner County, and Sunite Right Banner County are in the nomad pastoral region of semi-arid zone and represent a transition area between temperate steppe and temperate desert steppe. Maduo

Table 5. The development of desertified land (km^2) in different counties

Region	Agro-pastoral mixed regions				Inland river basin and marginal oasis			Nomad pastoral regions			
County	Naiman	Kulun	Yulin	Hengshan	Minqin	Linzhe	Shunan	Zhengbai	Zhenglan	Sunite right	Maduo
1966										1299.9	
1975	5657.12	2658.57	5729.8	1596.5				383.2	521.1		
1979										5641.6	
1987	5409.63	2327.08	4947.9	1292.4				918.4	885.5		2389.0
1991					4463.33*						
1994						1229.21	649.05				
2000	4505.84	2094.19	4360.0	782.5	15208.23*	1542.20	667.97	3236.8	7413.8	8118.0	7841.0

** Data from the local government reports and the area includes desert, Gobi and desertification land.*

County, located in the east of Tibetan plateau, is in the Alpine meadow of sub-humid zone. From Table 5 it can be seen that the desertified areas of the above four counties increased since 1960s. The annual average increase in the desertified area was 114 km^2, 275.7 km^2, 200.5 km^2 and 419.4 km^2 respectively in these counties. The rate of increase during the 1980s to1990s was bigger than during 1970s-1980s.

Future trends in desertification development in North China

Desertification is a dynamic process, and its development depends on many factors such as drought, land use, governmental policies, etc. From the analysis of these factors we got some preliminary indications about the future trends in the development of desertification in North China as follows:

1) *The desertification of agro-pastoral mixed regions will keep on reversing in the future*: Studies show that the ecological environment of agro-pastoral mixed regions in North China is very fragile due to drought, strong wind and sandy surface soil. In history, these were pastoral areas and stock-raising was the main land use there. But the pastoral economy was substituted gradually by agriculture economy in recent centuries because of several historical causes and mistaken policies. According to Sun (2003) Yikezao Meng (the west part of the agro-pastoral mixed region) had experienced three large-scale opening up of grasslands since the early 1950s (1956-1958, 1960-1960, 1969-1971), and some 333,333 hectares of grassland were changed into farmland. Without vegetation cover, this land rapidly became desertified under the drought and strong wind. Since the mid-1980s, Chinese government has carried out the policies of recovering grassland and has adopted a series of measures to combat desertification in the agro-pastoral mixed regions. Field survey shows that these policies and measures have been widely adopted and have made considerable impact. The reversing of desertified land in these regions mainly stems from these practices. So the situation of agro-pastoral mixed regions will keep on improving in the future as these measures and policies get further spread and popularized.

2) *The desertification of lower reaches of inland rivers will keep stable in the future*: Inland rivers of arid zone are mainly distributed in the northwest part of China. There are Shiyang, Heihe, and Shule rivers in Gansu Province, and Tarim and Yili rivers in Xinjang Province. Studies show that the desertification of these areas in the past mainly resulted from irrational use of water resources and unbalanced water distribution among upper, middle and lower reaches. According to the results from remote sensing and field surveys, the oases area of upper and middle reaches has either remained constant or slightly increased. In contrast, large scale withering of oases has occurred in the lower reaches and all the utilizable land has almost become desertified. Minqin county (Table 5) located in the lower reach of Shiyang River is a typical desertified region, and its desertified land, desert and Gobi occupy 94.51% of the total land area. There is no more land for any further expansion of desertification. It is to be noted that there have been no good policies and adoption of measures to adjust the use and distribution of water resources among the different reaches of inland rivers up to now. So, the desertification of these regions will keep constant and the whole desertified area will not change. But the extent of desertification will get aggravated and the large scale latent- and slightly-desertified lands will become severely desertified.

3) *The desertification of nomad pastoral region will develop rapidly in the future:* According to the studies, nomad pastoral region can be divided into two parts, one is the transitional region between temperate steppe and temperate desert steppe located in the northern part of Inner Mongolia, and the other is the alpine meadow area located in the east of Tibetan Plateau. In these regions, the desertification mainly results from the climate change and overgrazing. Research shows that during the last twenty years drought is a main feature in temperate steppe. Actually, the drought events have become more frequent and more severe since the 1980's. Twelve drought years occurred between 1980 and 1999 in temperate steppe. After the middle 1990's, drought is more severe and isohyet of 200mm has moved toward east and northeast (Figures 2 and 3). Drought and infestation by rodents and insects

have reduced the carrying capacity of grassland and it cannot carry the number of livestock and people as it did before. At the same time, the human population and number of livestock have rapidly increased in these areas in last 50 years (Fig. 4). These factors resulted in the increase of desertified land in last 20 years (Table 5); especially majority of the grassland degraded to become latent- and slightly- desertified land. From Table 5, it can be seen that the desertified land in Sunite Right Banner is 8,118 km^2 in 2000, occupying 30.4% of the total banner area of 26, 700 km^2. In addition, some 80% of the un-desertified land has encountered serious desertification.

Temperature is more important than precipitation for desertification in alpine meadow area. Research shows that the temperature has gone up by 1.0-1.6°C in this region (Fig. 5). The climate warming has resulted in descend of the upper line of the frozen soil layer and wither of water area, which has encouraged desertification.

Field survey shows that the policies and measures adjusting the balance between the carrying capacity of grassland and livestock number have not been carried out properly, due to herders' habits,

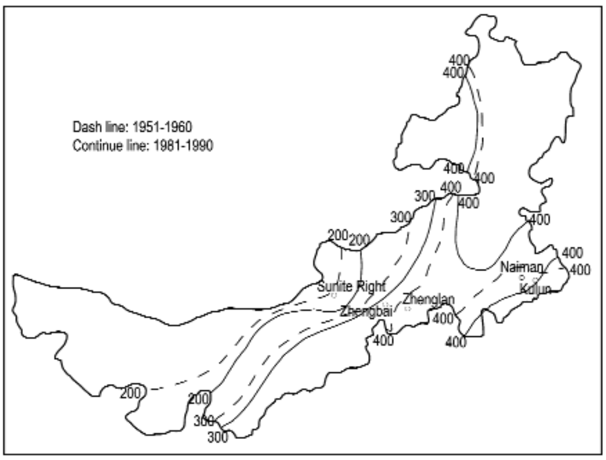

Fig. 2. The annual average isohyet map of Inner Mongolia.

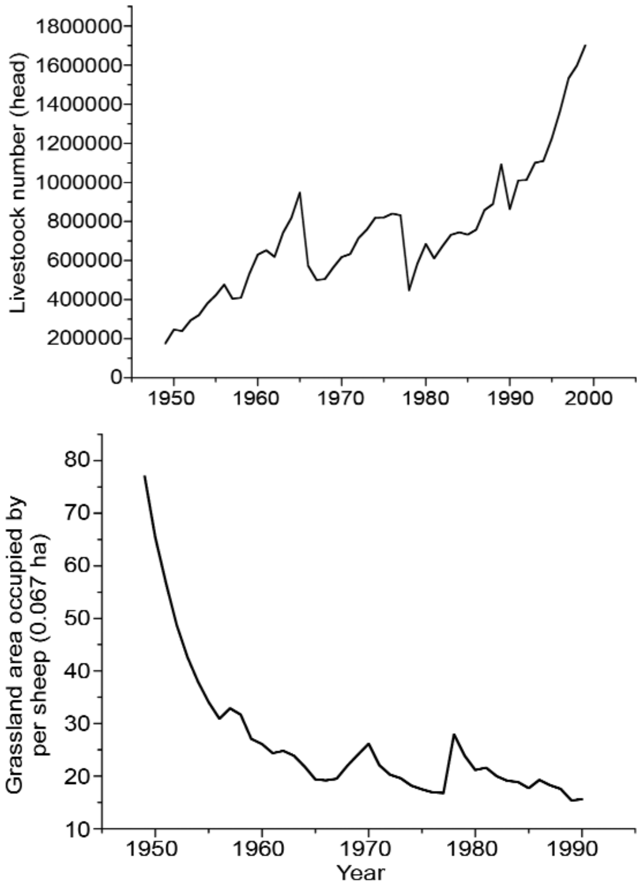

Fig. 4. The change in livestock number (upper part) and change of grasslands area per sheep (lower part) in Sunite Right Banner.

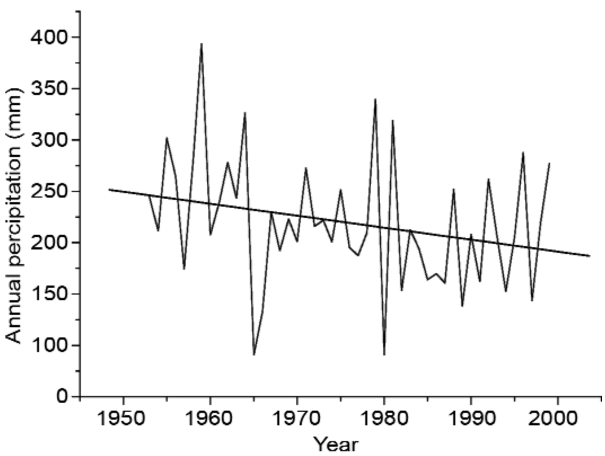

Fig. 3. The precipitation in Sunite Right Banner.

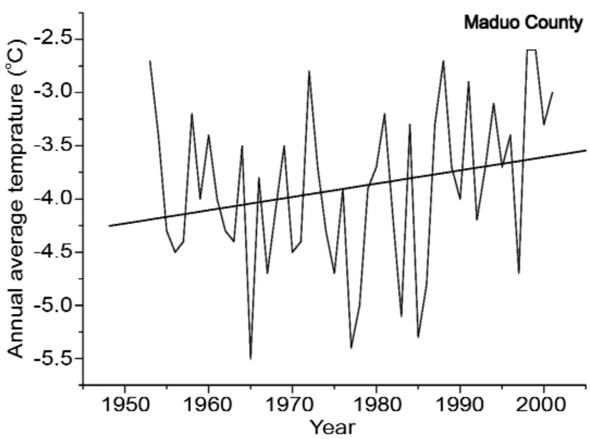

Fig. 5. The temperature change in Maduo County.

customs and other causes. All these natural and human factors will lead to an increase in the desertified area in this region in the future.

Conclusion

Remote sensing monitoring and field survey of desertification status in North China have shown that there has been a vast increase (3600 km^2 in 13 years) in desertified land in North China, which reached 385, 687 km^2 in 2000s.The desertified land had developed at a high rate since 1985 and the speed far exceeded that of the previous two stages (1960s-1970s, 1970s-1980s). The desertification however presents different characteristics in different regions because of the differences in the causal factors. The area of desertified land in the agro-pastoral mixed region has gradually reduced and this trend is likely to continue in the future. The desertified area in the lower reaches of inland rivers has already reached the maximum and there will not be any major change in the future, but the degree of desertification will get aggravated. In the purely nomad pastoral regions, especially in the transition zone between the temperate steppe and the temperate desert steppe, the size and degree of desertification will remain stable in the coming years. Results have shown that desertification is still a very important social and economic problem in North China. The government has already adopted some measures to combat desertification. But the forms and characteristics of the desertification process are different in different regions. Also, the causes of desertification are multiple and complex. For combating desertification, it is urgent to develop answers to such questions as how to rationally distribute water resources among the upper, middle and lower reaches of inland rivers, how to improve the carrying capacity of land under drought, what should be the rational number of livestock and people per unit area under the changing climate, and how to balance the needs of sustainable development with the basic needs for survival in some of the poor regions in North China.

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Factors affecting the formation of water-stable aggregates with sandy soil

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Abstract

The effects of several agents, including clay, silt, oligosaccharide, humus, and phenol compound, were examined on the formation of water-stable aggregates within sandy soil. The results showed that the water-stable aggregates are able to form even within sandy soil, and oligosaccharide (carboxymethycellulose) plays an essential role in aggregate formation, while humus, previously reported as an important component in aggregate formation, does not contribute to aggregate formation. Clay and silt (diatomaceous earth) are not able to contribute to aggregate formation alone but synergistically interact with oligosaccharide during aggregate formation.

Introduction

Improvement of soil properties benefits agriculture and tree planting in arid land. Especially, the water conductance and water-holding capacity of land should be improved. Increased porosity and water infiltration rate reduce the loss of water from run-off and water erosion, and increased air-space enhances root growth. Increased water-holding capacity can reduce the movement of water to deeper parts of the soil and retain it around the roots. To improve these two parameters simultaneously, the development of soil aggregates is useful (El-Samnoudi et al., 1993). Aggregates are higher size structures that consist of sand, silt, clay, and organic material via crosslink between these varied soil particles. The small-size of pores within soil particles in aggregates contributes to increased water-holding, while the large- size pores between aggregates contribute to the increased conductivity of water and air, and root growth. In particular, the water-stable aggregates are important for agriculture.

Several reports have described the components of aggregates such as clay, humus, oligosaccharides, and phenol compounds (Russell 1960; Ae et al. 1987; Angers and Mehuys, 1989; Dinel et al., 1991; Martens 2002). It has been speculated that these components contribute to condensation among larger soil particles and colloids (such as sand and silt), followed by the formation of aggregates. However, direct proof that those components contribute to aggregate formation has yet to be reported. Interactions between the different components during aggregate formation have also yet to be determined. If we can clarify the mechanism of binding the soil particles together, efficient and inexpensive soil improvement measures for arid lands can be developed. Therefore, in this paper we quantify the contribution of several materials to aggregate formation, and clarify the formation of water-stable aggregates within sandy soil.

Materials and methods

Preparation of aggregates

In this study, sandy soil from the Tottori Sand Dune was used as the basic component of aggregates. The soil consists of sand (82.3%) and fine sand (16.4%), with minor silt (0.5%) and clay (0.8%). We added the following to sandy soil: carboxymethycellulose-Na (as oligosaccharide, CMC, at 4, 8 and 20% w/w, WAKO, Japan), kaolin (as clay of particle size 0.4-4 μm, 0-20% (w/w), NAKARAI Co. Ltd, Japan), diatomaceous earth (DE; as a model of silt, as it has silica crystals of size similar to silt, particle size 45 μm on average, 0-20% w/w, KANTO Chem., Japan), humic acid (as humus, 0-2% w/w, KANTO Chem., Japan) and *p*-coumaric acid (0-0.1% w/w, WAKO, Japan) as a phenol compound that according to Ae et al. (1987) has the highest aggregate-forming ability.

We then added 0.5 g of water per g of the mixture and mixed well. The mixtures were incubated at 60°C for 24 hrs. The resulting dried matter was then crushed and sieved.

Estimation of water-stable aggregates

Particles of 5-10 mm in diameter were sieved, and about 10 g of these particles were weighed exactly and passed through a 1-mm pore sieve. The sieve was shaken at 30 rpm (40 mm wide) in water for 5 min. The remaining particles on the sieve were air-dried at 60°C for 24 hrs and weighed. The percentage of water-stable aggregates was estimated as follows:
[(weight of remaining particles after shaking) / (initial weight of particles)]×100

Results and discussion

We first examined the effects of several reagents on the formation of water-stable aggregates within sandy soil (Table 1). We found that aggregates prepared with kaolin (20% w/w), diatomaceous earth (20% w/w), humic acid (2% w/w), or *p*-coumaric acid (0.1% w/w) were not water-stable. In contrast, the application of CMC was effective in the formation of water-stable aggregates; aggregates prepared with 20% (w/w) CMC were almost completely water-stable. These results suggest that oligosaccharide is an essential component in the formation of water-stable aggregates within sandy soil.

Table 1. Effect of different substances on the formation of water-stable aggregates in Tottori Sand Dune soil.

Substances applied (%w/w)		Water-stable aggregates (%)
CMC	4%	39.7±7.2
CMC	8%	95.7±4.3
CMC	20%	98.8±1.1
Kaolin	20%	0±0
Diatomaceous earth	20%	0±0
Humic acid	2%	0±0
p-Coumaric acid	0.1%	0±0

Next, we examined the effects of components other than oligosaccharide on aggregate formation in combination with oligosaccharide. The application of kaolin alone did not affect aggregate formation at all, while the water-stability of aggregates prepared with 4% (w/w) CMC was higher than that with 2% (w/w) CMC. The water-stability of aggregates prepared with 2% (w/w) CMC and 20% (w/w) kaolin was about 47%, however, the application of 4% (w/w) CMC was required for similar water-stability in combination with 0 and 10% (w/w) kaolin. These results indicate that a lower concentration of oligosaccharide may be required to form water-stable aggregates in combination with more than a certain level of clay. Furthermore, the water-stability of aggregates prepared with 4% (w/w) CMC and 20% (w/w) kaolin was about 71%. This value is higher than the stability of aggregates prepared with the addition of 4% (w/w) CMC alone and 20% (w/w) kaolin alone. From these results, we suggest that interaction between oligosaccharide and clay in aggregate formation is synergistic.

Similar results were shown by the combination of CMC and diatomaceous earth (Fig. 1), however, the stability of the aggregates was always higher than in the combination of CMC and kaolin. Diatomaceous earth (DE) may have greater aggregate-formation potential than kaolin. The water-stability of aggregates prepared by a combination of CMC and humic acid was 0%, as was the case with aggregates prepared with a combination of oligosaccharide and *p*-coumaric acid (data not shown). The effects of DE on aggregate formation might result from its function as a silt or a DE-specific function, because DE has remarkable

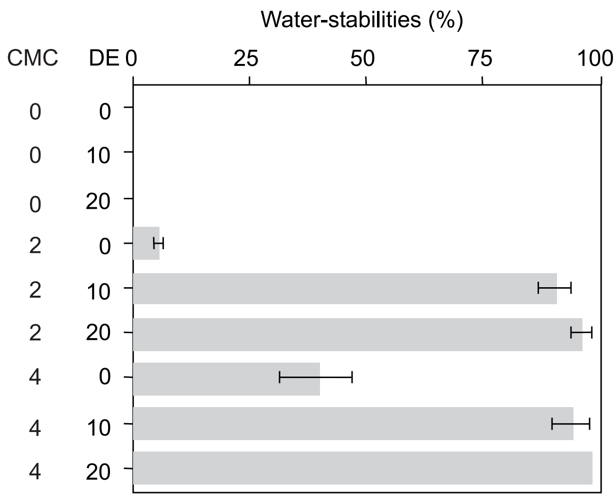

Fig.1. Effects of different combinations of diatomaceous earth (DE) and oligosaccharide (CMC) on the formation of water-stable aggregates within Tottori Sand Dune soil.

characteristics as silt, porous material, and amorphous silica. In future, we will determine whether the formation of aggregates was due to the porous or amorphous characteristic of DE.

We next examined the effects of humus and phenol compound on aggregate formation in combination with oligosaccharide and kaolin. Further application of humic acid and *p*-coumaric acid did not increase the water-stabilities of the aggregates prepared with a combination of 20% (w/w) kaolin and 4% (w/w) CMC (data not shown). These results suggest that humus and phenol compounds do not contribute to aggregate formation within sandy soil.

It has been considered that humus is involved in aggregate structure by crosslink among sand, silt, and clay (Russel, 1960). The results of the present study indicate that humus *per se* does not contribute to aggregate formation in the soil. The fact that organic matter (including humus) is reported to be effective in the development of aggregate structures (Aggelides et al., 2000; Barzegar et al., 1997) can be explained on the basis of the activation of soil micro-organisms that use the organic matter as nutrient (Kawamura et al., 1973); the micro-organisms may produce oligosaccharide. Ae et al. (1987) reported that the application of phenol compounds caused the development of aggregates. They proposed that aggregate formation resulted from the control of the number of micro-organisms and/or the involvement of compounds in the aggregate structure. In the present study, the preparation of aggregates was carried out under temperatures that are unsuitable for micro-organism growth. Our findings confirm that phenol compounds are not involved in the aggregate structure.

As mentioned above, oligosaccharide, clay, and silt are key components of the formation of water-stable aggregates. We therefore examined the effects of various combinations of these three components on aggregate formation. The stabilities of aggregates made from these three components are lower than those made from CMC and diatomaceous earth (Table 2). The results indicate that clay may interfere with the function of DE (for example, kaolin may fill the dimples of DE), and suggest that sandy soil that contains silt but no clay is suitable for the formation of aggregates.

Table 2. Effects of the combination of DE and Kaolin on aggregation stabilities.

Reagents (% w/w)	Water-stable aggregates (%)
CMC 2% + DE 10%	87.9±6.4
CMC 2% + Kaolin 10%	19.1±8.3
CMC 2% + DE 10%+Kaolin 10%	27.7±12.4

Conclusions

Following conclusions are reached from the above study:

1) Water-stable aggregates are formed even when using sandy soil as basic material; 2) oligosaccharide (CMC) plays an essential role in aggregate formation, while humus, previously reported as an important component of aggregate formation, does not contribute to aggregate formation, as with phenol compounds; 3) clay and silt (DE) synergistically interact with oligosaccharide during aggregate formation. Clay and silt are not able to contribute to aggregate formation alone, but aid aggregate formation in combination with oligosaccharide.

The results also indicate that smaller amounts of oligosaccharide are required for aggregate formation in the presence of clay and silt within sandy soil, and that the application of larger amounts of oligosaccharide can form aggregates even in the presence of trace levels of clay and silt in sandy soil. These results would be of use in improving the soil properties in arid land by the application of CMC or oligosaccharide-bearing material such as sewage sludge (Fujishima et al., 1999) and DE.

Acknowledgements

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Application of vegetation information to estimation of soil characteristics in arid environment

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Abstract

This study presents an example of large-scale estimation of soil characteristics using vegetation information in Leonora, Western Australia. Spatial variability of soil characteristics such as permeability and soil layer thickness affects the suitability of land for agriculture in arid environment. We focused on the link between these soil characteristics and vegetation information that would have particularly strong correlation in arid lands. Double-ring infiltrometer tests were performed to evaluate soil permeability in 23 sites which have characteristic ecosystems. Soil thickness measurements were carried out in 54 sites. The vegetation in these sites was surveyed, and distribution map of biomass and canopy coverage were also obtained from remote sensing analysis. Relationships between obtained indices were evaluated quantitatively by linear regression analysis. Results show that most of the infiltration parameters have positive or negative correlation with the biomass and the canopy coverage. Surface soil permeability showed particularly high correlation with vegetation data. Both constants of Kostiakov equation closely correlated with biomass, thus cumulative infiltration for any time and place could be estimated using the biomass distribution map in the whole research area. Soil thickness also had positive and strong correlation with biomass, and distribution map of soil thickness could be made. From these relationships, it was considered that the ecosystems in the research area were formed by the interaction among the soil permeability, soil thickness, water flow and vegetation. Infiltration properties and soil thickness could be estimated using biomass information at large-scale, and ecosystem quality was clarified in the research area.

Introduction

Large-scale estimation of soil characteristics is important in environmental prediction, precision agriculture, and natural resources management. Especially in arid environments, soil permeability is one of the most important information because it governs movement of water resources through infiltration and runoff occurrence. Soil thickness of the surface layer above underground hardpans or basement rocks is also significant because hardpans and basement rocks are impermeable and they limit water movement. These kinds of soil information are also essential as input data for water balance calculation and analysis by rainfall-runoff modeling. However, a number of recent studies have shown that the soil characteristics vary greatly within short distance (e.g., Sharma et al., 1980; Tricker, 1981; Berndtsson et al., 1985).

Estimation of the spatial variability of soil characteristics is one of the major topics in recent studies (e.g., Burrough, 1993). Generally, as the distance between two data points decrease, the differences in soil properties will also decrease. Therefore, geostatistical methods are useful in quantifying spatial variability of soil properties. Analysis of spatial correlation by geostatistics can evaluate relationships between values and distance of spatially separate data points using concepts such as auto-correlation or cross-correlation. However, in the spatial correlation, data between more distant points have a lower correlation in soil characteristics. This means that quantification of the spatial variability using spatial correlation can be more difficult with scaling-up of the observation area (Berndtsson and Larson, 1987).

Berndtsson and Larson (1987) showed that understanding of the relationships among soil properties and geological, topological, ecological factors is more important than the approach based on spatial correlation in quantifying spatial variability in a small catchment scale. This tendency would be more apparent with scaling up of the target area. Geological, topological and ecological information can be estimated relatively easily and inexpensively using remote sensing technique over large areas, even in arid environments. Therefore, directly clarifying and quantifying of relationships among soil characteristics and geological, topological and ecological factors would be effective in estimating soil characteristics at large scale such as including several small watersheds.

A considerable number of studies have been conducted on the strong connectivity between infiltration parameters and vegetation information (e.g. Bruce et al., 1992; Weltz et al., 2000; Wainwright et al., 2002). Concerning the relationships between soil thickness and vegetation information, Lamotte et al. (1994) showed the depth and distribution of hardpans of arid zone is closely associated with differences in vegetation by electrical resistivity survey and morphological observations in Cameroon. Therefore, if strong and quantitative correlations can be found between these relationships, spatial variability of infiltration properties and soil thickness would be estimated directly using a vegetation map by remote sensing. In the present paper, we conducted infiltration tests, soil thickness measurements and vegetation surveys in number of sites which have characteristic ecosystems in a large arid field including several small watersheds, and evaluated quantitatively the relationships between these obtained indices by linear regression analysis.

Materials and methods

Research area

The research area was in Leonora, about 600km northeast from Perth, Western Australia. The area stretched approximately 30 km east to west and 50 km north to south (Fig. 1). Originally, this research area was established to develop a methodology for afforestation and to estimate the effect of carbon fixation, and for various other studies (e.g., Yamada, 2004). With an average annual rainfall of 211.7 mm (S.D. = 109.1) it is a typical arid area (Yasuda et al., 2001). The topographical gradient is less than 1%. However, these gentle slopes construct many creeks. When rainfall events occur, the creeks function as drainage paths for runoff to the vast and shallow salt lake in the lowest elevation. The surface soil contains abundant quantities of ferric oxide and is colored red due to laterization (Vreeswyk, 1994). Low permeable crust and impermeable hardpans are formed under the topsoil. About half of the research area is bare ground and low open woodland, where canopy coverage was less than 10% and the other half was woodland and open forest, where canopy coverage varied between 10 and 50% (Suganuma et al., 2004). The dominant species is *Acacia aneura*, which is the main woody species. *Eucalyptus camaldulensis* open forest and woodlands are observed adjacent to some creeks. Around the salt lake, salt-tolerant shrubs and bushes are observed.

Analyzed data set

Infiltration data:
Double-ring infiltrometer tests were performed in 23 sites (Fig. 1). The inner rings, 0.30 m diameter and 0.30 m deep were carefully driven into the

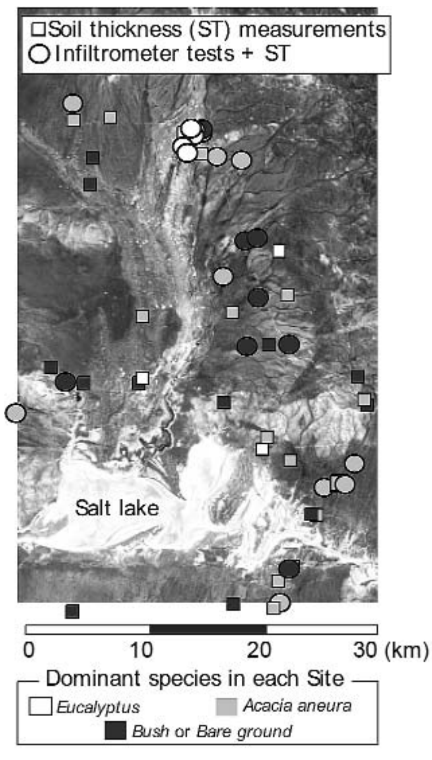

Fig. 1. Map of research Area and distribution of measurements.

soil 0.10 m. Each infiltration run continued for 1.5 h by which time a steady state rate had been attained. Two commonly used infiltration equations, Kostiakov and Philip, were fitted to the infiltration data collected during tests (Kostiakov, 1932; Philip, 1957). Cumulative infiltration (D) in mm can be expressed by the Kostiakov equation as follows:

$$D = ktn \quad (1)$$

where t is the time that water has been in contact with the soil in min, and k and n are the constants, and k also means 1 min infiltration in mm. The Kostiakov equation is empirical one and its parameters do not have clear physical meaning while it is simple and easy to define. On the other hand, the Philip equation is physically based, and given by:

$$D = St1/2 + At \quad (2)$$

The parameters S and A in the Philip equation have some physical meaning, S accounts for sorption of water at the beginning of the infiltration process while A accounts for the long-term infiltration rate. We also introduced a parameter Dt, which is the cumulative infiltration for any t minutes, as an infiltration parameter. Therefore, the parameters k, n, S, A and Dt were obtained in each test site as soil infiltration characteristics.

Soil thickness data:

Soil thickness (*ST*) measurements were carried out in 54 sites (Fig. 1). In 23 out of these 54 sites, infiltration tests were also performed as stated above. The surface soil above the underground hardpan was dug out by an engine auger, and the soil layer thickness was measured. In the some sites, soil layer thicknesses varied within short distance. Therefore, we measured them at least at 10 points in each site area, and average soil thickness was calculated and used as *ST* of the site.

Vegetation data:

The method has been described in detail by Suganuma et al. (2006). We established 35 sites (mainly 50 m × 50 m) and tree height and canopy silhouette area of all trees were measured. All of the infiltration tests and most of the *ST* measurements were also carried out at the same sites. Each tree biomass was calculated by allometric equations using a destructive sampling method (Taniguchi et al., 2002). As the result of remote sensing analysis and above mentioned field measurements, the biomass (*BM*, in kg m^{-1}) distribution was estimated in the whole area. The canopy coverage (*CC*, in m^2 m^{-2}) distribution was also calculated from aerial photograph computational interpretation by Suganuma et al. (2004). Therefore, the *BM* and the *CC* as vegetation data could be obtained to correspond to the infiltration and the *ST* data for every soil survey site. In addition, from the result of the ground truthing, all of the soil survey sites were put into three vegetation categories by the dominant species and the ecosystem in the sites: Eucalyptus (EP) sites, *Acacia aneura* (AA) sites, and bush or bare ground (BB) sites.

Data analysis

Regression analysis was used to evaluate quantitatively the relationships between infiltration parameters, soil thickness, and vegetation data. Of the different regression functions the linear equations showed relatively high value of correlation coefficient. Therefore, only linear regression equation was used as follows:

$$Y = a + b(x) \quad (3)$$

where Y is the dependent variable, x is the independent variable, a and b are the regression constants. In this paper, soil characteristics would be predicted by vegetation data, thus *BM* and *CC* were used as the dependent variables, and k, n, S, A, Dt and *ST* were used as the independent variables in equation (3).

Results and discussion

Table 1 shows the output of resulting linear regression equations relating vegetation data to infiltration parameters. Most of the infiltration parameters were well correlated with the biomass (*BM*) and the canopy coverage (*CC*). Surface soil permeability showed particularly high correlation. With decrease of t value of Dt, correlation coefficient between Dt and *BM* or *CC* was increased. This means that shallower soil has stronger correlation with vegetation in this area. This might be because of the interaction among soil permeability, water flow and vegetation.

Table 1. Linear regression equations relating vegetation data to infiltration parameters

Vegetation data (x) vs.	Infiltration parameters (Y)	Regression R	parameters R^2	a	b	n
Biomass (BM)	k	0.90	0.80	2.53	1.16	23
	n	-0.70	0.50	0.86	-0.02	23
	S	0.85	0.72	2.89	0.96	23
	A	0.20	0.04	1.32	0.05	23
	D_5	0.82	0.68	12.51	2.51	23
	D_{10}	0.77	0.59	21.83	3.64	23
	D_{60}	0.54	0.30	101.77	10.29	23
Canopy coverage (CC)	k	0.80	0.64	2.29	17.17	23
	n	-0.58	0.34	0.85	-0.27	23
	S	0.80	0.64	2.37	14.95	23
	A	0.30	0.09	1.11	1.20	23
	D_5	0.82	0.68	10.19	41.36	23
	D_{10}	0.79	0.62	17.72	61.86	23
	D_{60}	0.60	0.36	85.44	186.26	23

R = Correlation coefficient; R_2 = Determination coefficient; a and b = Regression coefficients; n = Number of sites; D_5, D_{10}, D_{60} = Dt (t = 5, 10, 60 min).

Fig. 2 shows the relationship between constant k of Kostiakov equation and BC. The constant k had positive and extremely strong correlation with BC. The regression line between k and BC was as follows:

$$k = 1.16BM + 2.53 \quad (4)$$

Fig.3 shows the relationship between constant n of Kostiakov equation and BC. The constant n had negative but strong correlation with BC. The regression line between n and BC was as follows:

$$a = -0.02BM + 0.86 \quad (5)$$

Therefore, both constants of Kostiakov equation closely correlated with BM. Thus, substituting the regression equations (4) and (5) to Kostiakov equation (1), cumulative infiltration D could be expressed as a function of BM and t as follows:

$$D(BM,t) = (1.16BM + 2.53)t\ -0.020BM + 0.86 \quad (6)$$

Fig.4 shows the relationship among cumulative infiltration, biomass and time which was expressed by equation (6). Simultaneous use of equation (6) and the biomass distribution map enable estimation of the cumulative infiltration for any time and place in the research area. Therefore, we could estimate spatial variability of infiltration using biomass and get the infiltration distribution map in the area.

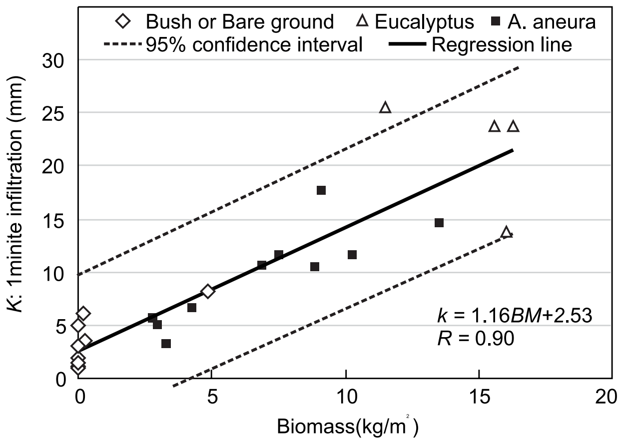

Fig. 2. Relationship between constant k of Kostiakov equation and biomass.

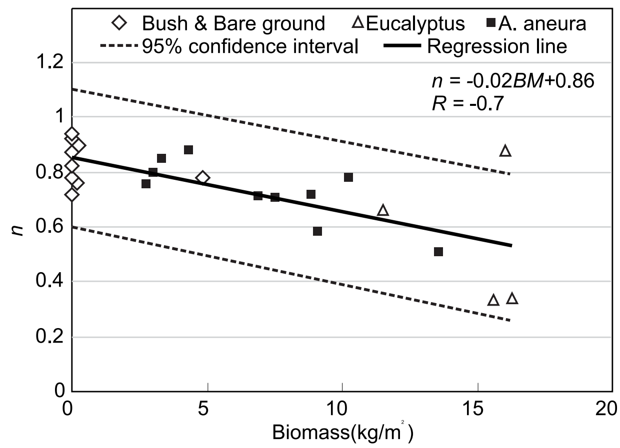

Fig. 3. Relationship between constant n of Kostiakov equation and biomass.

The relationship between soil thickness (*ST*) and biomass are shown in Fig.5. *ST* had positive and strong correlation with *BM* (R = 0.82; n = 54). Bush or bare ground (BB) sites concentrated in lower biomass and thinner soil areas, because the underground hardpans would limit not only the infiltration capacity but also the root growth (Saito et al., 2000). However, *Acacia aneura* (AA) sites dispersed widely in thin to deep soil area, and low to high biomass. It is considered that *Acacia aneura* can grow without any dependency on soil thickness. This might be a reason why *Acacia aneura* is the dominant spices in the research area. Eucalyptus (EP) sites concentrated in higher biomass and thicker soil areas, thus, Eucalyptus would need much soil thickness for growth. As shown in Fig.5, *ST* could be expressed as a function of *BM* using the regression equation as follows:

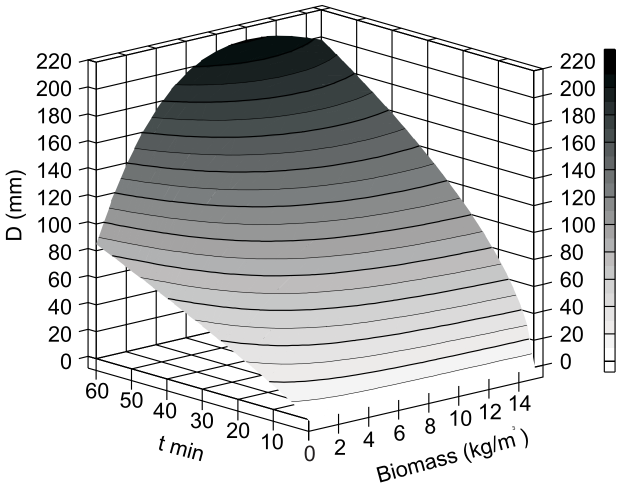

Fig. 4. Relationship among cumulative infiltration, biomass and time.

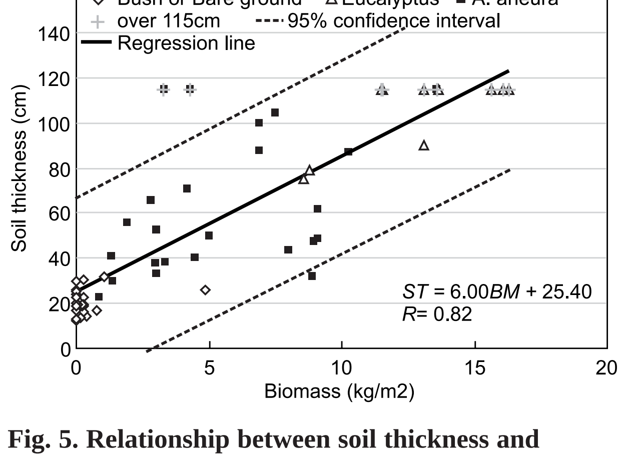

Fig. 5. Relationship between soil thickness and biomass.

$$ST(BM) = 6.00BM + 25.40 \quad (7)$$

By simultaneous use of equation (7) and the biomass distribution map, *ST* distribution could be estimated in the whole research area, and distribution map was made as shown in Fig. 5. *ST* also showed close correlation with canopy coverage (*CC*) (R = 0.75; n = 54), but it was weaker than the relationship between *ST* and *BM*.

Through the measurements and the analysis in this study, the interaction among infiltration, soil thickness, water flow and vegetation could be clarified in the research area. In the low vegetation area, the soil permeability was low and the soil thickness was thin. Less coverage with vegetation enhances the runoff rate and accelerates soil erosion. Moreover, erosion reduces the soil thickness and that means the decrease of infiltration and root growth capacity. Low permeability of the soil also reduces the water supply to root zone. Consequently, a bad environment is constructed for plant growth under this bad cycle in the low biomass area. On the other hand, the high vegetation area had the high soil permeability and the thick soil layer. In this area, the litter from vegetation improves the soil permeability, and the coverage of the soil surface with plants makes the velocity of runoff slower under this good cycle for

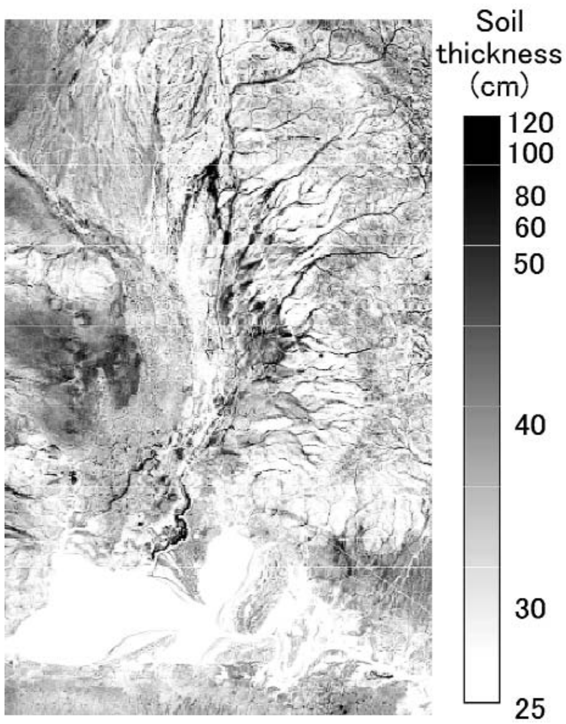

Fig. 6. Distribution map of soil thickness.

vegetation. Abe et al. (2003) conducted a comparative analysis between biomass and topographic features in the same research area and concluded that plant growth is related to the movement and the volume of runoff water derived from inequalities of the ground, which leads to biased distribution of the nutrient accumulation and of the surface soil thickness. It is believed that this study confirms the explanation described above.

Conclusion

The study showed that infiltration properties and soil thickness could be estimated using biomass information at large-scale in this arid environment. Most of the infiltration parameters were correlated with the biomass and the canopy coverage. Surface soil permeability showed particularly high correlation with vegetation information. Both constants of Kostiakov equation closely correlated with biomass, thus cumulative infiltration for any time and place could be estimated using the biomass distribution map in the whole research area. Soil thickness also had positive and strong correlation with biomass, and distribution map of soil thickness could be made. These relationships show that the ecosystems in the research area were formed by the interaction among the soil permeability, soil thickness, water flow and vegetation. Soil permeability and soil thickness information are essential as input data for water balance calculation and analysis. Some results of this study have already been made use of in the large-scale rainfall-runoff modeling, and almost satisfactory results have been obtained (Kojima et al., 2004). We hope that this study will improve the rainfall-runoff modeling in the future.

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Hydrological characteristics of a dam farmland in the Loess Plateau, China

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Abstract

This study presents hydrological characteristics of a dam farmland in the Loess Plateau, China. The area has clearly separated rainy and dry seasons. Rainfall in the rainy season (June, July, August and September) exceeds 70 % of the annual precipitation. Typical of the semi-arid environment, there is a large temporal fluctuation in the annual precipitation. Some frequencies were detected by the spectrum analysis and the Fourier series with those frequencies followed the trend of the precipitation time series. There is a link between the precipitation time series and the sea surface temperature over the South China Sea. Using this link, precipitation in summer was forecasted by the Artificial Neural Network model. Results of the hydrological observation showed that groundwater level in dam farm land was not sensitive to precipitation less than 10 mm day^{-1}. In a case of heavy precipitation event, soil water content at shallow depth increased only temporarily. Few days after big precipitation event, soil water content at deep layer increased prior to groundwater table. Precipitation at the upper hilly region infiltrated and recharged groundwater in the lateral direction. Calculation of the conceptual tank model indicated delayed groundwater recharge. Numerical simulation for unsaturated – saturated water movement at the longitudinal section of the dam farmland indicated delayed recharge in the lateral direction.

Introduction

Soil erosion is very serious problem in the Loess Plateau region of China. The Yellow River transports huge amount of yellow sediment to the Gulf of Bohai from the Loess Plateau. Some of the soil erosion results in the spring dust storms in East Asia. To prevent serious erosion reforesting has been promoted and the positive effects of the reforesting on the mitigation of floods have been reported (e.g. Huang et al., 2003; Huang and Zhang, 2004).

The Yellow River was an ‘incubator’ of great ancient Chinese culture and has supported a large population in the north China Plain until today. However, the river is showing signs of drying in last few decades because of increasing water withdrawals due to the economical development and desertification in the upper reaches. In the Loess Plateau, reservoirs of check dams are often filled by sediment within only a few decades after the construction because of serious soil erosion. These filled reservoirs have long been used as ‘dam-farmland’ (Xu et al., 2004). Since they are filled by fertile soil material evenly, dam farmlands have high potential for agricultural productivity.

While reclamation of dam farmlands is done for sustainable production, the irrigation facility is not always developed for the economical reasons. Information on the hydrological characteristics of dam farm land is therefore essential to initiate effective irrigation planning. Results of hydrological observations of small watershed in the Loess Plateau have been reported (e.g. van den Elsena et al., 2003; Stolte et al., 2003). However hydrological observations on dam farmland are limited. Since dam farmland is one hydrological unit of the Yellow River, hydrological information of such lands in the Loess Plateau would contribute to development of the strategy for integrated water management of the Yellow River.

This study presents the hydrological characteristics of a dam farm land in the Loess Plateau, undertaken under the ‘21st Century Center of Excellence (COE) Program for Arid Land Research’ of the Ministry of Education, Japan and the Project on ‘Combating Desertification and Research on Developmental Utilization in Inland China’ supported by the Japan Society for the Promotion of Science. The hydrological observations have been carried out at a small watershed of Liudaogo, Shenmu city in the north of Shaanxi Province, China (Fig. 1).

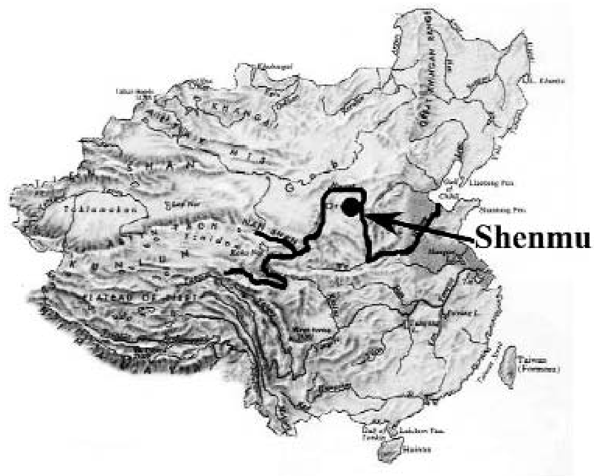

Fig. 1. Location of study area in the Loess Plateau.

Precipitation

Precipitation is an important resource of the hydrological circulation. Analysis of precipitation time series of the study area therefore is of high priority. However historical precipitation data of Shenmu city are not available. In stead, we used precipitation record of three surrounding stations, Xinxian, Yulin and Hequ (Fig. 2). Rainfall data of those cities for 40 years (1961 – 2000) were used for analysis (Yasuda et al., 2005).

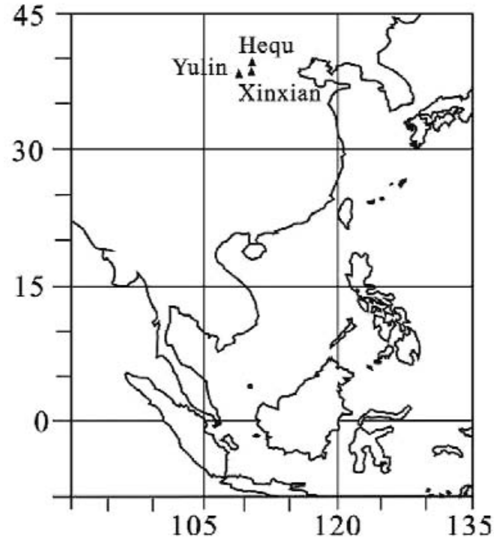

Fig. 2. Location of 3 rainfall measurement stations.

Monthly and annual precipitation

Big annual fluctuation is shown in the time series of the monthly precipitation in Fig. 3. Occasional occurrence of the drought can also be recognized. The monthly average precipitation for 40 years (1961-2000) is shown in Fig. 4. There is a clear difference between the rainy and the dry season.

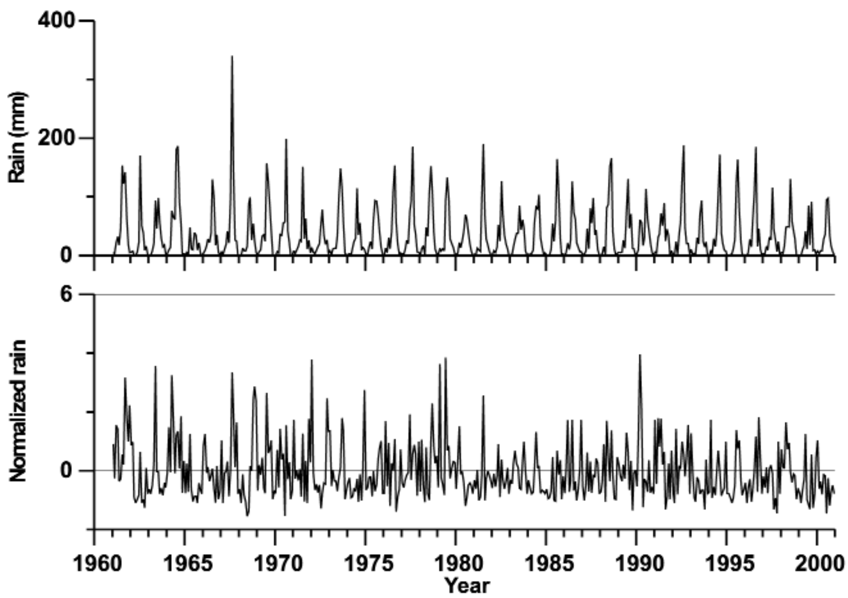

Fig. 3. Time series of the monthly precipitation.

Total for the rainy season (June, July, August and September) exceeds more than 70 % of the annual precipitation. Rainfall in both July and August is double that of any other month, and the combined precipitation for these two months contributes half of the total annual precipitation. The maximum precipitation is in July and the coefficient of variation also indicates a maximum in July.
The annual precipitation time series of three stations, Hequ, Yulin and Xinxian is shown in Fig. 5. The time series is normalized by the mean and the standard deviation for the data span. Large fluctuations of more than two times the standard deviation appear to have occurred in 1960's. The maximum value appeared in 1964 and the minimum in 1965. The normalized monthly precipitation in July and August are also shown in the figure. The tendencies of the annual precipitation follow the variations of the monthly precipitation in July and August. Correlation coefficient of the annual precipitation with the monthly precipitation in July and August was 0.717 and 0.718 respectively.
Fig. 6 shows the strange attractor of moving average 3 months (MA3) of the precipitation time series. The attractor consists of R(t) and R(t+2). The attractor may be separated to two groups, the normal trajectory and the drought trajectory. There is the threshold of the maximum monthly precipitation, 90 mm to separate the attractor.

Fourier series fitting by the optimum combination of frequencies

The optimum combination of frequencies was obtained by the spectrum analysis and the Akaike Information Criterion (AIC) optimization. Table 1 indicates the optimum combination of frequencies. The optimum Fourier series follows the trend of the original precipitation time series (Fig. 7). The precipitation time series of the study area contains frequencies in Table 1.

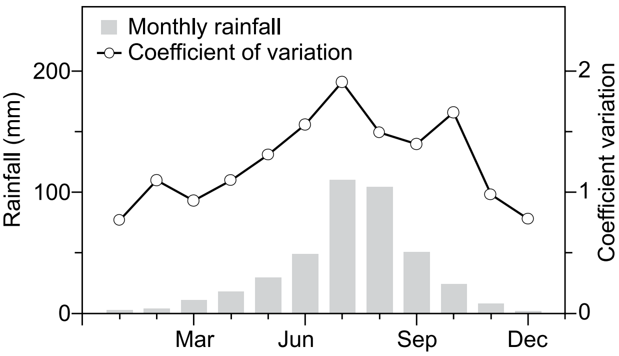

Fig. 4. Monthly average rainfall for 40 years and the coefficient of variation.

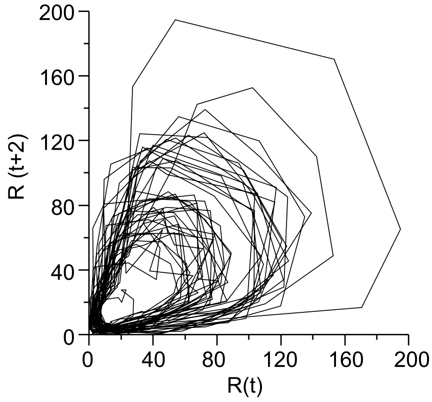

Fig. 6. The attracter of time series 3-month moving average (MA3).

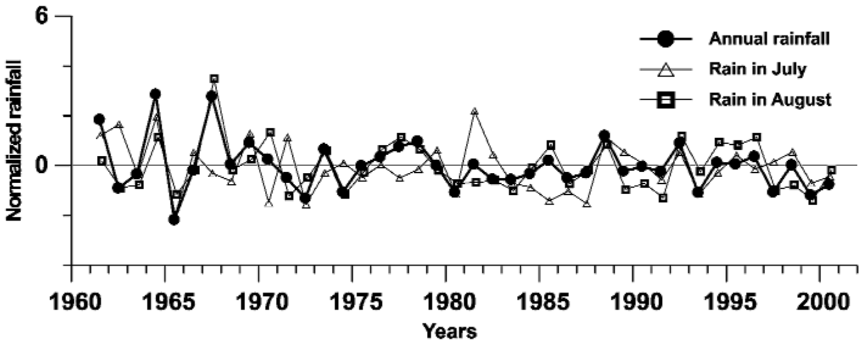

Fig. 5. Normalized annual rainfall and monthly rainfall in July and August.

Table 1 The optimum combination of frequencies

f (cycle/month)	0.1553	0.1056	0.0593	0.0525	0.0293	0.0227	0.0059
T (year)	0.5	0.8	1.4	1.6	2.8	3.7	14.1

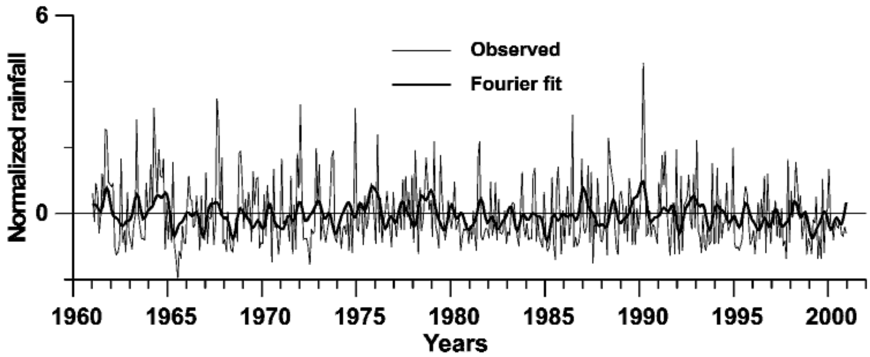

Fig . 7. Fit of Fourier series to the original rainfall time series. The optimized Fourier parameters in Table 1 were applied.

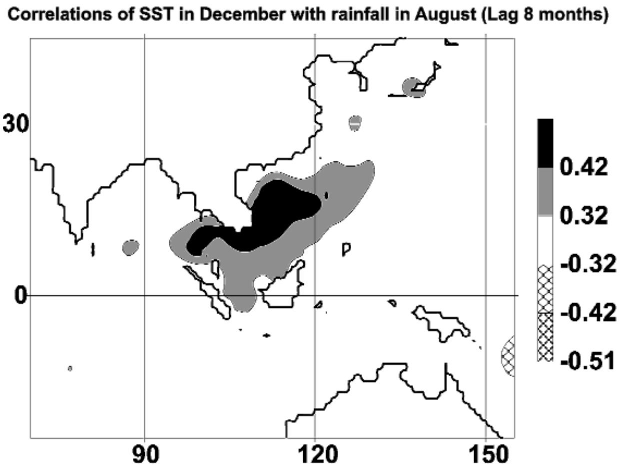

Fig. 8. Region of SST of correlation coefficient more than 0.32 and 0.42., which correspond respectively to the significance level of 0.05 and 0.01.

Precipitation forecasting using the link with the sea surface temperature

Cross-correlation between the precipitation time series and the sea surface temperature (SST) indicates significant link of the precipitation and the SST over the South China Sea. Fig. 8 shows significant correlation of SST over the South China Sea with precipitation in August. Using this link, the artificial neural network model (ANN model) was used to forecast precipitation in August. Fig. 9 shows fit of the forecast by the ANN. Tendency of the original time series is well followed by the ANN model.

Hydrological observation

Study area in the Loess Plateau

Hydrological observations on precipitation, groundwater level and soil water content were carried out at a small watershed at Liudaogo, Shenmu, Shaanxi Province. There is an observation station of the Institute of Soil and Water Conservation at Liudaogo (ASMWR, 1993). The study areas were two small watersheds (Fig. 10) at the upstream of Liudaogo area (6.89 km^2). Check dams have been constructed at the down boundary of those watersheds a few decades ago (Fig. 11). Both the watersheds have been filled by sediment. A watershed in the left bank (0.94 km^2) is used as a dam farm land (Xu et al., 2004). Only downstream site was used as a farm land at another watershed of the right bank (0.79 km^2). Groundwater level in sediment was observed at the both sides.

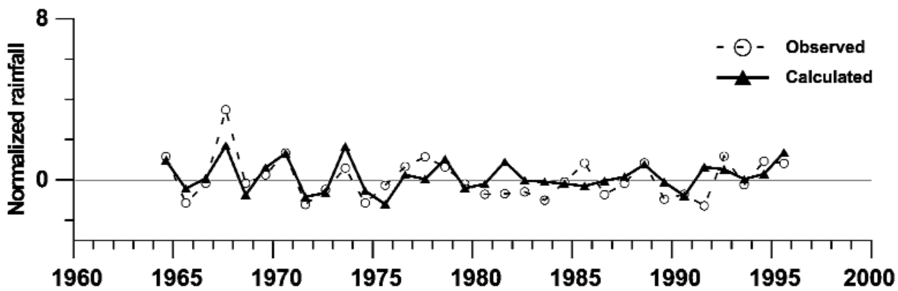

Fig. 9. Forecast of rainfall in August from SST in December by the ANN.

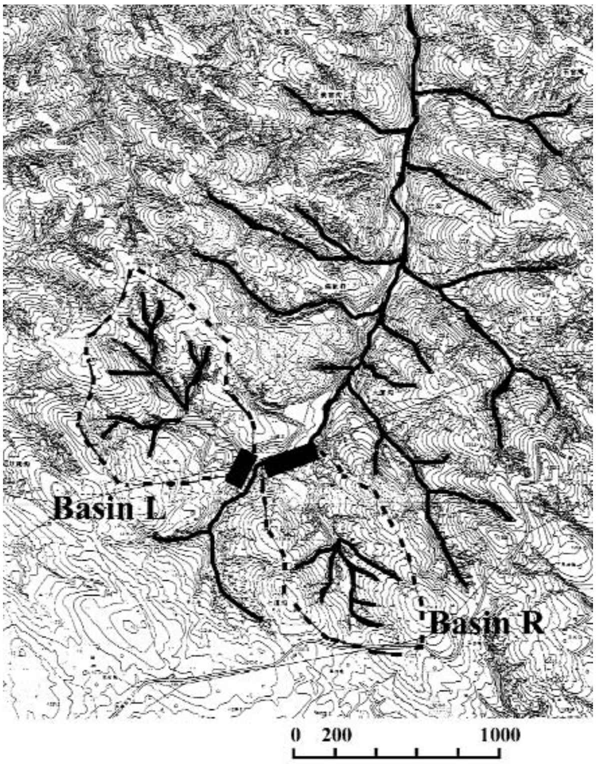

Fig. 10. The location of the two small watersheds used as study area. Black bar shows the location of check dams.

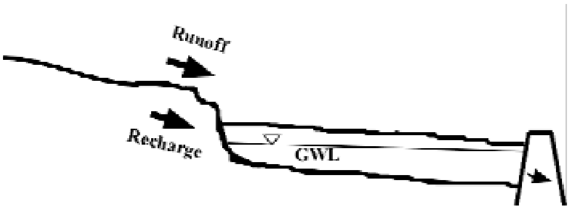

Fig. 11. Diagrammatic representation of runoff and recharge of ground water level (GWL) in the dam farm land.

Soil property of the study area was analyzed by Zheng (2004). Average distribution in the 0 – 160 cm profile is 40.3 % sand (>0.05 mm), 44.2 % silt (0.05 - 0.002 mm) and 15.5% clay (<0.002 mm). Soil water retention characteristics were given as in the van Genuchten model (Zheng, 2004) and shown in Fig. 12. The capillary rise height is about 20 – 30 cm, so 20 – 30 cm thickness of the saturated soil zone covers the groundwater table.

Groundwater level and soil water content

Fig. 13 shows groundwater level (m from the sea level), volumetric soil water content (m^3 m^{-3}) and precipitation (mm day^{-1}) from 2004 to 2005. Just

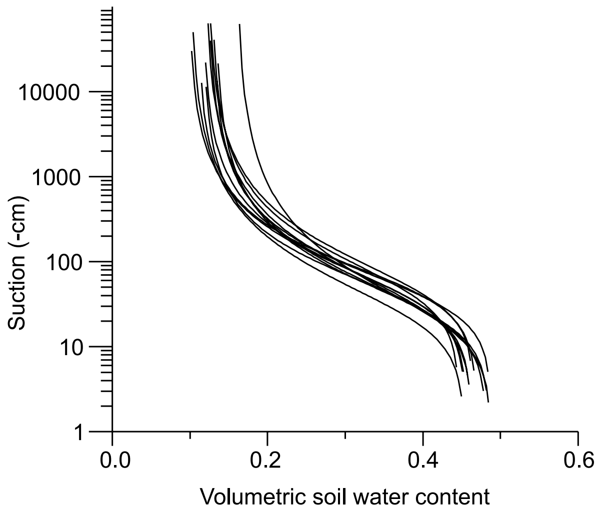

Fig. 12. Soil water characteristic curves (Zheng, 2004).

after setting up of the measurement devices (in August 2004), heavy precipitation event was observed and groundwater level increased more than 1 m. Prior to the rise in the groundwater level, soil water content increased. Groundwater level did not show response to precipitation less than 10 mm day^{-1}. Groundwater level at the left bank watershed occasionally showed intensive increase. These were caused by the change in pumping at the wells. Farmers at the left bank use groundwater for irrigation. In spring 2004, groundwater level increased due to snow and ice melt. Groundwater level was higher in 2004 than 2005 because of higher precipitation. To see short span response of the groundwater level, groundwater and soil water content after a precipitation event in August 2004 is shown in Fig. 14. Due to a big precipitation event, soil water content at 0.3, 0.7, 1.0 and 2.0 m depth increased. The increase first occurred at 2.0 m depth and then at 1.0, 0.7 and 0.3 m in that order. Increase of soil water content at 0.3 m depth was only slight and temporary. High water content at 0.7 and 1.0 m depth continued several days and turned to decrease. Few days after the precipitation event groundwater level started to increase. These phenomena suggest groundwater recharge in the lateral direction. Precipitation over the filled sediment part of the watershed increased soil water content at the shallow region temporarily. Precipitation over the upper hilly area infiltrated and turned to lateral recharge of groundwater. Height of the capillary rise was 20 – 30 cm depending on the soil type.

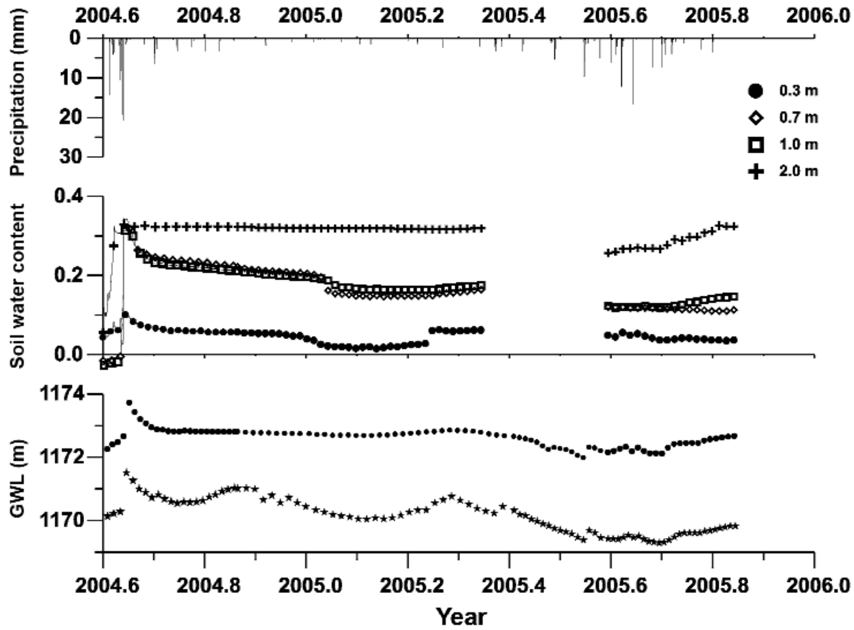

Fig. 13. Groundwater level and soil water content after the precipitation event.

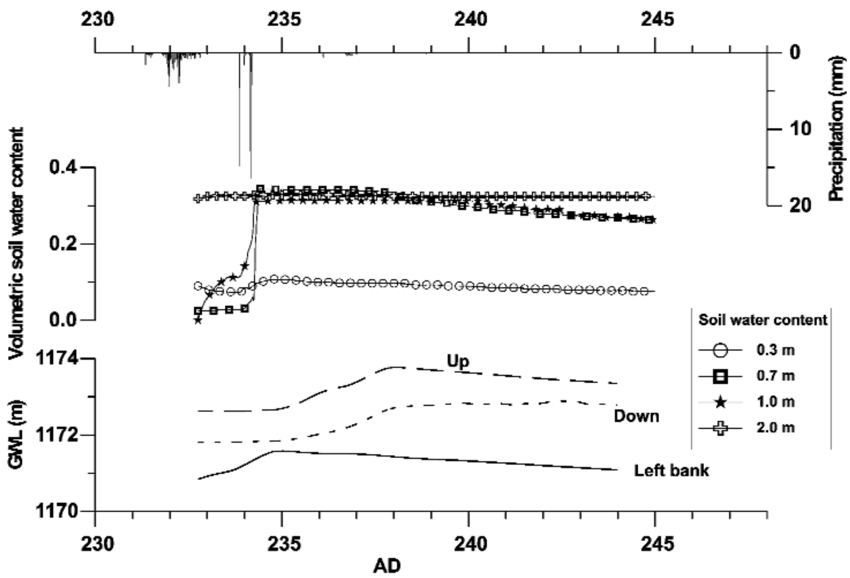

Fig. 14. Groundwater level and soil water content after the precipitation event.

Recharge mechanism of groundwater in the dam farm land

As shown in Fig. 13, there was few days lag between the change in the groundwater level and the precipitation event. It was caused by the lateral recharge process. Tsutsumi et al. (2004) developed a groundwater recharge model for shallow unconfined groundwater using the conceptual tank model (Fig. 15). This model presents the vertical recharge. In the model, outlet level R0 gives a delay effect of groundwater recharge. To evaluate groundwater recharge and runoff at the upper stream region of the farm land, calculation was carried out (Fig. 16). The model showed that runoff occurred only for high precipitation intensity and groundwater recharge continued for long period. At the right bank watershed, the boundary between the upper stream region and the dam farm land forms a water-fall and runoff flows down to the top of the dam farmland to infiltrate. Those phenomena indicate the effect of lateral recharge of the groundwater.

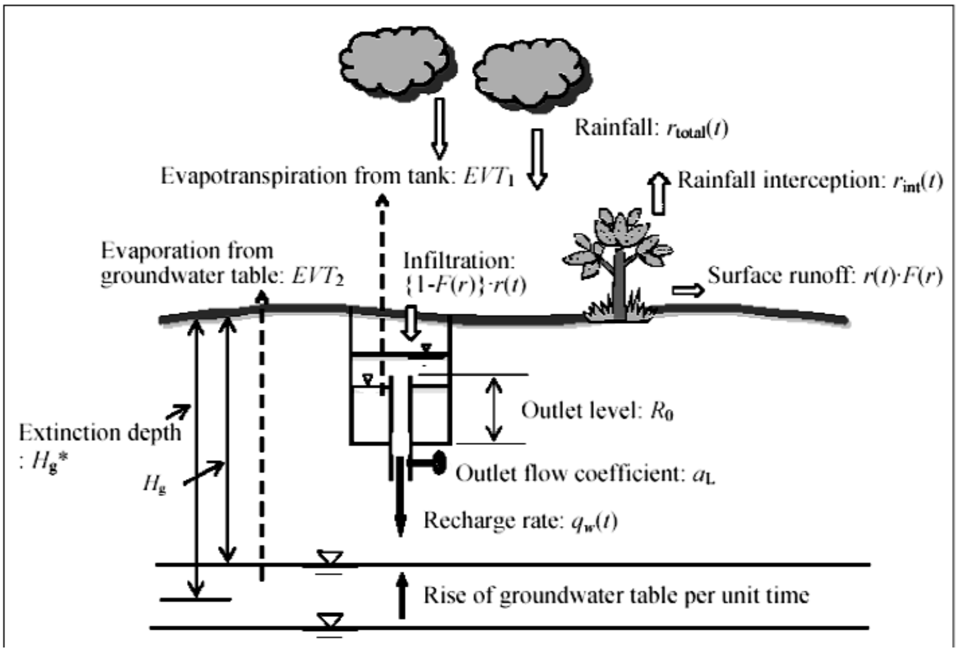

Fig. 15. Conceptual groundwater recharge model.

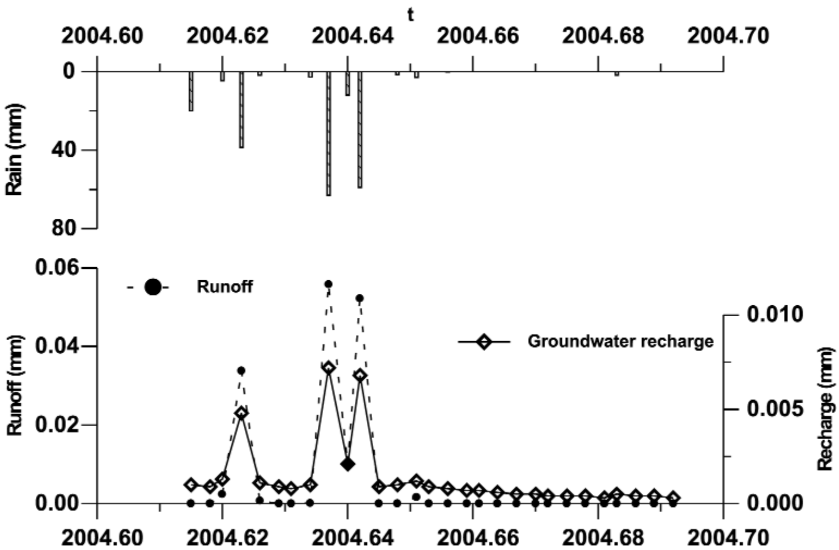

Fig. 16. Runoff and recharge calculated by the model.

For modeling of the recharge mechanism of groundwater in the dam farm land, numerical calculations were carried out. Saturated-unsaturated water movement on a vertical longitudinal section (100 m × 4 m) of a valley (supposing the right bank) was calculated by numerical calculation model, SWMS–2D (Simunek et al., 1994). The soil water characteristics distribution is necessary for the calculation.

Zheng (2004) obtained the van Genuchten parameters at Liudaogo as shown in Table. 2 and those values were used for the numerical calculation. Fig. 17 shows distribution of the matric suction of the vertical longitudinal section. Overland flow was caused by high precipitation intensity and it flowed into the upper boundary as the ponding condition. The ponding water infiltrated downward as the groundwater recharge and groundwater level (the matric suction is 0 m) increased. In the figure, groundwater level is corresponding to 0.0 m matric suction. Due to the layered structure of the soil water retention characteristics, the horizontal distribution is recognized at 0.5 and 1.0 day. As shown

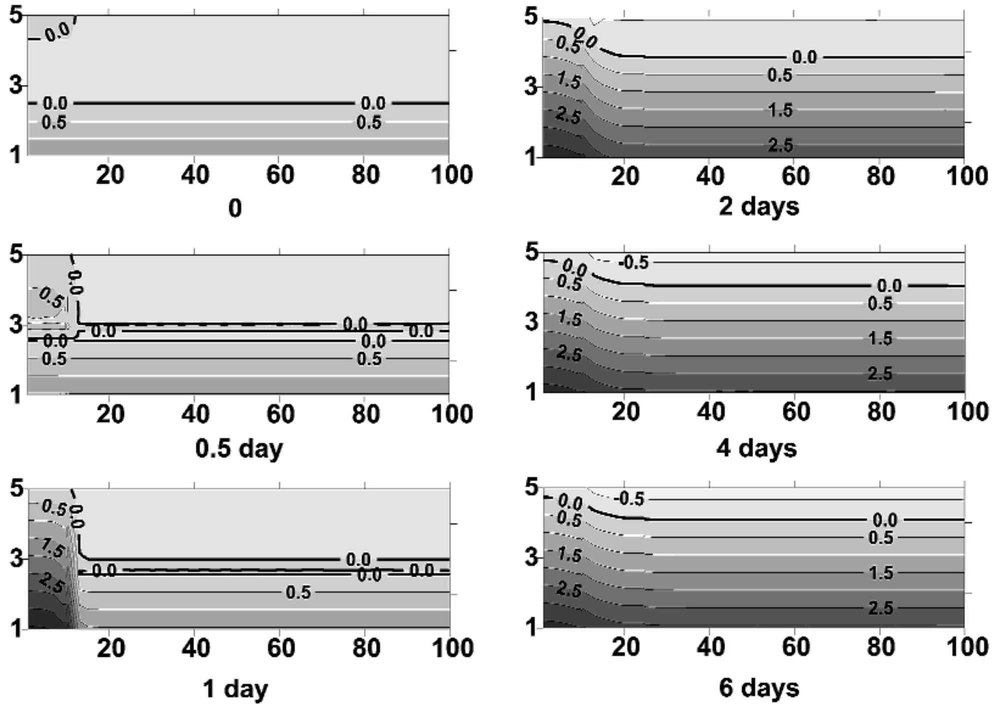

Fig. 17. Pressure head distribution on the longitudinal section of the dam farm land. Iso-lines indicate pressure head (m H_2O). Line of 0.0 is corresponding to the groundwater table.

Table 2. Vertical distribution of the van Genuchten parameters (Zheng, 2004)

Depth (cm)	èr	ès	á	n	ks (cm/day)
0-10	0.1607	0.4879	0.0467	1.5771	27.27
10-20	0.1006	0.4530	0.0405	1.6047	32.91
20-30	0.1174	0.4609	0.0265	1.8057	32.14
30-40	0.1230	0.4814	0.0358	1.6338	31.33
40-60	0.1197	0.4627	0.0296	1.6106	27.03
60-80	0.1327	0.4849	0.0368	1.6898	38.62
80-100	0.1313	0.4875	0.0242	1.7969	28.66
100-120	0.1113	0.4649	0.0186	1.8430	21.13
120-140	0.1169	0.4540	0.0229	1.7397	21.14
140-160	0.1279	0.4463	0.0196	1.6886	16.02
160-180	0.1232	0.4692	0.0207	1.6411	14.13
180-200	0.0986	0.4556	0.0225	1.7063	15.36

in Fig. 14, there was a lag of a few days in the groundwater level increase and the occurrence of precipitation. This time lag was caused by lateral recharge. Results of the numerical simulation also showed delay of groundwater level increase.

Conclusion

There is a large fluctuation in the time series of the annual precipitation in the north of the Loess Plateau as is usual in the semi-arid environment. The Fourier series with some frequencies follows the precipitation time series. There is a link between the precipitation time series and the sea surface temperature over the South China Sea. Using this link, precipitation in summer could be forecasted by the Artificial Neural Network model. Groundwater level did not respond to precipitation if it was less than 10 mm day-1. In a case of heavy precipitation event, soil water content at shallow depth increased temporarily. A few days after the precipitation event, soil water content at deep layer increased prior to the rise of groundwater level. Precipitation in the upper hilly region infiltrated and recharged groundwater from the lateral direction. Results of numerical calculation using the conceptual tank model and simulation model on unsaturated – saturated soil water movement (SWMS_2D) indicated groundwater recharge in the lateral direction.

Acknowledgement

This study was financially supported by the Program for Arid Land Research, 21st Century COE program of the Ministry of Education, Japan and the project of Combating Desertification and Researches on Developmental Utilization in Inland China of the Japan Society for the Promotion of Science. The first author gratefully acknowledges the kind help of staff of the Institute of Soil and Water Conservation, Chinese Academy of Sciences, PRC, and also thanks the inhabitants of Liudaogo for their cooperation in the study.

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Theme: Dust-storm Process

Assessing wind erosion vertical dust fluxes: direct measures vs. models

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Abstract

Within the framework of the Sino-Italian cooperation project "WinDust", aiming at studying dust and sand storms in Northern China, a new technology was developed to measure net vertical fluxes of mineral dust by wind erosion. The system (named EOLO, *Eddy cOvariance dust upLift Observation system*) is based on the *eddy covariance* methodology. The first prototype of the system was used to monitor wind erosion in 6 sites selected in two focus areas of northern China, the Alashan prefecture and the surroundings of Beijing, over two months (May-June 2005). The focus in Alashan was to assess relative importance of emissions from several soil types thought to be major sources of dust. Effects of vegetation cover were also investigated. In the Beijing area, wind erosion from agricultural sites and from abandoned rubble pits was monitored. In order to carry out direct comparison with the measures the Lu & Shao dust emission model (WEAM) was applied. For this purpose an extensive data collection was done in order to accurately set model's parameters. A good agreement between measured and modeled dust fluxes was obtained. However, a detailed comparison highlighted that some wind erosion dynamics, such as the effects of wind direction with respect to roughness geometry, that are not modeled in WEAM, need to be taken into account to enhance model's accuracy and reliability. Direct measures also gave some insight on the functional relation between friction velocity and dust fluxes in different conditions. The study can also help improving theoretical wind erosion modeling.

Introduction

Central Asia is among the world regions most plagued by dust and sand storms (DSS) events; however, detection of Asian dust storms origin is still under debate (Wang et al., 2001). It is generally agreed that most of the DSS arise from the arid and semi-arid regions of northern China, where the Tarim Basin, Alashan Gobi Plateau, Taklimakan and Hexy Corridor are considered the most important areas. Nonetheless, whether the dust arises from the desert and Gobi (Sun et al., 2001), or from the outer edge of the deserts, the degraded grasslands and the farming lands is still under discussion (Zhang et al., 1997; Liu, 2001; Dong et al., 2004).

To develop better understanding for controlling DSS in northern China, the Environmental Protection Bureau of Beijing Municipality and the Italian Ministry for Environment and Territory started a project named "WinDust" (Fratini et al., 2005) in 2004. The project is operated in the Alashan prefecture of Inner Mongolia and in the Beijing municipality. The research focus is on formation and evolution of DSS at the local and the regional scale. The final goal is to assess the relative importance of dust storms arising in northern-central China in determining dust events on Beijing, compared to the small scale erosion events plaguing agricultural areas, dry river beds and quarries surrounding the capital city. One of the crucial points is to detect the most relevant dust sources and quantifying their emission, both in the desert regions and in the suburban areas of Beijing. To achieve this goal, a new technology was developed that allows direct measurement of vertical dust flux during wind erosion events.

Direct *vs.* indirect measures of wind erosion

Following the sandblasting approach, most of the efforts in measuring wind erosion are based on the direct measurement of saltating particles' horizontal flux and the indirect derivation of the vertical suspended particles flux, by means of theoretical relations (e.g., *k* factor). Attempts to apply the micrometeorological gradient-method have been made to estimate directly the vertical flux of dust in the natural environment (Breshears et al., 2003). Other attempts to estimate dust emission or deposition rates rely on cumulated concentration data of dust collected in traps located at surface level (see, e.g., Li et al., 2004). Here, empirical correlations between horizontal and vertical fluxes are used to derive emission factors from saltation data. Various dust emission/deposition measuring techniques have been described by Zobeck et al. (2003)

In this study, an innovative, eddy covariance-based system (named EOLO, *Eddy cOvariance dust upLift Observation system*), for the direct measurement of net mineral dust flux due to wind erosion, is presented. Here, mineral dust is considered as solid particles with an aerodynamic diameter ranging between 0.26 and 7.00 µm. As far as we know, it is the first attempt to measure directly wind erosion vertical dust fluxes in a way that allows clear detection of any dust emission or deposition event. Measuring the net vertical flux (emission less deposition) of suspended particles outside the saltation layer (above 7 meters) does not rely on any interpretation about the physics of erosion, thereby providing a powerful tool to validate wind erosion models. The resulting high-frequency flux data allow a set of analysis, such as analysis of the dependence of dust fluxes on wind direction, that were not possible for field measurements up to now. Furthermore, the system allows detailed study of the influence of vegetation and non-erodible element cover on wind erosion.

Material and methods

Theoretical background

The *eddy covariance* (EC) is a supporting methodology to many fields of investigation. Among these, the surface exchange of greenhouse gases (GHG) is probably the most popular. Much of the theoretical benchmarks that helped refining the methodology have been reached in the framework of CO_2 and H_2O net (emission/absorption) vertical fluxes, VOCs and aerosol fluxes and deposition velocity studies. Many papers have been published about the issues involved in the EC methodology (e.g., Baldocchi et al., 1988; Aubinet et al., 2001; Aubinet et al., 2003).

The eddy covariance theory has been developed under the assumption that the scalar quantity involved is passive; it means that it is passively transported by turbulent motions, not only to a large scale, but also up to the highest, relevant frequencies of the flow spectra. In this assumption, inertia and gravitational effects can be neglected. After averaging conservation equation for the concentration of such a scalar, integration along the vertical axis *z*, assumption of no horizontal turbulent flux divergence and under conditions of atmospheric stationarity and horizontal homogeneity, the eddy flux (right-hand side term) equals the source/sink term:

$$S = \overline{w'c'} \qquad (2.1)$$

This is the basic equation of the classical EC methodology, the one applied in this study. Accordingly, the net emission/deposition flux can be estimated through the covariance between the scalar concentration and vertical wind velocity. In this study, an *a priori* spectral analysis was used to assess validity of the theory when applied to relatively large particles. An overall *a posteriori* comparison with a wind erosion model was also performed.

Description of the EOLO system

The prototype of the EOLO system (Eddy Covariance Dust Uplift Observation system) was designed and produced to fit the eddy covariance theory requirements as far as possible.
EOLO is composed of two main parts: the ‘wind system’ and the ‘concentration system’. The wind system includes an ultrasonic anemometer that allows fast and accurate measure of the 3D wind components and the sonic temperature, an acceptable estimation of the actual air temperature. The concentration system includes two main parts: an Optical Particle Counter (OPC, CLIMET CI-3100 series) and the Multi-Channel Analyzer (MCA8000, Amtek, USA). The inlet of the concentration system is placed within the measuring volume of the anemometer.

The nominal diameter of sampled particles was restricted to 0.26-7.00 μm, in order to focus on the mineral dust. Because of limits in the electronics, the overall range was split in two channels*:* the fine channel (0.26-0.70 μm) and the coarse channel (0.70-7.00 μm). Each channel is further divided in several sub-ranges; a total of 10 sub-ranges are thus available. The acquisition frequency was set to 5Hz. In the subsequent text the sampled particle size range is referred as PM7. Even though it is not rigorously correct (PM7 includes all particles with aerodynamic diameter less than 7.00 μm), there is no difference from the practical point of view when dealing with mass fluxes.

In EOLO the pneumatic circuit, powered by a 220 Vac pump, forces the air sampled at the inlet in a duct through the OPC, where each particle is counted and sized by a sensor based on the backscattering of a laser diode. Before being sensed, the sampled air is mixed in a suitable dilution ratio with clean air obtained through absolute filters. This dilution is necessary to avoid small particles being masked by larger particles passing in the same time through the laser beam and to avoid counting saturation in case of high concentrations. The sampling flow rate is 1.42 Lm^{-1}.

The whole software needed to control the system and process data was developed in ANSI C/FORTRAN90 languages. Following is the full set of stored output:

- instantaneous (5Hz) data of 3-components wind speed
- instantaneous (5Hz) data of air temperature
- instantaneous (5Hz) data of volume and weight particle concentration for the 10 sub-ranges
- mean data (averaged over a user-defined time period) of wind, temperature and concentration
- standard deviations and auto/cross-correlations of wind, temperature and concentration data
- net (emission minus deposition) 30-min averaged vertical particle flux for each of the sub-ranges
- aggregated PM1, PM2.5 and PM7 net 30-min averaged vertical fluxes
- friction velocity, Monin-Obukhov length, heat flux

The most critical point when dealing with EC is the fast acquisition of concentration values. In the present case the problem is even more serious, because the number concentration of particle in air can reach very low values, thus fast counting of such particles could lead to a statistically invalid sampling. To evaluate data quality in this respect, an *a priori* spectral analysis was carried out on the raw data on concentration.

Study sites

The monitoring campaign lasted two months and involved areas surrounding Beijing capital city and the desert areas of Alashan prefecture (Inner Mongolia, China). Six sites in all were monitored (Table1) for time periods spanning from 2 to 10 days, according to weather conditions and time availability. The four Alashan sites (GB1, GB2, DG1, DG2) correspond to typical deserted landscapes of the region, and are thought to be among the major origin sites for dust storms (Wang et al., 2004). GB1 and GB2, located in the Ejin'a area, are typical Gobi type lands. DG1 is representative of a deserted land, which has been a site of a long-lasting air-sown reforestation project established by Chinese government in the 1970s and is still under development. DG2 is a typical deserted landscape in the Alxa Zuoqi region. Two sites were monitored in the Beijing area. Here, the abandoned quarries and the agricultural sites were considered the main dust sources; one site of each type was selected (AS1, AS2) (Fig. 1).

All sites except AS2 met the covariance requirements very well, being completely flat and homogeneous. AS2, the rubble pit, had to be considered with care, because of unevenness of vegetation cover and topography.

Evaluation of EOLO performance

A comprehensive spectral analysis was carried out in order to evaluate the quality of acquired data. The purpose was to compare normalized spectral densities derived for sensible heat and for particle concentration, in order to evaluate particles' dynamic behaviour. Spectral density of a generic scalar *u* quantity is defined as:

$$S_u(\omega) = \frac{1}{\pi}\int_{-\infty}^{\infty} R_u(t)\cdot e^{-j\omega t}dt \tag{2.2}$$

Table 1. Sites description: vegetation cover data refer to the monitoring period, spring of 2005

SITE ID	SITE FULL NAME	area	latitude (°)	longitude (°)	soil type	topography	vegetation cover
GB1	Ejin'a Gobi 1	Ejin'a qi	41,8833	100,5362	Gobi	flat	shrubs with small dunes downwind
GB2	Ejin'a Gobi 2	Ejin'a qi	41,9381	100,9751	Gobi	flat	none
DG1	Alxa Desert Grassland 1	Alxa Zuoqi	38,8676	105,6096	sandy	small dunes	dense homogeneous shrubs
DG2	Alxa Air-sowed Desert Grassland	Alxa Zuoqi	39,0270	105,6454	sandy	flat	sparse small bushes and some grass
AS1	Changping Maize field	Beijing	40,1867	116,4092	silt	flat, tilled	standing and flat residue of maize
AS2	Nankou Rubble Pit	Beijing	40,1953	116,0997	gravely, sandy	irregular	sparse and various (grass and trees)

SITE ID		particles density		grave	sand	silt	clay
GB1	AVR	2,54	AVR (%)	46,65	48,75	4,14	0,46
	ST_DEV	0,07	ST_DEV (%)	14,02	14,20	0,47	0,31
GB2	AVR	2,48	AVR (%)	50,55	39,85	8,20	1,40
	ST_DEV	0,08	ST_DEV (%)	0,01	1,52	1,19	0,35
DG1	AVR	2,41	AVR (%)	0,00	83,03	16,03	1,11
	ST_DEV	0,06	ST_DEV (%)	0,00	3,75	3,69	0,68
DG2	AVR	2,45	AVR (%)	0,00	76,81	22,38	0,81
	ST_DEV	0,04	ST_DEV (%)	0,00	6,57	6,41	0,16
AS1	AVR	2,48	AVR (%)	0,00	43,76	55,75	0,49
	ST_DEV	0,13	ST_DEV (%)	0,00	7,83	7,68	0,22
AS2	AVR	2,40	AVR (%)	69,60	15,40	14,41	0,59
	ST_DEV	0,08	ST_DEV (%)	6,06	6,06	0,13	0,13

where *Ru(t)* is the autocorrelation function of the variable *u(t)* and *ù* is the frequency. Following the classical theory of turbulence (Kolmogorov, 1941), in case of fully developed turbulence (high *Re* number), spectra of flow variables show a universal behaviour in the inertial sub-range, i.e. the frequency range where the dominant mechanism is energy cascade from larger to smaller scales and no net production or dissipation of energy occurred. In this range, flux variables' spectra and co-spectra are expected to collapse on a common curve, when properly nondimensionalized; analytical expressions for such curve exist for transported scalars in some special conditions, e.g. atmospheric stability (Stull, 1988). Sensible heat is a scalar quantity passively transported by the turbulent motions up to the higher frequencies. In this respect it acts like a perfect gas, thus its spectral behaviour can be taken as a reference for dust concentration spectra. Furthermore, sonic temperature is proportional to sensible heat (if air density is considered constant), so that the former is a proxy to the latter; thus, sonic temperature spectral density was considered as the reference.

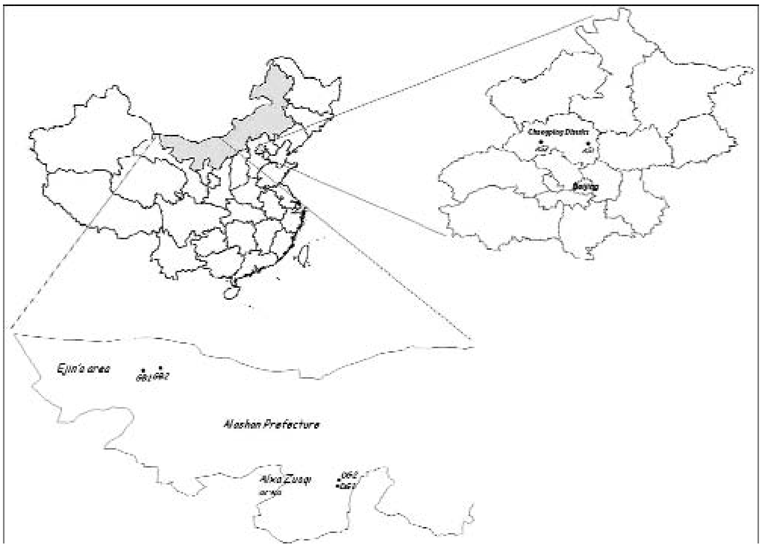

Fig. 1. Sites location: the four western sites (GB1, GB2, DG1, DG2) are located in the Alashan Prefecture - Inner Mongolia - (bottom); the two eastern sites (AS1, AS2) are located in the northern surroundings of Beijing - Beijing Municipality (top right).

What is expected here is that, in conditions of high turbulence levels, gravitational effects acting on the particles can be neglected. Another issue is related to the number concentration of coarse channel particles that in case of no or very weak erosion can reach very low values, leading to statistically invalid datasets. However, both these unsuitable conditions (gravity influence and low number concentrations) tend to vanish with increasing turbulence intensity, which is the most important as far as wind erosion is concerned.

Three situations were explored: (*i*) a strong dust emission event (dust storm) that occurred at the GB1 site on 25 May 2005; (*ii*) a weak dust emission event that occurred at the AS2 site on 19 June 2005; and (*iii*) a deposition event that occurred at the GB2 site on 28 May 2005.

Fig. 2 shows normalized, regularized spectral densities for the first event. Similar results were obtained in the other cases. Upper figure refers to particles from the fine channel (0.26-0.70 μm); these are expected to provide better fitting with the theoretical spectra, as they are smaller in size (and hence lighter and subject to weaker inertia effects) and larger in number concentration; lower figure refers to particles in the coarse channel (0.70-7.00 μm). Regularized, normalized spectra were obtained by single (30-minutes) datasets referred to relevant events, applying a standard sequence of operations: (*i*) Hanning filtering; (*ii*) FFT; (*iii*) raw spectra block averaging over exponentially-spaced frequency ranges; (*iv*) as single datasets, each raw spectrum presented high levels of irregularity; thus, further local filtering (block-weighted average) was applied to highlight the main slopes; and (*v*) normalization by the variable variance.

Both fine and coarse channels particles show very good agreement with the reference. In virtually all cases the spectra collapse on a common curve in the inertial sub-range. The dynamic description of a transported scalar is completed by the analysis of the correlation with the transporting variable, i.e. the velocity. With this aim, a co-spectral analysis was performed in order to check consistence between the vertical transporting features of the sonic temperature and the particles' ones.

Fig.3 shows the results, also for the first event; co-spectra between vertical velocity and the other variables were derived following the same procedures as mentioned above; the normalizing factors are the correlations $\overline{w'x'}$ between *w* and the actual variable *x*. The reference co-spectrum is $Co(w,T)$. Co-spectral behaviour was found to be satisfactory in most cases, even though the agreement is generally lower than in the case of the spectra.

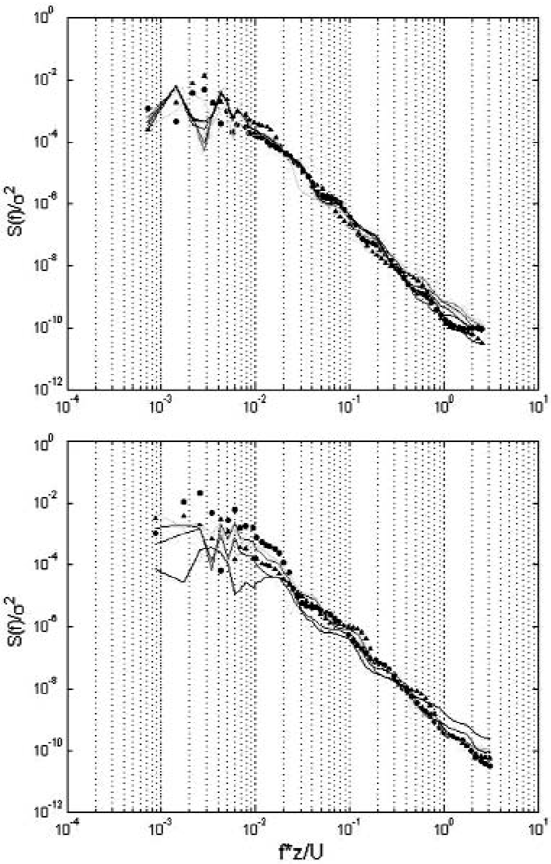

Fig. 2. Spectral analysis: Comparison among reference spectra of sonic temperature and horizontal wind speed (circles and triangles, respectively) and particles spectra (gray-scale lines; the darker the line, the larger the particles) for fine channel (0.26-0.70 μm, top) and coarse channel (0.70-7.00 μm, bottom) particles.

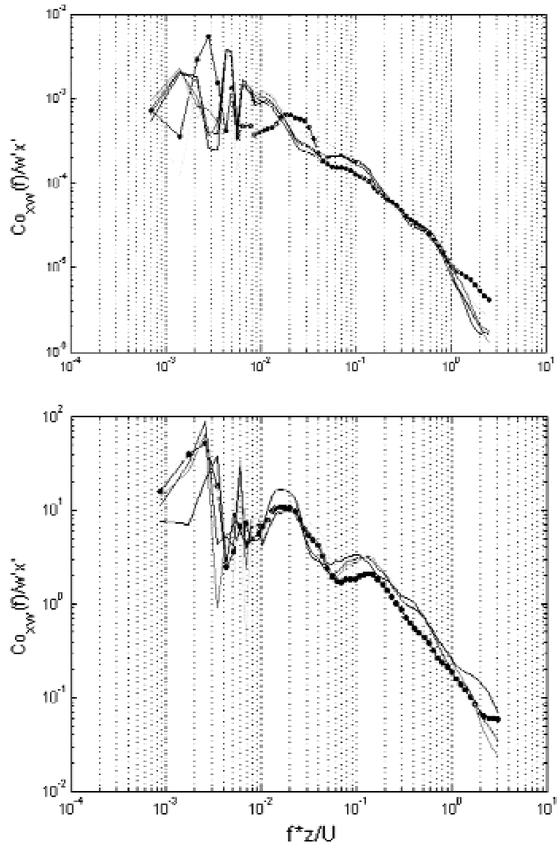

Fig. 3. Spectral analysis: Comparison among reference co-spectra of temperature (black, dotted line) and particles spectra (gray-scale lines; the darker the line, the larger the particles) for fine channel (0.26-0.70 μm, top) and coarse channel (0.70-7.00 μm, bottom) particles.

In summary, particles up to 7.00 ìm show the overall dynamic behaviour typical for gases, and hence the eddy covariance theory can be applied without taking into account gravitational and inertia effects. Events of net deposition can also be confidently accepted This means that the system can be used not only as a monitoring system for wind erosion events, but also to monitor particulate deposition, as long as it can be considered as *dry* deposition.

Results and discussion

Time series of net fluxes

The results obtained in field study show some interesting features of wind action on different soil types and land covers. Fig. 4 shows time series of PM7 net emission/deposition fluxes, along with the actual friction velocity measured at the same time. Positive values of fluxes correspond to a net emission, while negative values correspond to a net deposition.

The difference in the order of magnitude of the higher emission values obtained on 25 May in the GB1 site (Fig. 4, top), with respect to all other values, was great. Indeed, in that day a strong dust event happened, classified as a small dust storm. The maximum 30min-averaged wind speed registered during such dust event was 13.90 ms^{-1}.

With a slightly higher maximum wind speed (14, 15 ms^{-1}), no dust event happened in the second site, GB2. This is interesting result, especially because GB2, being a completely bare land, was supposed to be a stronger source than GB1, where some sparse vegetation is present. As indicated in Table 1, small dunes are present downwind each shrub of GB1as a consequence of sand/dust deposition. It is likely that these dunes act as strong sand source, feeding the saltation flux and thus enhancing dust suspension. It can also be argued that after a rain event (GB2, Fig. 4, centre), when emission is no more likely, a strong wind could also lead to a net deposition. EOLO allowed quantification of such deposition. When used for longer time periods, the system allows accurate quantification of net soil loss on a monthly or seasonal basis, which is important information when dealing with desertification processes.

One of the goals of the monitoring was to assess relative importance of dust emission from desert sites in Alashan and from anthropogenic-driven degraded sites. Data from the AS2 site (a rubble pit in NW surroundings of Beijing) need to be considered with a greater care because of the unevenness and non-homogeneity of vegetation cover and the complexity of site topography. Nonetheless, both the spectral analysis and the correlation between wind speed and fluxes allow confidence on the data quality; PM7 fluxes follow wind speed patterns to a great extent (Fig. 4, bottom), and the absolute flux values show that emissions from ‘anthropogenic’ sites can be as strong a dust source as natural sites. Indeed, even with a very low maximum wind speed of 5.62 ms^{-1}, the AS2 site show considerable flux values (up to 60 Kg $Km^{-2}h^{-1}$).

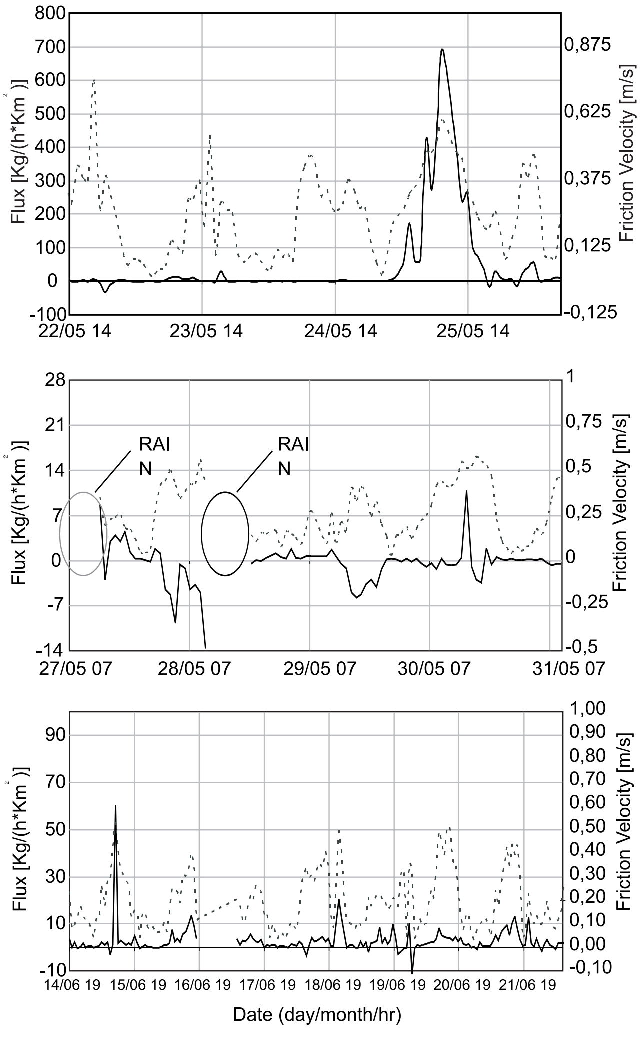

Fig. 4. PM7 fluxes time series: PM7 net (emission less deposition) vertical fluxes (solid line) and friction velocity (black dashed line) vs. time for GB1 (top), GB2 (centre), AS2 (bottom) sites.

Fig.5 shows relative contribution of PM7, PM2.5 and PM1 in terms of mass flux during the dust event on 25 May. Particles in the range 2.50-7.00 μm dominate the mass exchange during the erosion event, while no determinant contribution is expected from particles in the range 7.00-10.00 μm, according to the particle size distribution under 7 μm (Fig.7). The relative importance of the three particle classes remains virtually constant during the dust event, suggesting that no peculiar phenomena happen at different wind speeds and during an intense wind event merely the amount of particles being uplifted from each range changes.

Application of the WEAM erosion model

A dust emission model was selected to carry out an overall comparison with EOLO measurements. The model, developed by H. Lu and Y. Shao (Lu & Shao, 1999; Shao, 2001), provides horizontal (saltation) and vertical (suspension) fluxes and estimates dust emission rates by the volume removed by impacting grains, following the sandblasting concept. To accurately set input parameters for a detailed comparison, an extensive field study was done by sampling 23 plots in the six sites, each plot being 10x10 m for soil and 30x30 m for vegetation study, located in the same points as for EOLO. Attention was focused on particles smaller than 7 μm for direct comparison with measured data. The friction velocity used is defined according to Stull (1988) as:

$$u* = \sqrt{\frac{\tau_{RE}}{\overline{\rho}}} = (\overline{u'w'}^2 + \overline{v'w'}^2)^{1/4} \tag{3.1}$$

where τ_{RE} is the Reynolds stress. This definition of the friction velocity was used because of the availability of high frequency wind data, which allows detailed statistics about the turbulent flow field. A total of 34 disturbed soil samples were collected for soil texture analyses. About 64 distribution classes, from 0.339 to 2000 μm were obtained, after sample dispersion (Fig. 6). Following the model developers (Lu & Shao, 1999), the concept of minimally and fully dispersed soil particle sizes was considered, whose weights are computed to estimate particle size distribution of emitted dust from the equation:

$$p(d) = \gamma p_f(d) + (1-\gamma)p_m(d) \tag{3.2}$$

where *p(d)*, *pf(d)* and *pm(d)* are suspended particle size distribution, and fully and minimally dispersed soil particle size distribution, respectively. Here, γ is a weighting factor (depending on *u** and *u*t*) that approaches *zero* for weak erosion and 1 for strong erosion (Chatenet et al., 1996; Shao 2001); Fig. 7 shows *p(d)* up to 7 μm as derived from (3.2) for GB1 site, compared to the one with EOLO.

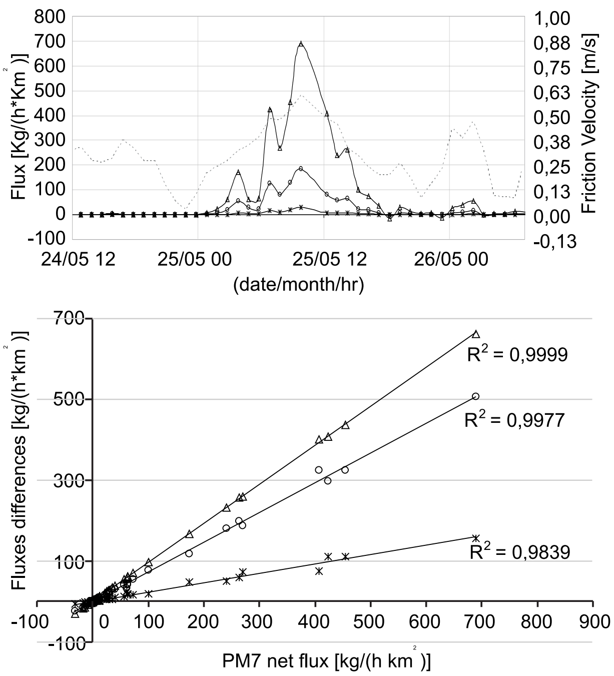

Fig. 5. Top: PM7 (solid line with triangles), PM2.5 (solid line with circles) and PM1 (solid line with stars) net vertical fluxes and friction velocity (dashed line) vs. time for GB1 during an intense dust event, classified as a small dust storm; bottom: differences is net vertical fluxes among PM7, PM2.5 and PM1: PM7-PM1 (triangles), PM7-PM2.5 (circles), PM2.5-PM1 (stars) versus PM7 net vertical flux, during the same event; solid lines, linear regressions.

Log-normal particle size distributions *pf(d)* and *pm(d)* were assumed, constituted by several populations. The MIX 3.1 code (Macdonald & Green, 1988) was used to perform sediment analyses of populations (Fig. 8) whose mean, fraction and standard deviation were included in model computation for fully dispersed distribution. For the minimally dispersed one, this distribution parameters were estimated by comparing soil texture (sand, silt and clay percentage), with those from previous studies (Shao et al., 2002).

Moisture content from undisturbed (about 5 cm deep) and disturbed samples (soil from the first 1-2 cm from the surface) was observed to differ by about 90%; this is a very important value for assessing role of water in particle interspaces (Fècan et al., 1999). In this study the soil moisture enlargement factor *H* for the threshold wind friction velocity has been parameterized as (see also Table 2):

$$H = 1 \qquad \textit{for } w < w'$$

$$H = \left[1 + 1.21(w-w')^{0.68}\right]^{0.5} \qquad \textit{for } w > w'$$

where *w* is the moisture content on a volumetric (or gravimetric) basis and

$$w'(\%) = 0.0014(\%clay)^2 + 0.17(\%clay)$$

Soil erosion is known to depend strongly on vegetation cover and on the presence of clods, rocks, crop residues etc. (Raupach et al., 1993), that can together be treated as non erodible elements. The impact of non erodible elements on threshold wind friction velocity was modelled, following Raupach et al. (1993) as:

$$u_{*t} = u_{*t0}\sqrt{(1-\lambda\sigma)(1+m\beta\lambda)}$$

where the first term of the product under root accounts for coverage, the second one for drag. u_{*t} and u_{*t0} are threshold friction velocity over rough and "smooth" surfaces, respectively; λ is the roughness density, σ is the basal to frontal area

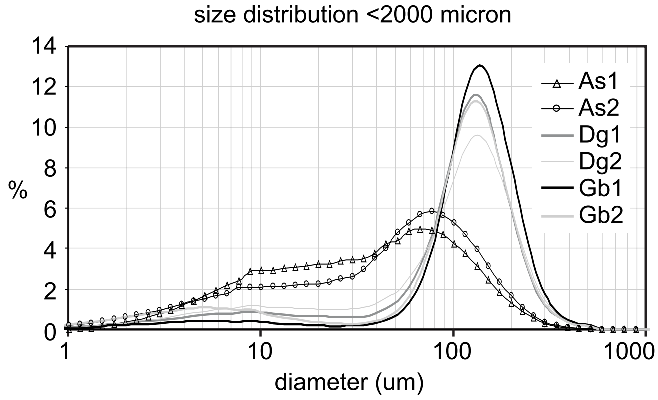

Fig. 6. Particle size distribution: Less than 2 mm, derived from analysis of a total of 34 disturbed samples; red lines highlight degraded sites (Beijing sites).

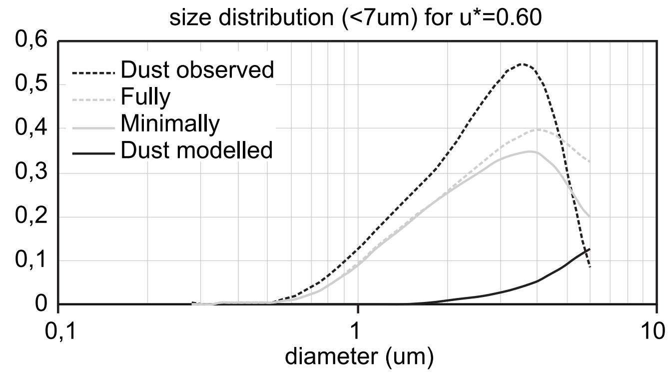

Fig. 7. Particle size distribution: under 7 μm, at site GB1. Modelled distribution depend on u* value (0.60 in the figure), through γ.

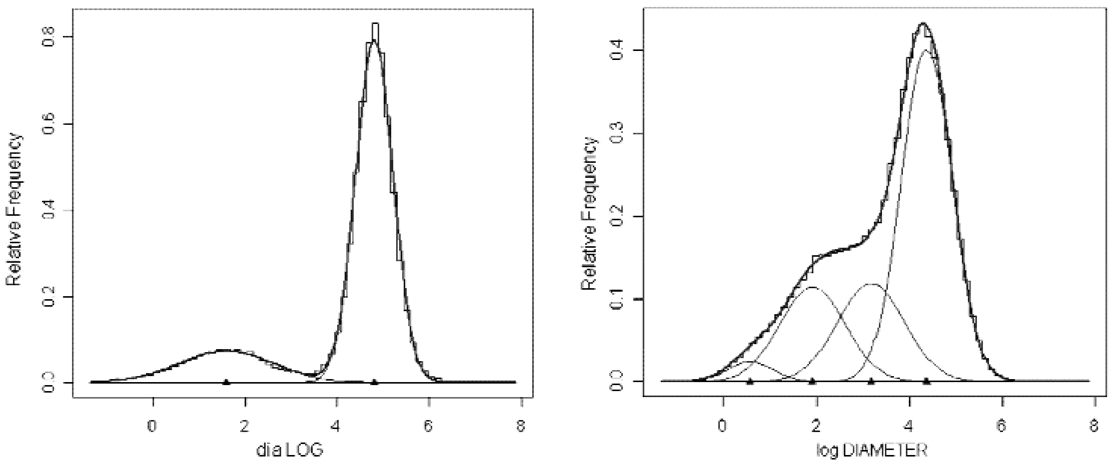

Fig. 8. Particle size distribution: detection of size distribution modes by means of the MIX 3.1 software for a desert site (GB2, left) and for a degraded site (AS1, right).

ratio (commonly assumed to be 1); *m* is a parameter indicating uniformity (if 1) or non-uniformity (if <1) in the surface stress, in this study, m=0.5; *β* is the ratio between drag coefficient of roughness element *CR* and that of bare soil *CS*:

$$\beta = \frac{C_R}{C_S}$$

Several studies (e.g. Raupach et al., 1993, Crawley & Nickling, 2003) assessed β at about 90-100 for vegetated surfaces and 1 for bare soils; these values have been used in our study.

Non erodible surface cover includes any material lying on the soil surface, protecting from wind stress and from the impact of saltating grains. Generally, an exponential decrease in soil loss with increasing surface cover it is assumed (Bilbro & Fryear, 1995). An automatic image analysis was developed and used to estimate soil cover fraction by nadir-view photographs taken on site, to account only for particles greater than 2 mm and for both flat and standing vegetation cover. The method includes a preliminary "manual" digitalization of cover elements on the photograph and a comparison with automatic detection by a sequence of image processing steps (including edge detection, smoothing, de-speckling, filtering etc.) carried out with the *Image J* software (Fig. 9).

Comparison shows good agreements between manual and automatic procedure, both for vegetation cover and cobble cover with correlation coefficients of about R^2=0.91.

Fig.10 shows a direct comparison between modelled and measured PM7 fluxes. While the trends of emissions are generally well reproduced, frequently there are large differences in flux absolute values. Obviously, model simulations in a specific site perfectly follow the friction velocity trends, because all other parameters are kept constant. Indeed, even without macroscopic changes in environmental conditions (as is the case in the GB1 site), the link between friction velocity and emission fluxes is not so deep, and events of strong wind without intense emissions were observed (first days at GB1). This is possibly related to the duration of the 'strong wind' conditions, or to wind direction. Of course, direct comparison is affected by the fact that the model predicts only dust emission while EOLO measures a net flux; however, this is not expected to be a major drawback in the case of intense events. Not accounting for deposition, if strong winds occur after a small rain event, the model predicts dust suspension while EOLO detected quite intense deposition (GB2). Comparison at the AS2 site shows the best agreement between modelled and measured data, despite the unevenness of the site that affects its suitability for eddy covariance measurements. It is possibly related to the substantial lack of depositions from outside the site.

Functional relation between wind speed and net emission fluxes

While main factors influencing wind erosion are already well known, quantification of such influ-

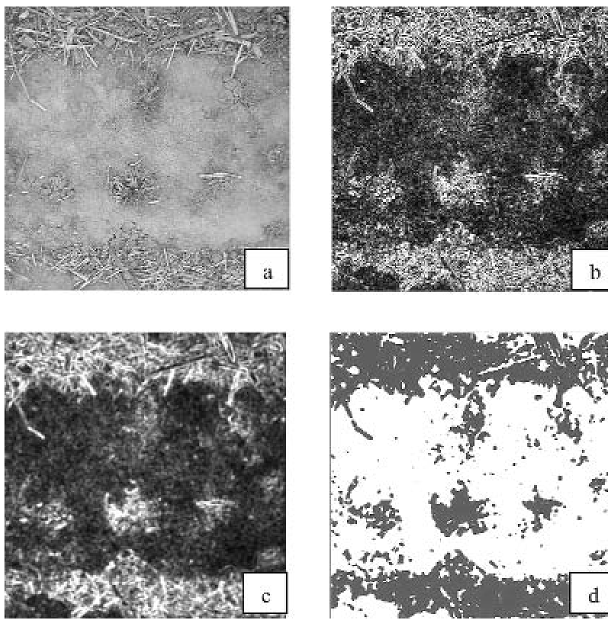

Fig. 9. Automatic images processing for vegetation cover definition with Image J: a) original image; b) after 8-bit conversion and "find edge" convolution; c) after de-speckling and smoothing; d) after "threshold" digital values selection.

Table 2. Observed soil properties: soil moisture enlargement factor H, following Fecan et al. (1999); w_{obs} is the observed moisture content on a gravimetric basis.

Site	Clay	w'	w_{obs}	H (Fecan et al., 1999)
GB1	0.462	0.079	0.6	1.333
GB2	1.401	0.241	1.7	1.601
DG1	1.111	0.191	0.5	1.243
DG2	4.897	0.866	0.8	1.000
AS1	0.49	0.0841	5.2	2.945
AS2	0.588	0.100	4.9	2.125

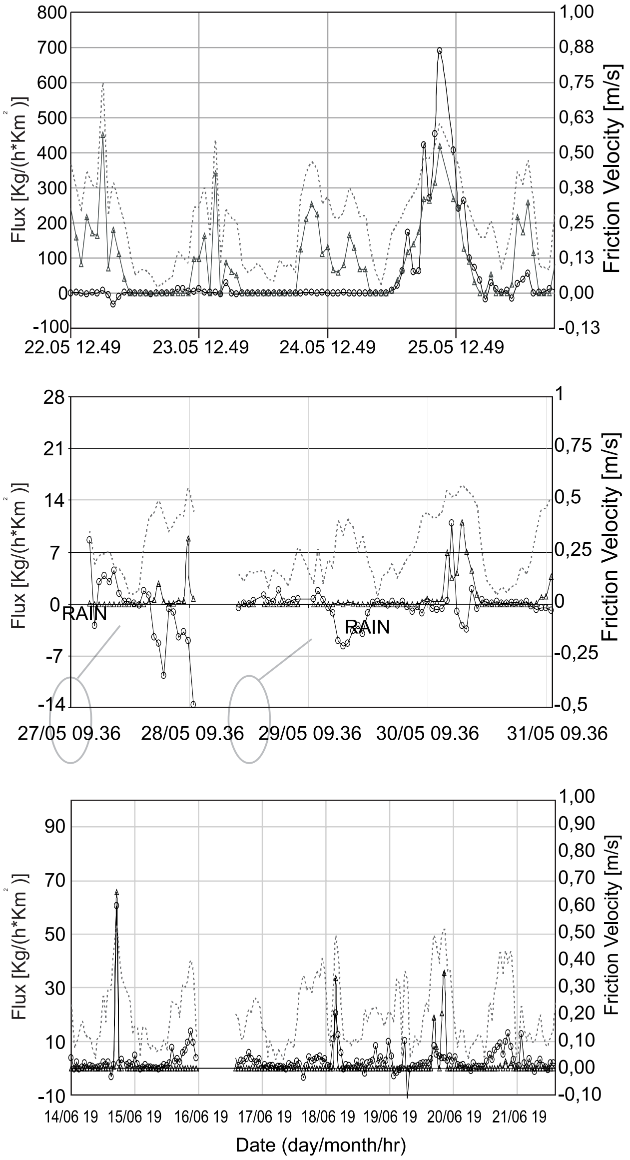

Fig. 10. Comparison among CoDY and WEAM: PM7 net vertical fluxes (black lines with circles), modelled PM7 emission fluxes (black lines with triangles) and friction velocity (gray dashed lines) vs. time for GB1 (top), GB2 (centre), AS2 (bottom) sites.

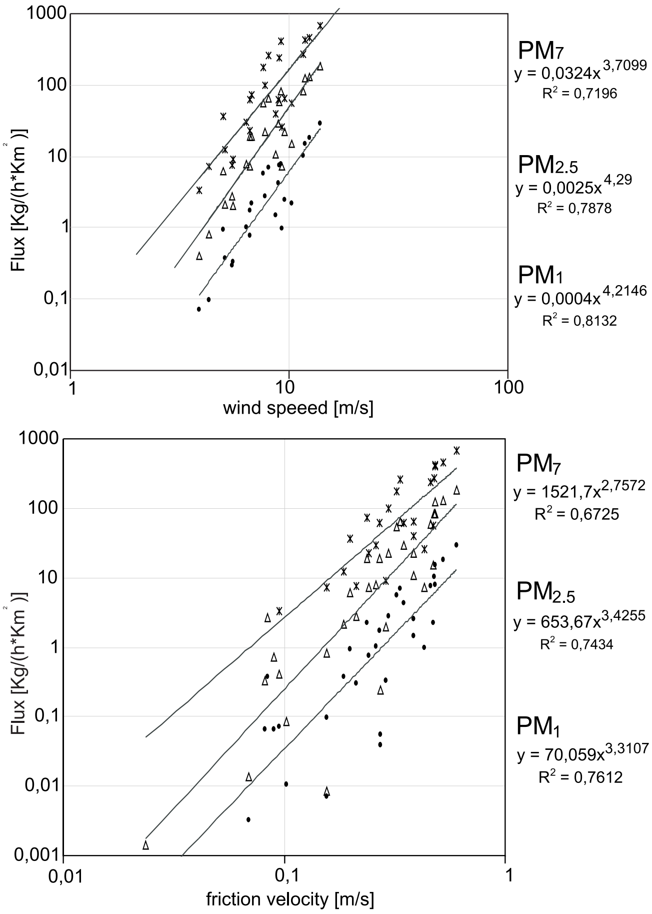

Fig. 11. Relation wind-fluxes: PM7 (stars), PM2.5 (triangles), PM1 (dots) net vertical fluxes vs. wind speed (top) and vs. friction velocity (bottom); solid lines, power regressions; on the right, best fit formulas and correlation coefficient are reported. Data refer to the dust event occurred at GB1.

ences is inadequate. Thus, many models mostly rely on the parameterization of the relation between friction velocity and emission fluxes, while modeling all the other physics involved often needs some constant to be tuned according to experimental evidences. Although this relation has not been definitively agreed to as yet, it is assumed to be of the form of a power law, the exponent has been observed to vary from 1.89 to 6.54 (Nickling & Gillies, 1989), such variations being variously attributed to inter-particle bonds strength or crusting effects (Houser & Nickling, 2001).

Fig.11 shows the experimental relation found among wind speed and PM7, PM2.5, PM1 fluxes for the GB1 site; the relation between these fluxes and the friction velocity is also shown. In this situation, all the factors but wind speed are kept virtually constant, thus the relation between wind speed and particles fluxes can be analyzed separately. The best fitting was obtained with power functions whose exponents range between 3.71 and 4.29 for the wind speed and between 2.76 and 3.42 for the friction velocity, also suggesting that a certain difference exists between smaller and larger particles. Correlation coefficients are relatively good, ranging between 0.67 and 0.76 for fluxes *vs.* friction velocity. Moving from PM7 to PM1 the power fits are closer to the actual data, suggesting that smaller particles dynamics is less affected by changes in other parameters than wind speed; the power function fits better the relation between flux and wind speed, instead of the one between flux and friction velocity, even though the traditional modeling approach is to relate the flux to *u**. This is generally true for all the soil types monitored; however, the relation is less clear in other cases, because of disturbance effects.

Conclusions

EOLO proved to be a flexible and powerful system to monitor dust uplift due to wind erosion; events of dust deposition can be detected and measured as well. Not relying on any interpretation about wind erosion mechanisms, it has the potential for becoming a validation tool for wind erosion models. It provides continuous, accurate and high frequency erosion measurements, allowing at the same time detailed study of wind erosion dependence on site-specific features, such as wind direction, non-erodible covers, humidity. Nonetheless, as a prototype, EOLO is affected by some limitations. Perhaps, the most important is that presently it can only measure one channel (fine or coarse) at a certain moment. It means that it is impossible to have contemporary measures of fine and coarse channels particles, thus limiting the monitoring efficiency of the overall system, also considering that wind erosion is a 'scattered' phenomenon that may last even only for some minutes. A quantitative data-quality criterion should be derived from the spectral analysis; this should allow discarding flux data in conditions of low number concentration and of low wind speed, when gravitational effects may dominate particle dynamics.

Acknowledgement

This work was done within the framework of the WinDust project, established in 2004 and funded by the Italian Ministry of Environment and the Beijing Municipality Environmental Protection Bureau. Thanks go to the Chinese staff for their technical assistance and to the Chinese experts for their continuous active cooperation and valuable suggestions. Special thanks to the staff of the Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI), Lanzhou for their scientific contribution and assistance during the field work.

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Dust sandstorm dynamics analysis in northern China

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Abstract

The application of Numerical Prediction Models to strong weather phenomena such as dust sandstorm (DSS) is considered of prime importance in the evaluation of control/mitigation measures. In the framework of the WinDust Project, a three-dimensional comprehensive atmospheric, emission, dispersion large-scale model was developed for the northern Asia domain in order to provide a regional characterization of DSS dynamics acting on the area covering Alashan to Beijing. This comprehensive system was based on three different modules: 1) atmospheric model - Regional Atmospheric Modeling System (RAMS), 2) dust emission model, named DUSTEM, and 3) dispersion model - Comprehensive Air quality Model with extensions (CAMx). Using the Reanalysis-2 dataset as atmospheric forcing for RAMS, a three-nested grid approach with different horizontal resolution was adopted. The proposed regional characterization was based on numerical modeling simulations for two relevant DSS events (20-22 March 2002 and 28-30 March 2004). These simulations were aimed at inferring large-scale meteorological factors responsible for DSS events affecting the Beijing area and analyzing the DSS dynamics. By running different emission scenarios, the contribution of the Alashan area to the DSS affecting Beijing was estimated. The effects of mitigations measures in terms of dust/sand emission reduction were evaluated by running future intervention scenarios. Full system implementation and validation, based on both meteorological and dust concentration data, is presented.

Introduction

The application of Numerical Prediction Models (NPM) to strong weather phenomena such as dust sandstorm (DSS) is considered of prime importance in the DSS analysis in the 'WinDust' Project and, therefore, in the evaluation of control/mitigation measures. WinDust project is being implemented to combat DSS in northern China, as a Sino-Italian cooperation project launched in 2005 in the framework of the Sino-Italian Cooperation Program for Environmental Protection (SICP) by the Italian Ministry for the Environment and Territory (IMET) and the Beijing Municipal Environmental Bureau (EPB).

A three-dimensional comprehensive atmospheric, emission, dispersion NPM was developed for the northern Asia domain in order to provide a regional characterization of DSS dynamics acting on the area covering Alashan to Beijing. The modeling activities required considering different modules (i.e. atmospheric, emission, and dispersion) since the natural phenomena involved in the DSS consist of two major physical mechanisms. First, a wind stress lifting mechanism, which is able to raise up dust/sand particles from some type of bare soil surfaces in specific weather conditions. Then, a long range transport mechanism with a high degree of spatial coherence (i.e., low value of transversal dispersion of wind field and long fetch patterns). The adopted different modules are: (i) Regional Atmospheric Modeling System, (ii) DUST Emission Model, and (iii) Comprehensive Air quality Model with extensions.

Numerical modeling simulations for two recent relevant DSS events (20-22 March 2002 and 28-

30 March 2004) were carried out to perform a DSS regional characterization. Furthermore, to evaluate how the DSS origin and propagation will change on the basis of the change in the land cover features (e.g. reduction in the extension of the potential DSS originating sources, increment of vegetation around sensible areas) DSS modeling was carried out for two intervention scenarios. The "remote scenario" considered a fifty percent reduction in the potential emission in two selected areas in the Alashan region, possibly related to the implementation of reforestation/afforestation programs. The "local scenario" considered the emission reduction consequent to the rehabilitation of a relevant number of abandoned rubble pits in the Beijing area, corresponding to a fifty percent reduction of the potential emission.

Approach to dust sandstorms modeling

The performed analyses and modeling activities were carried out to (i) infer the dust/sand transport dynamics from Alashan to the Beijing target area; (ii) understand the role played respectively by the Alashan area and degraded areas surrounding Beijing in the DSS affecting the capital; and iii) evaluate DSS reduction based on the land cover changes (e.g. implementation of large scale mitigation and control measures).

To provide a regional characterization of the DSS dynamics acting on the study area, the Regional Reanalysis approach was chosen. DSS atmospheric modeling was based on the Reanalysis forcing. However, due to the specific geomorphology of northern China, the low resolution Reanalysis datasets cannot solve many characteristics of atmospheric regional events. Therefore, a "downscaling technique" for catching local atmospheric behavior was necessary. A dynamic downscaling strategy using RAMS model nested into the Reanalysis atmospheric fields (along with a weekly high resolution sea surface temperature datasets) was adopted for all simulations. Specifically, a regional dust coupled model was established through developing dust transport model and embedding it in a nonhydrostatic mesoscale atmospheric model, which simulate and forecast the meteorological fields. The dust/sand surface fluxes from remote sources were parameterized based on the friction velocity by developing an emission module (called DUSTEM) that considering the effects of surface cover and moisture. While the dust/sand fluxes from local sources (i.e. abandoned

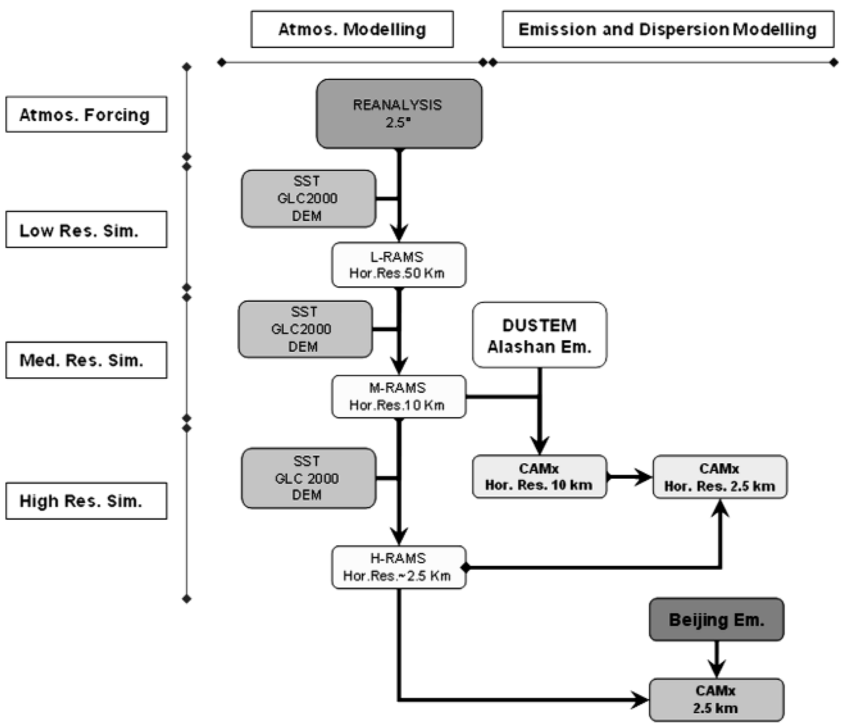

Fig. 1. Overview of the atmosphere-dispersion modeling system.

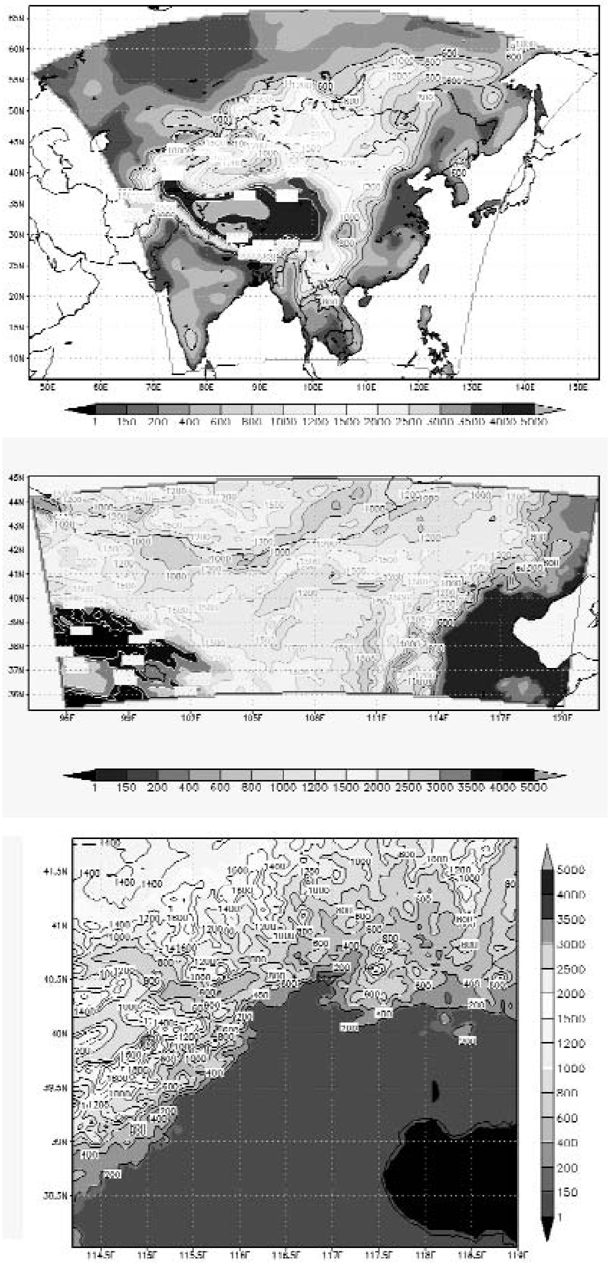

Fig. 2. Global L-RAMS (top), regional M-RAMS (center), and local H-RAMS (below) RAMS grids. The topographic input data are represented (elevation in m).

rubble pits in the Beijing area) were estimated based on *in situ* measurements. As shown in Figure 1, the atmospheric model, forced by the Reanalysis datasets, was set up on a system of nested grids characterized by different spatial resolution (i.e., 50 km, 10 km, and 2.5 km) (see Figure 2).

The RAMS model provided the atmospheric data for the dispersion modeling, while the emission module supplied the dust/sand emission fluxes.

Atmospheric model

Atmospheric modeling was carried out by means of RAMS 4.3 modified-version, developed in collaboration with the Applied Meteorological Foundation (AMF) of the Institute of Biometeorology of National Research Council (Institute of Biometeorology of National Research Council Website; Pasqui et al., 2000; Meneguzzo et al., 2004; Meneguzzo et al., 2001; Pasqui et al., 2002; Soderman et al., 2003; Pasqui et al., 2004a; Pasqui et al., 2004b; Avissar & Schmidt, 1998; Chen & Avissar, 1994; Golaz, 2001; Pielke, 2001). RAMS is a regional model constructed around the full set of nonhydrostatic, compressible equations that use atmospheric dynamics and thermodynamics, plus conservation equations for scalar quantities plus a large selection of parameterizations for turbulent diffusion, solar and terrestrial radiation, moist processes, cumulus convection, and energy exchange between the atmosphere and the surface through vegetation. A general description of the model can be found in Pielke et al. (1992), while a technical description is available on the Atmospheric, Meteorological, Environmental Technologies Website.

Each simulation is characterized by an ensemble of physiographic dataset needed to represent the atmospheric dynamical behavior: topography, land cover, and sea surface temperature. For the present study, a recent land cover dataset provided by Joint Research Centre called Global Land Cover 2000 (GLC2000) was adopted (GLC2000 Website) as long as NASA-PODAAC SST archive: AVHRR Pathfinder SST dataset and MODIS (AQUA/TERRA) SST dataset (see AVHRR Pathfinder Website and MODIS SST Website).

The selected grids allowed providing, both at regional and local scales, a fairly good description of the complex topography and, therefore, a good representation of the wind flow around the topographic obstacles. Three nested grids, characterized by different spatial resolution, were employed: (i) Low-resolution RAMS grid (L-RAMS) or global grid, with 50 km of horizontal resolution, 36 vertical levels, and 130/130 grid points; (ii) Medium-resolution RAMS grid (M-RAMS) or regional grid, with 10 km of horizontal resolution, 36 vertical levels, and 220/100 grid points; and (iii) High-resolution RAMS grid (H-RAMS) or local grid, with 2.5 km of horizontal resolution, 40 vertical levels, and 180/180 grid points. The vertical layers were defined based on a stretched vertical coordinate algorithm and resulted to be denser in the lower elevation rather than in the upper ones ranging form 100 m near the ground surface to 1200 m in the free troposphere.

All the adopted choices in the atmospheric forcing scheme were established after a long and specific experience on the atmospheric modeling (Pasqui et al., 2004; Pasqui et al., 2005).

Emission model

Modeling wind erosion is one of the crucial aspects in a DSS modeling and requires the capability to identify the dust/sand originating sources and to estimate the amount of the dust/sand effectively transported by wind. To this purpose, two emission typologies were identified as *remote emissions* and *local emissions*. In any case, the emission models provided hourly maps of dust/sand vertical fluxes that were implemented in the dispersion model, along with the atmospheric dataset provided by RAMS and additional input data as required by CAMx.

The emission model for remote sources:
The DUSTEM model estimates the dust/sand emission rates using empirical relationships based on soil texture and friction velocity. Following Nickovic et al. (2001) the emission fluxes are estimated as follows:

$$F_S = const \times u_*^2 \left[1 - \left(\frac{u_{*T}}{u_*} \right)^2 \right] \quad for \quad u_* \geq u_{*T},$$

where u_* is the friction velocity, *const* is a calibrated constant and u_{*T} is the threshold value for the friction velocity below which dust production ceases and depends on the particle characteristics. Since different soil types act as different dust/sand sources depending on their particle radius, density, and dust productivity, in order to obtain the effective surface vertical flux for different soils the previous formula was rescaled by a constant δ:

$$F_S^{EFF} = const \times \delta \times u_{*T}^2 \left[1 - \left(\frac{u_{*T}}{u_*} \right)^2 \right] \quad for \quad u_* > u_{*T} \qquad [2]$$

The constant δ depends on dust productivity and on the soil type. The threshold friction velocity

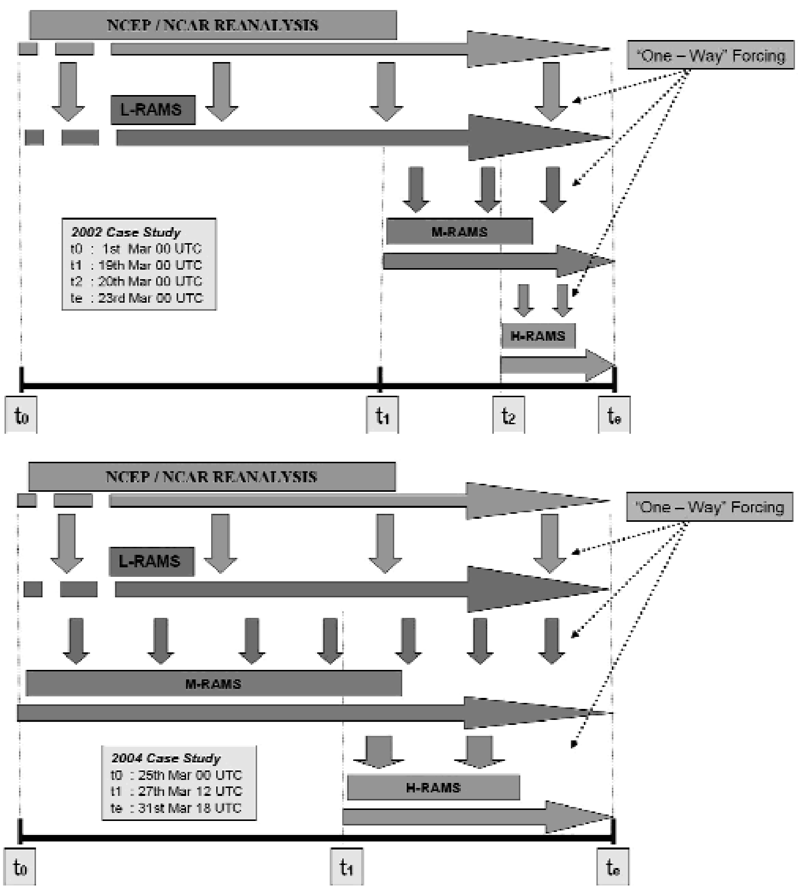

Fig. 3. Atmospheric forcing scheme. March 2002 DSS event (top) March 2004 DSS event (bottom).

u_{*T} strongly depends on soil moisture and particle size. The dependence of threshold friction velocity on the soil water content and particle radius is expressed by the following formula:

$$u_{*T} = A\sqrt{2gR\frac{\rho_p - \rho_a}{\rho_a}} \cdot \sqrt{1+1.21(w)^{0.68}} \quad [3]$$

where A is a constant, g is the gravity acceleration, ρ_p is the particle density, ρ_a is the air density, R is the radius of the particle and w is the soil moisture. The constant A only depends on the particle Reynolds number and typically assumes the value $1.5x10^{-5}$ m^2/s.

The DUSTEM model takes into account the snow coverage as one of the input parameters to estimate dust fluxes which can completely inhibit such phenomenon. More specifically, in order to characterize the different soil types, a soil textural map was obtained by projecting the 1 km GLC2000 land cover onto the 8 km FAO Textural Map. Using the Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent, the snow coverage was taken into account. Depending on the percentage of snow coverage, the areas covered by snow during the period of the simulations were thus masked out or the contribution to the dust/sand fluxes was proportionally reduced.

Accordingly to equation 3, to compute the threshold friction velocity, information on soil water content was used from the hourly soil moisture data from RAMS. By combining the FAO textural map, GLC2000 land cover, NHE snow cover, and the RAMS soil moisture and friction velocity, the DUSTEM model implemented the emission formula and estimated the effective emission rates. Such estimation was carried out both at regional and local scale (i.e. 10 km and 2.5 km) so that to provide hourly emission maps to be implemented in the CAMx dispersion model. Cumulated fluxes from remote sources at regional scale are given in Fig. 4.

The emission model for local sources

The adopted *ad-hoc* emission formula compute the emission fluxes based on the *in situ* measurements and modeling activities carried out in the framework of the WinDust project by University of Tuscia. Based on the collected data, emission formula interpolates the vertical fluxes as a function of the friction velocity. The emission formula is represented by a polynomial expression of fourth order:

$$F_S^{EFF} = 69.63u_*^4 + 37.8u_*^2 + 0.8559 \quad [5]$$

where $u*$ represents the friction velocity and is the corresponding dust/sand vertical flux. Based

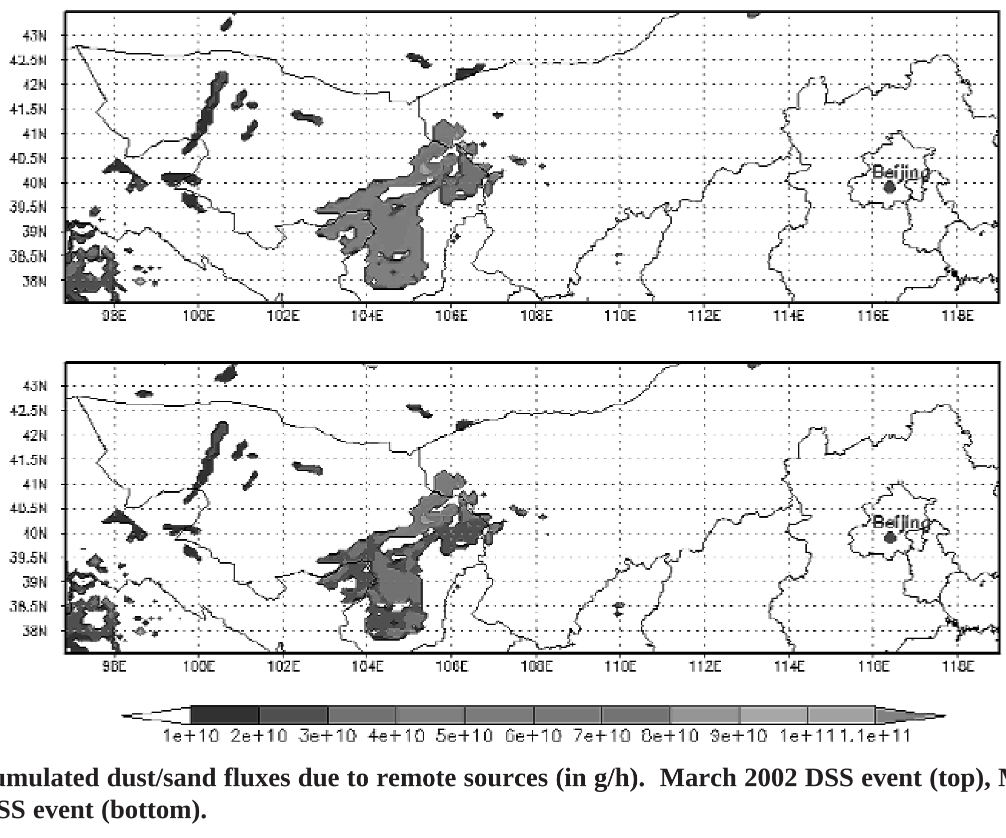

Fig. 4. Cumulated dust/sand fluxes due to remote sources (in g/h). March 2002 DSS event (top), March 2004 DSS event (bottom).

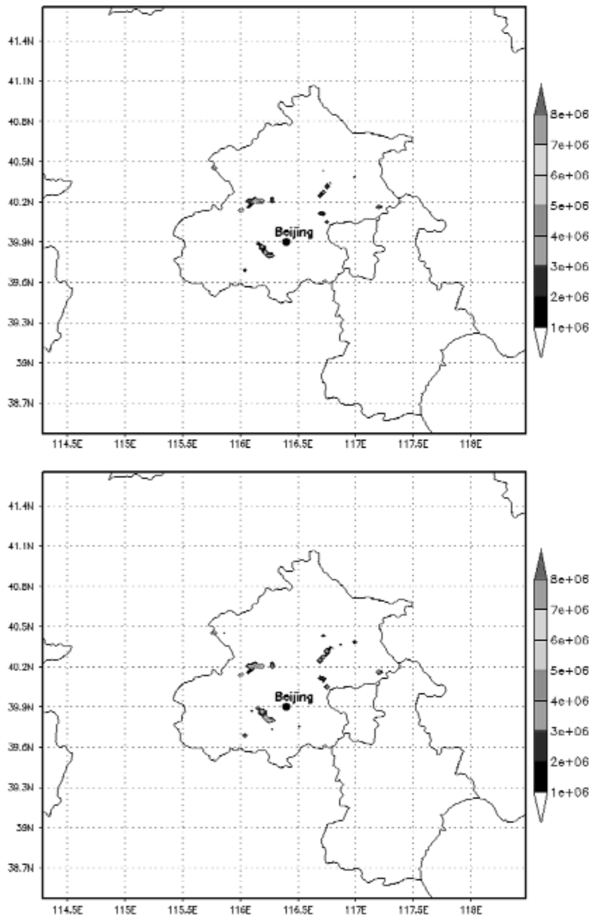

Fig. 5. Cumulated dust/sand fluxes due to local sources (in g/h). March 2002 DSS event (top), March 2004 DSS event (bottom).

on the adopted emission formula and the friction velocity data as provided by RAMS, hourly maps of vertical dust/sand fluxes were obtained and, therefore, implemented in the CAMx dispersion model. In Fig. 5 cumulated fluxes from local sources at local scale are shown.

Dispersion model

The Comprehensive Air quality Model with extensions (CAMx version 4.11s, developed by ENVIRON International Corporation, California, 2004) is an Eulerian photochemical dispersion model that allows for an integrated "one-atmosphere" assessment of gaseous and particulate air pollution over many scales ranging from urban to super-regional.

Two domains were employed: (i) a regional domain, characterized by a 10 km horizontal resolution, 22 vertical levels ranging from 39 to 6716 m a.g.l., 189 by 67 grid points; and (ii) a local domain, contained in the first one, with a 2.5 km spatial resolution, 22 vertical levels, 142 by 142 grid points, centered on Beijing. Once the CAMx configurations were set along with the necessary atmospheric and emissive input data, the model was run for the selected DSS case studies. As shown in Fig. 6, the March 2002 and March 2004 events were simulated considering remote emission only, local emission only, and the combined remote and local emissions.

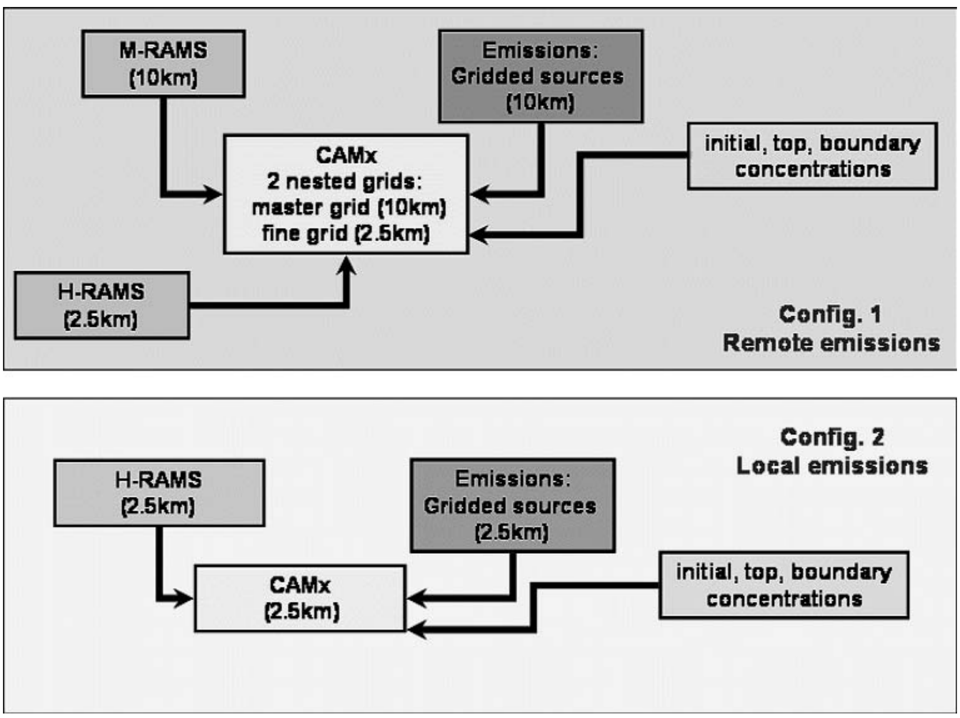

Fig. 6. Flow diagram of two CAMx configurations implemented.

Results

March 2002 case study: remote emissions

The Beijing area got affected by the event since the evening of 19 March. Here, the highest vertical-integrated concentrations were found during 19 March night and 20 March early morning (Fig. 7). Nevertheless, the Beijing area got significantly involved in the DSS event until 21 March at around noon. Vertical cross-section concentrations at regional scale and referred to the Beijing latitude (Fig. 8) suggested that dust/sand concentrations are vertically spread, even reaching heights of 3000 m a.g.l. Such a remarkable vertical spread accounts for the fact that concentrations are able to move over the Miaofeng Shan chain and affect the Beijing area, thereby avoiding the barrier effect usually played by the Miaofeng Shan chain located westward. Along horizontal cross-section (longitude) concentration pattern exhibits a low spread bell-shape with a peak value centered at the Alashan longitude, particularly remarkable at the beginning of the event. As the simulation proceeds concentrations are strongly dispersed into the atmosphere affecting a wider geographic area, while peak values and vertical extent decrease. Accordingly, vertical profiles of concentrations due to remote emissions show that dust/sand was transported to elevated heights in Beijing.

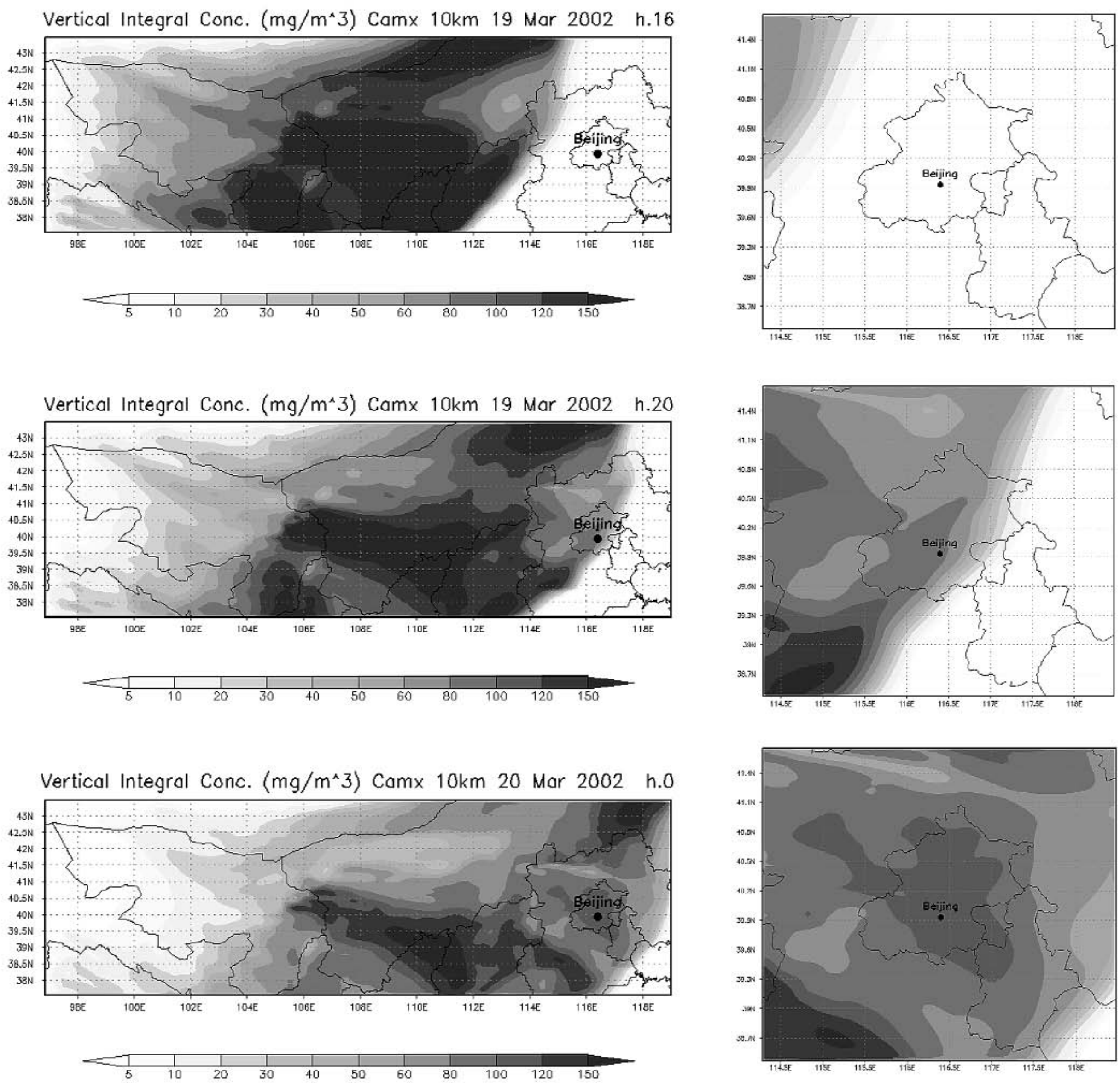

Fig. 7. March 2002 dust concentration maps (expressed in mg/m3) for the regional (left) and local (right) domains due to remote emissions, 19 March 2002 4:00 p.m. (top), 19 March 2002 8:00 p.m. (centre), 20 March 2002 0:00 a.m. (bottom).

Concentration time series due to remote emissions at the first vertical layer and referred to the Beijing centre show that the event lasted about 50 hours and was characterized by two peaks. First peak was 12-hours long (from 19 March at 8:00 p.m. to 20 March at 9:00 a.m.), with a maximum of about 9 mg/m^3 occurring on 20 March at around midnight. A 15-hours plateau followed, featuring a steady value of 2 mg/m^3. A second peak reached a maximum concentration of 4 mg/m^3 on the early morning of 12 March. From midday of 21 March dust/sand concentrations decreased up to a complete depletion on 22 March (Fig. 9).

March 2002 case study: local emissions

The concentration due to local emissions, located in Beijing surrounding, is three times lower than that due to remote emissions and is referred to as µg/m^3 instead mg/m^3. Concentration time series at the first vertical layer and referred to the Beijing centre shows that the DSS event lasted from the afternoon of 19 March to the evening of 22 March and was characterized by a number of low marked peaks. Maximum concentrations ranged between 2 and 3 µg/m^3 (Fig. 9). Vertical profiles showed that local emissions only affect the first 150 m of the atmosphere.

March 2004 case study: remote emissions

The DSS started in the early morning of 27 March in the Alashan region and Mongolia, spreading throughout the Inner Mongolia and reaching the Beijing area in the afternoon of 27 March. Peak concentrations were found over large areas. In the morning of 28 March a second DSS event took place starting from the Mongolia and Alashan, which moved southeast negligibly involving Beijing. Concentration time series due to remote emissions at the first vertical layer and referred to the Beijing centre show two different episodes (Fig. 9). In the first episode two peaks were found (6 and 3 mg/m^3 respectively). Two peaks lower than 3 mg/m^3 characterize the second episode.

March 2004 case study: local emissions

Same considerations as made for the 2002 simulation apply, since phenomenon development is particularly affected by the lower atmosphere turbu-

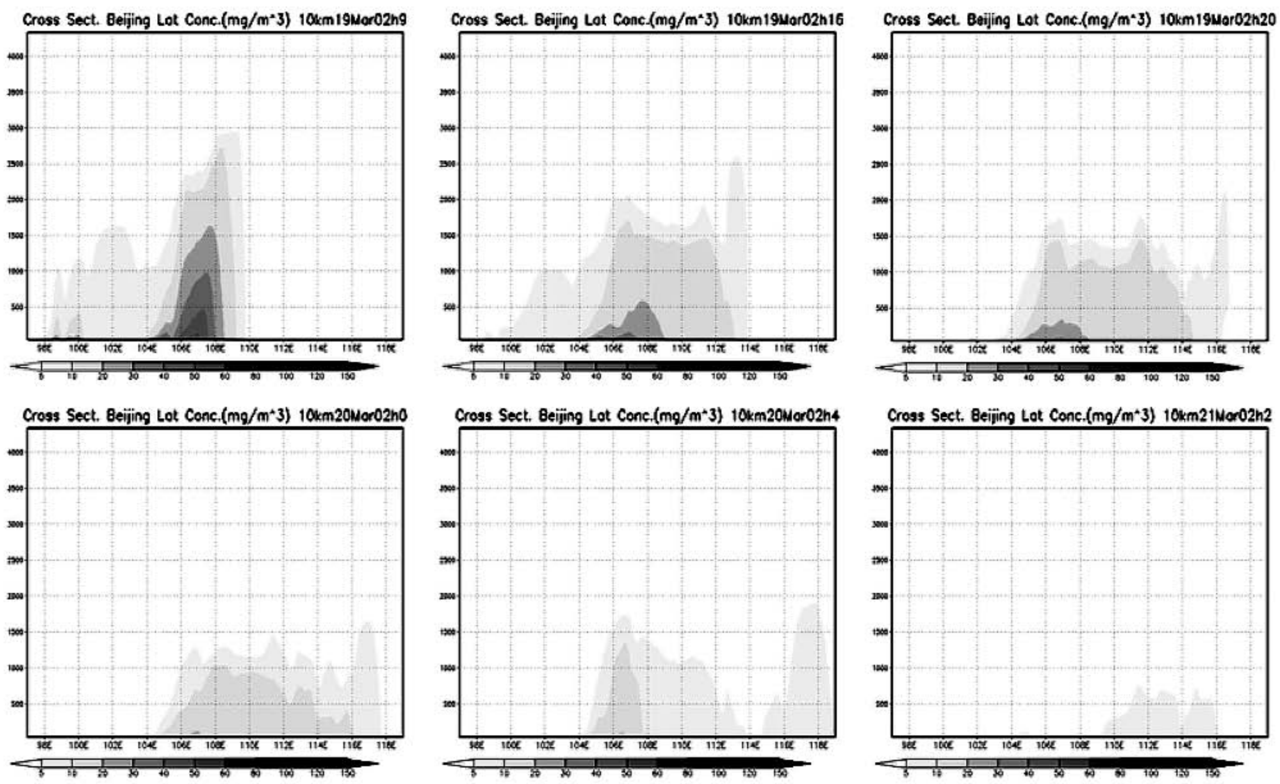

Fig. 8. March 2002 vertical cross-section concentrations due to remote emissions at regional scale and referred to the Beijing latitude (expressed in mg/m3) (a) 19 March 2002 9:00 a.m.; (b) 19 March 2002 4:00 p.m.; (c) 19 March 2002 8:00 p.m.; (d) 20 March 2002 0.00 a.m.; (e) 20 March 2002 4:00 a.m.; (f) 21 March 2002 2:00 a.m.

lence. Concentration time series at the first vertical layer and referred to the Beijing centre shows that the DSS event was characterized by a number of marked peaks lower than 4 μg/m³ (Fig. 9).

Remote emission scenario

The cumulated dust/sand fluxes representing the Alashan intervention scenario are presented in Fig. 10. The arrows indicate where the cumulated emissions got reduced by about fifty percent. A dust/sand concentration reduction was found in the proximity of the intervention area. Nevertheless, no relevant reduction in concentrations was observed in the Beijing area.

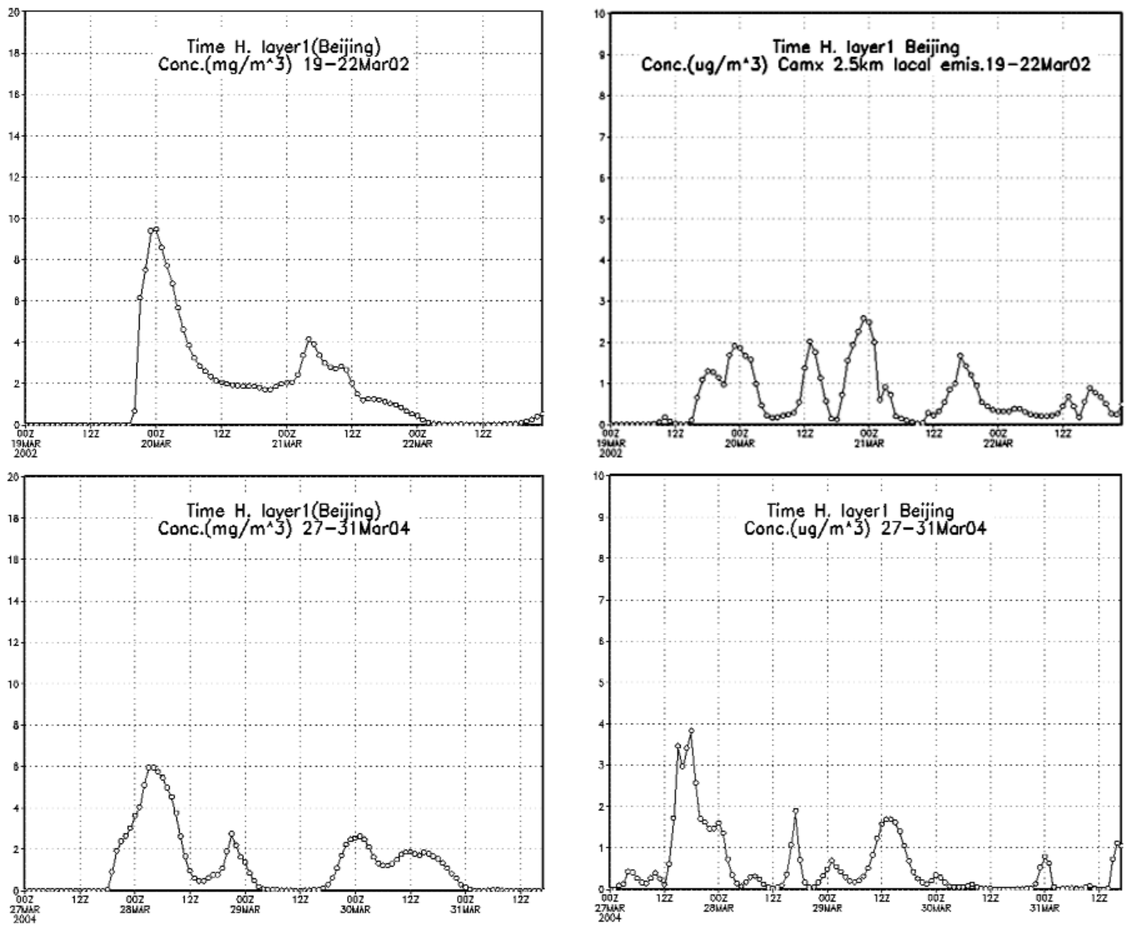

Fig. 9. Concentration time series at the first vertical layer and referred to the Beijing centre. March 2002 concentrations due to remote emissions (top left) and due to local emissions (top right). March 2004 concentrations due to remote emissions (bottom left) and due to local emissions (bottom right). Note that concentrations due to remote emission are expressed in mg/m3, while concentrations due to local emissions are expressed in μg/m³

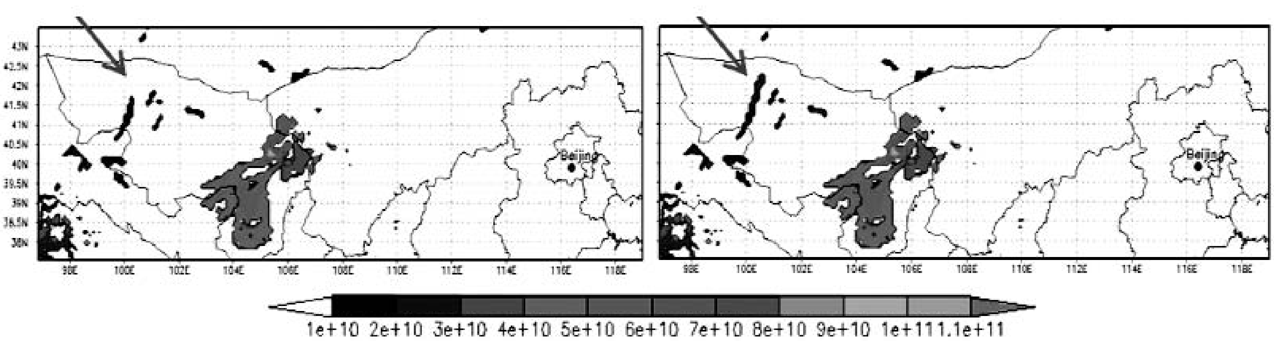

Fig. 10. Cumulated dust/sand fluxes (in g/h) due to reduced remote sources (left) compared to the remote emission scenario (right).

Local emission scenario

As for the local emission scenario, cumulated concentrations due to reduced local emission scenario were observed to be remarkably inhomogeneous both in space and time, but a remarkable decrease in concentration values was found. Observed peak values were reduced by about fifty percent. These considerations could be supported also by comparing the concentration time series at the first vertical layer (Fig. 11).

Conclusions

This study confirms known findings on the DSS dynamics namely the important role played by strong winds and air and soil temperatures in the DSS dynamics. The distribution of cumulated concentration appeared to be strongly influenced by the wind field. Also, the Alashan region was observed to reach quite high daytime heating of the ground surface, which results in an unstable boundary layer and, therefore, in high values of the surface friction velocity that is recognized as the basic physical condition for raising the dust/sand. A direct interpretation of the DSS dynamics at local scale should take into account factors other than the wind field pattern. Local dust phenomena affect a thin atmospheric layer where turbulence is highly developed since the

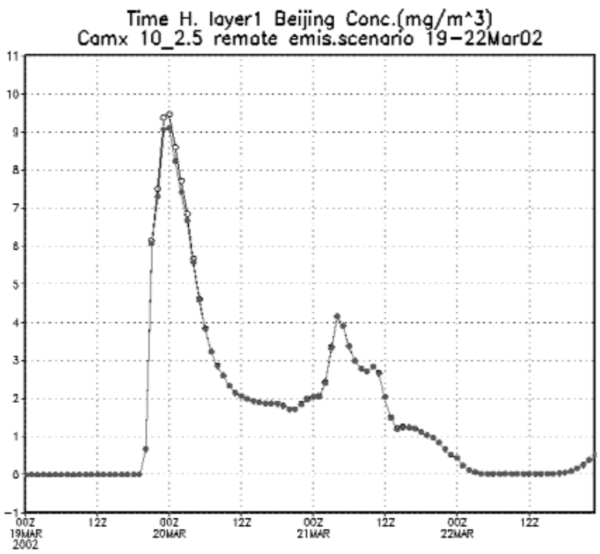

Fig. 11. Concentration time series comparison between the original emission and the reduced ones, at the first vertical layer and referred to the Beijing centre (expressed in μg/m³).

atmospheric circulations are strongly affected by topography and urban heat island phenomenon. According to the modeling of the different emission scenarios, the contribution of local sources to the DSS affecting the Beijing area was negligible compared to the contribution of the remote sources. The model outputs showed that the maximum concentration in Beijing area due local emissions was less than 5 μg/m³ for both the case studies (March 2002 and March 2004). The maximum concentration in Beijing area due to emote emissions was found to be about 10 mg/m³ and 6 mg/m³, for the March 2002 and March 2004, respectively. This estimation, even if influenced by the incomplete localization of the degraded area surrounding Beijing and the preliminary emission mapping, appears to be reliable considering the big difference between the amounts of the two contributing sources.

Furthermore, it was observed that meteorological conditions strongly influence the propagation of DSS due to remote emissions and, therefore, the extension of the affected areas. Conversely, the extension of the DSS affected areas due to local emission was not found to change significantly with the different meteorological conditions. Therefore, even though local emissions were found to be minor in terms of contribution to strong DSS affecting the Beijing area, it was concluded that, since dust/sand emissions from local sources do not necessarily need extreme meteorological conditions to be dispersed, they likely affect the deterioration of the Beijing air quality on a more frequent and continuous basis than the remote emissions. Finally, a reduction in the potential dust/sand emissions due to remote sources should be considered as relevant in the mitigation and control of DSS affecting the Beijing area. Also, reducing the dust/sand emission from local sources should be considered towards the improvement of the Beijing air quality.

The intervention scenarios were mainly selected to evaluate the model capabilities to support decision makers in the identification of actions aimed at DSS control and mitigation. Concerning remote sources, on the one hand, a reduction in the potential dust/sand emission sources was found to result in a decrease of dust/sand concentrations in the proximity of the intervention areas; on the other hand, no relevant decrease in concentrations was observed in the Beijing area, where only a slight reduction in the peak values was observed. With reference to local sources, a reduction in dust/sand emissions was observed to result in a decrease (approximately proportional) in the concentrations in the affected areas. No specific inference could be made concerning the extension of the involved areas, since the concentrations were observed to be remarkably inhomogeneous both in space and time. Finally, modeling of intervention scenarios showed how reducing dust/sand emissions results in a decrease in the dust/sand concentrations in the areas affected by DSS, giving reasons for additional future modeling to support the analysis of strategic intervention activities.

The numerical prediction model was found to represent a practical and flexible tool to simulate and analyze DSS dynamics and could be considered a monitoring tool in the integrated management approach to DSS mitigation and control. The model was efficiently employed in the characterization of DSS affecting Beijing and in the discrimination of the main source areas. Modeling also showed good results in simulating the intervention scenarios, allowing the implementation of small and large-scale interventions and, therefore, the quantitative evaluation of the mitigation effects produced by the intervention activities. Knowledge and know-how acquired in the DSS modeling could set the basis for the design and implementation of a DSS forecast system based on meteorological forecasts, as well as for the development of specific local scale analyses.

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An integrated approach to combat dust sandstorms in northern China

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Abstract

Dust sandstorms (DSS) events are frequently experienced in the arid and semi-arid areas of China. In order to understand DSS's causes and effects and evaluate proper countermeasures, the project 'WinDust' was developed jointly by Italian Ministry for Environment and Territory (IMET) and Beijing Municipal Environmental Protection Bureau (EPB), China. Within the WinDust project an integrated approach was developed for the study area, from the Alashan prefecture (Inner Mongolia) to Beijing, to test methodologies to prevent and mitigate the impact of DSS. Advanced Remote Sensing (RS) and Geographical Information System (GIS) techniques were implemented to characterize the potential DSS source areas and the evolution of the land cover in the last twenty years. A fully coupled atmospheric/emission/dispersion model was set up to understand a) the DSS dynamics b) the large-scale meteorological factors responsible for DSS affecting Beijing area, and c) the contribution of the Alashan area to the DSS affecting Beijing. Direct emission dust fluxes were measured in the area by an Eddy Covariance-based technology. Such emission measurements allowed to select the most effective dust emission model. Demonstration activities (energy and water saving in agriculture, low-tillage techniques, micro-propagation-based plant production, rubble pits restoration) were undertaken in order to identify the most suitable and cost-effective mitigation and control measures, both in the Alashan area and in the degraded areas surrounding Beijing. The results were assessed to set up an integrated management approach.

Introduction

Dust and sandstorms (DSS) constitute a serious environmental phenomenon occurring in northern China. It causes considerable hardship and loss of income to the people, affects their health, disrupts communications, and in extreme cases, leads to the death of people and destruction of livestock and crops over large areas in the affected countries (UNCCD, 2005). In the recent years unprecedented heavy and frequent DSS events have affected extensive areas in northern China, including Beijing. Chinese Government and the Beijing Municipal Administration have attached great importance to the recent increase in DSS intensity and the affected areas. A series of measures have been taken to improve the ecological environment of the surroundings of Beijing and other susceptible areas in northern China and to mitigate the DSS effects by combating on-going desertification processes. However, combating desertification effectively is problematic. Good knowledge about the DSS event and its causes is a critical issue for proper land use management by policy makers. The lack of adequate information about the phenomena highlights the need of research activities with a long-term perspective.

Within the framework of the Sino-Italian Cooperation Program for the Environmental Protection (SICP), Italian Ministry for Environment and Territory (IMET) and Beijing Municipal Environmental Protection Bureau (EPB) lunched in 2005 a project to combat dust sandstorms in northern China called 'WinDust'. The rationale of the WinDust project was to increase the knowledge on the phenomena involved in DSS and to propose and test interventions for the prevention and mitigation of DSS impacts. With this aim, a number of *in situ* pilot projects were designed and an integrated framework of atmospheric, emission, and transport models, Remote Sensing (RS) technologies, Geographical Information System (GIS) tools, and field measurements was set up to investigate DSS mechanisms. The distinctive idea characterizing the project was to combine scientific research, experimentation, and practical implementation for rural development into an integrated effort of cooperation to develop a comprehensive and participatory methodology rather than "a single solution to a single problem".

WinDust approach to dust sandstorm analysis

DSS is non-point source and serious transboundary environmental problem, which requires an integrated regional approach. Undertaking one isolated activity (e.g., only the planting of trees) will not solve the DSS problem (UNCCD, 2005) and a cross-sectoral approach in combating desertification is more likely to achieve desired results. Learning from the UNCDD experience, the WinDust adopted an integrated, cross-sectoral approach to study the DSS phenomena and to propose, design, and implement prevention, control, and mitigation measures to combat DSS in northern China. The area considered in the project (hereinafter referred to as "study area") extends east-west for about 1800 km and north-south for about 700 km; from the Alashan to the Beijing target areas (see Fig.1).

Due to substantial lack of knowledge about the mechanisms involved, the enormous dimensions of the problem, and the extreme environmental conditions of the region, several objectives had to be reached in order to assess feasibility and reliability of intervention activities. The knowledge about the DSS processes and their interactions had to be significantly improved and systematized; effectiveness and reliability of technologies and methodologies, as well as people's acceptance of such technologies, had to be assessed (Fratini, 2005). WinDust was thus envisaged as a phased project where the activities were planned based on a multi-annual approach. In the WinDust Project-Phase I, conducted during 2005, several vertical activities were carried out (see Fig.2): (a) RS analysis aimed at the identification of the baseline environmental conditions; (b) *in situ* measurements and modeling of emission dust fluxes due to wind erosion; (c) modeling of DSS dynamics at regional and local scale; and (d) design and implementation of demonstration projects on different aspects related to DSS mitigation and control.

The integrated approach also resulted in a number of transversal activities such as (i) the measurements of dust fluxes where demonstration projects were implemented (e.g. restored rubble pits) to evaluate the effectiveness of the applied techniques in reducing the dust/sand emissions; (ii) the evaluation of the collected dust fluxes measurements to select and calibrate the dust emission model; (iii) to refine the DSS modeling; and (iv) the implementation of a Digital Elevation Model (DEM) derived from the RS analysis into the DSS numerical model.

The results were evaluated in the assessment phase, setting the basis for the planning of future interven-

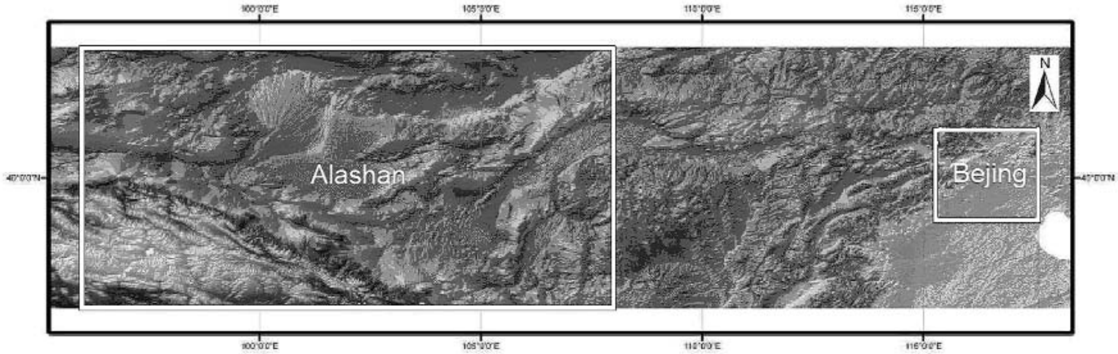

Fig. 1. Geographic coverage of the study area and indication of the Alashan and Beijing target areas. The Digital Elevation Model obtained from the Remote Sensing analysis of interferometric and stereo data is shown as background.

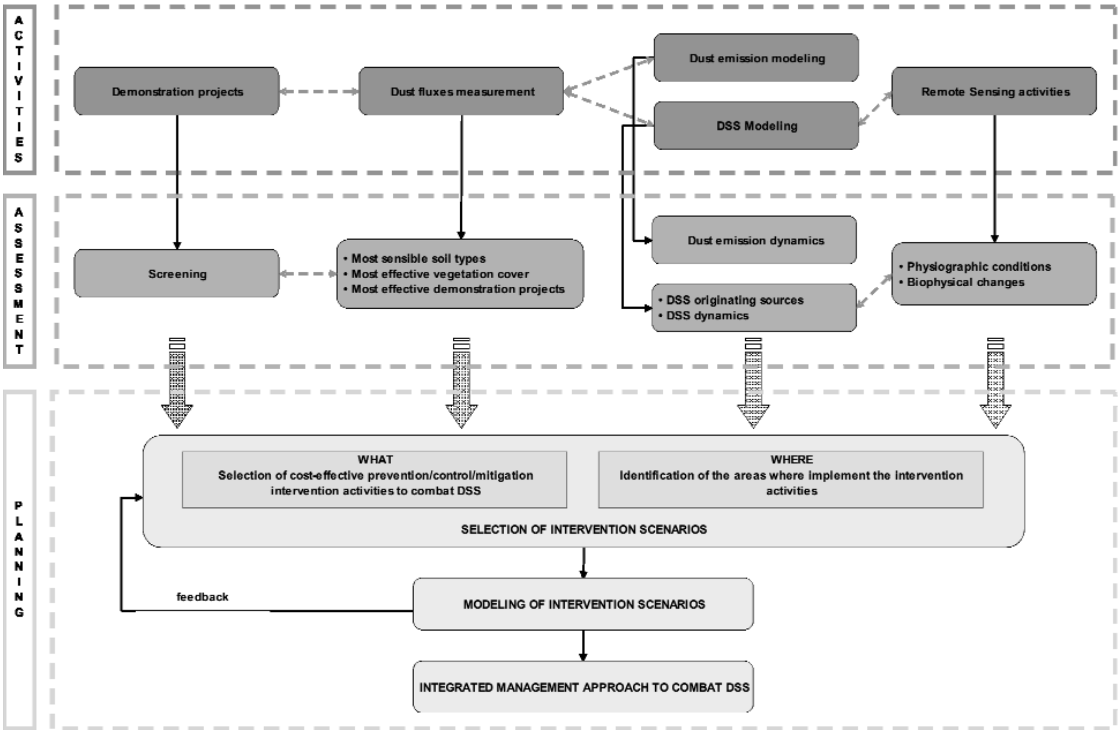

Fig. 2. The integrated approach of WinDust project. Performed activities (top panel) included cross-sectoral actions (broken arrows) and produced several results that were assessed. The results of the assessment (center panel) set the basis for the planning of future intervention activities and for the contribution to the definition of an integrated management approach to DSS mitigation and control (bottom panel).

tions for designing an integrated management approach to DSS mitigation and control. The assessment aimed at screening of the cost-effective pilot projects that could be implemented at large scale; identification of the most susceptible soil types, most effective vegetation cover and demonstration projects; evaluation of the DSS originating sources and dynamics; and evaluation of the present physiographic conditions responsible for DSS and biophysical changes of the land cover in the past 20 years (i.e. on-going desertification processes).

Identification of the baseline environmental conditions

Advanced RS technologies were employed to develop an extensive multi-source and multi-temporal analysis to identify the baseline environmental conditions in the study area and to detect the potential dust/sand sources at regional and local scale in northern China. For the Beijing and Alashan (Inner Mongolia) target areas, dust/sand sources characterization was carried out by means of the Spectral Mixture Analysis (SMA) using Landsat ETM+ imagery (Small, 2004). The SMA allowed mapping the spatial extents of spectrally distinct rock and soil substrates that may be identified as dust/sand sources. The differentiation of the substrates was based on the selection of the most suitable ‘endmembers’ (i.e. the spectral signature for pure surface covers) to represent the spectral mixing space in the selected areas. A SMA calibration and validation was done with field observation, where several soil samples were collected and studied in laboratory with spectroscopic analysis. Providing detailed information on the distribution of different soil types, the results of the SMA allowed obtaining a more refined land cover classification from MODIS imagery at regional scale.

Changes in the vegetation cover over the past two decades were investigated by analyzing time series of the Normalized Difference Vegetation Index (NDVI). The NDVI profile, obtained by the low resolution AVHRR images, was employed to evaluate the land cover evolution during the seasonal, annual, and decadal changes over the study area in the period 1981-2003. The analysis allowed estimating the relative aridity as a potential for dust/sand sources. Areas where the changes on the vegetation cover appeared relevant were identified and analyzed.

A Digital Elevation Model (DEM) covering the study area was produced from interferometric and stereo data using the Shuttle Radar Topography Mission (SRTM) available from National Geospatial-Intelligence Agency (NGA) and National Aeronautics and Space Administration (NASA). The obtained DEM was employed to study the topographic response of the study area to DSS events and was implemented as input for the DSS modeling. The DEM guaranteed a precise representation of the topography and, therefore an accurate representation of the atmospheric circulations. Synthetic Aperture Radar (SAR) dataset was employed to characterize aerodynamic roughness and unconsolidated surfaces in the study area, so that to provide an indication on the potential for surface materials raising.

Dust fluxes measurements and modeling

Detecting precisely the most intense sources of dust was one of the main goals of the project study. A new technology was developed and applied to measure vertical net fluxes of dust by wind erosion and was combined with a recently developed wind erosion model. The system is based on the Eddy Covariance methodology, already widely used and assessed in the framework of greenhouse gases (Aubinet et al., 2001). The first prototype of the system was employed to monitor wind erosion in six sites selected in the focus areas of Alashan and Beijing target areas over a period of two months (May and June 2005). The focus of the monitoring in Alashan was to assess the relative importance of emissions from several soil types considered to be major sources of dust. Effects of vegetation cover were investigated as well. The applied methodology is one of the first attempts to directly measure wind erosion vertical dust fluxes in a way that allows clear detection of any dust emission or deposition event. Directly measuring the suspended net vertical particles fluxes, it doesn't rely on any interpretation about the physics of erosion, thereby providing a powerful validation tool for wind erosion models. The high sampling frequency allowed a set of analysis that were not possible up to now for field measurements, such as the analysis of the dependence of the dust fluxes on wind direction and speed (Fratini et al., 2006).

The Lu & Shao dust emission model (WEAM, Lu & Shao, 1999; Shao, 2001) was applied on the same sites, in the same climatic and environmental conditions of the *in situ* measurements. A physically based wind erosion scheme was used in the adopted model in order to determine the dust emission from the surface. The model provides horizontal and vertical fluxes and estimates dust emission rates based on the volume removed by impacting grains. Applying the model in the same conditions monitored with the measuring system, allowed a detailed comparison and detection of some of its limits. Both modelled data and measured data of dust emission were considered to set up input to the dispersion module of the DSS integrated model.

Dust sandstorm modeling

A three-dimensional atmospheric, emission, dispersion numerical prediction model was developed for the northern Asia domain in order to provide a regional characterization of DSS dynamics acting on the area covering Alashan to Beijing. The investigation was supported by the analysis of the occurrence of the meteorological conditions responsible for DSS origin and propagation in northern China based on the NCEP-NCAR Reanalysis meteorological daily data and the Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent for the period 1979-2004.

The adopted numerical prediction model consisted of three different modules for the atmospheric, emission, and dispersion modeling respectively: (i) Regional Atmospheric Modeling System (RAMS parallel version 4.3), (ii) DUST Emission Model (DUSTEM version 1.0), and (iii) Comprehensive Air quality Model with extensions (CAMx version 4.11s). The RAMS module was employed to simulate the atmospheric fields, and provided the hourly atmospheric data necessary for the DUSTEM emission module. The emission module, in turn, provided the hourly dust/sand emission data to CAMx, which simulated, based on the atmospheric data, the dust/sand transport and dispersion mechanisms. To calibrate the model and perform a DSS regional characterization, the numerical prediction model was employed to simulate two recent and relevant DSS events (20-22 March 2002 and 28-30 March 2004). The simulations allowed to better understand the mechanisms of the DSS propagation in the area and to evaluate the role played by the degraded areas surrounding Beijing in the DSS affecting the capital; different simulations were set up for remote and local emissions. To evaluate how the DSS origin and propagation could change based on the changes in the land cover features (e.g. reduction in the extension of the potential DSS originating sources, increment of vegetation around susceptible areas) DSS modeling was carried out for two intervention scenarios. The “remote scenario” considered a reduction in the potential emission in two selected areas in the Alashan region, possibly related to the implementation of reforestation/afforestation programs. The “local scenario” considered the emission reduction consequent to the rehabilitation of a relevant number of abandoned rubble pits in the Beijing area.

Demonstration projects for DSS mitigation and control

Human activities are known to be one of the main factors enhancing DSS, mostly through overexploitation of natural resources in areas already threatened by severe climatic conditions. Thus, any environmental action dealing with desertification has to be a social action as well.

To reduce anthropogenic impacts on the territory while helping DSS mitigation, several pilot projects were designed and implemented. On-going activities were tested under development to evaluate the effectiveness, reliability and potential of innovative agriculture technologies and methodologies. State-of-the-art methodologies and technologies were integrated with traditional practices, in order to gradually turn the local economy toward a sustainable one, while mitigating and preventing DSS. Once the most suitable technologies and methodologies are selected, they will be introduced in a large scale intervention scenario to support land use management.

Energy and water saving in agriculture:
A pilot project of energy substitution and energy/water saving in agriculture was developed in Alashan. A socio-economic investigation of the area preceded the implementation of the project, to detect main threats to the environment and the basic needs of local population. Two urgent ecological problems, listed among the major causes of desertification in this region, were recognized: (i) overexploitation of groundwater and (ii) over-cutting of forestry resources. An integrated systems was designed by including a fully renewable energy-based drip irrigation system, a short-rotation plantation to produce biomass using fast growing cover plants (i.e. *Populus alba*, *Rubinia pseudoacacia*, *Salix matsudana*), and a plantation of *Haloxylon ammodendron*, a key ecological resource in the region. The project was implemented on a 2 ha area rural farm, 20 km south of

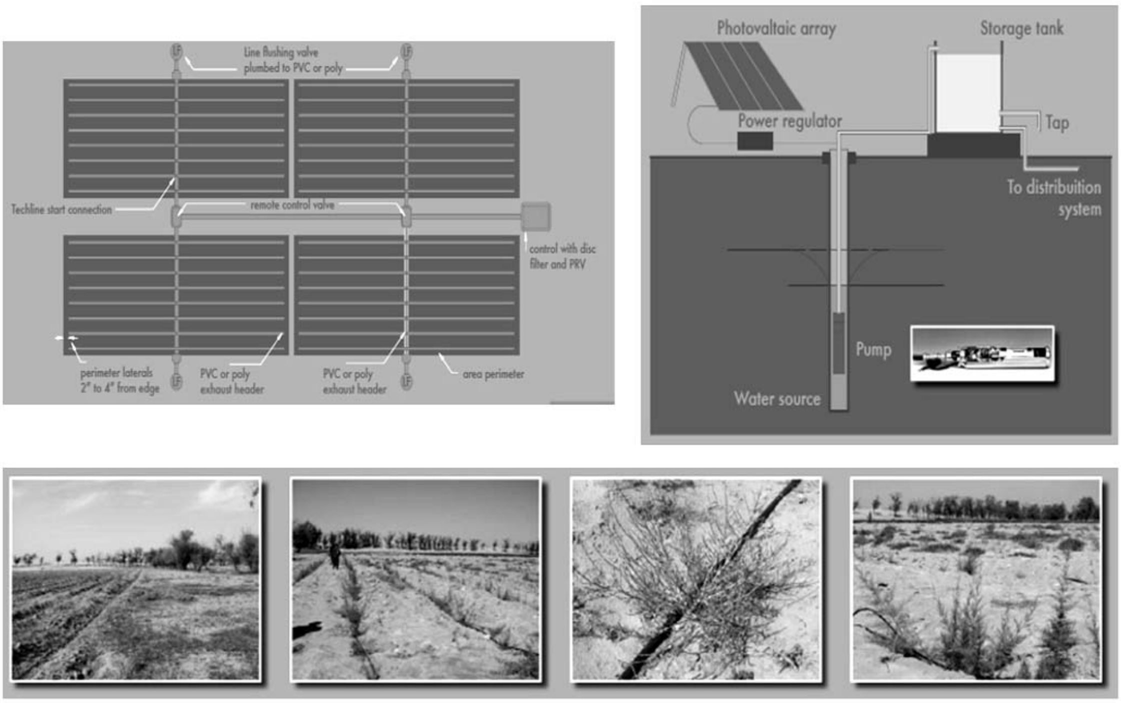

Fig. 3. Layout of the drip irrigation system and a sketch of the solar pumping system (top). Details of the installation (bottom).

Jartai (Alashan Left Banner). In the first implementation phase, the test area was equipped with a gravity drip irrigation system (Tiphon 150 –Netafim) that was connected with a solar pump (Solaflux – Fluxinos) alimented with solar panel array (EurosolarePN8 – Eni). In Fig. 3 the layout of the irrigation system is sketched and details of the installation are shown.

Micro-propagation-based plant production:
To complete the set of interventions in Alashan, a laboratory test for *in vitro* propagation of *Haloxylon ammodendron* was carried out in the laboratories of University of Tuscia, Viterbo, Italy. The applied methodology is one of the first attempts to reproduce such species in laboratory conditions: examples were found for *in vitro* propagation of *Haloxylon aphyllum* (Parveen & Birnbaum, 2001). The rationale was to find a convenient way to produce high numbers of healthy young plants to be grown in nurseries and then to be transplanted in the natural environment, in Alashan. The activity was aimed to develop a procedure for optimizing plants development from seeds. At present, growing media and conditions have been optimized for germination, multiplication of adventitious shoots and rooting.

Conservation-tillage trial fields:
Abandoned and active agricultural fields covering over 50,000 hectares were recognized as one of the most important sources of dust in the surroundings of Beijing. To tackle the problem, a pilot project of ‘conservation tillage’ was designed and is currently being implemented on maize and wheat fields. The intervention has largely proved effective in reducing wind erosion on cultivated lands. Italian technologies (Gaspardo seeder machineries) were used with the purpose of comparison with traditional techniques. The fields trial involved: (*i*) leaving maize stalks standing in the fields in autumn, no-till sowing in spring and weed control with herbicides; (*ii*) chopping stalks and covering the ground in autumn, no-till sowing in spring and weed control with herbicides; (*iii*) traditional mouldboard ploughing in autumn; (*iv*) minimum tillage (modified ridge tillage system); and (*v*) no-tillage.

Reclamation of rubble pits:
Two pilot projects developed by Beijing EPB were selected in order to evaluate the best practices for the environmental reclamation of the sites and for reducing dust/sand emissions. Technical advice included a) techniques for rehabilitation and stabilization of the slopes, also providing specific product to combat the erosion (i.e. geotextile); b) methods for re-vegetation of the sites; c) evaluation of different local rehabilitations methods; d) methodology for the assessment of rehabilitation projects; e) landscaping techniques; etc. The results provided a reference for further similar rehabilitation actions in the Beijing surroundings.

Results

Potential dust/sand sources

Mapping of vegetated sensible areas was found to provide evidence for DSS originating sources. The analysis of the NDVI profiles based on AVHRR images allowed highlighting the major potential dust/sand sources in the study area, i.e. extremely arid regions in the Alashan area that has little vegetation throughout the year. Areas with a decreasing signal, that could serve as potential dust/sand sources in the future and areas where noticeable changes were detected from 1981 to 2003 were also identified. (See figures 9 and 10 in Bach et al., 2007)

Considering spatial, temporal, and spectral resolution, Landsat imagery was found to be the most appropriate to support synoptic regional analyses aimed at the discrimination of different land covers such as rock/soil substrates. In the Alashan area, the SMA allowed discriminating four different endmember classes (i.e. mud/silt substrate, sand substrate, vegetation, and dark surface). In the Beijing area, three endmember classes (i.e. rock/soil substrate, vegetation, and dark surface) were detected. To obtain a more complete representation of different substrates, potential dust/sand sources regions should be isolated in a follow up field campaign.

Based on the SMA of the Landsat images, the MODIS land cover classification map showed the distribution of the 2004 United States Geological Survey land cover classes throughout the study area.

Soil types most susceptible to wind erosion

The first results obtained in field monitoring campaign showed some interesting features of wind action on different soil types and land covers and help assessing the susceptibility of several soil types to wind erosion. Fig. 4 shows time series of PM7 net emission/deposition fluxes, along with the actual friction velocity measured at the same time, for the two most relevant sites. Among the four sites monitored in the Alashan region, the Goby-type soil areas (GB1 site), covered by sparse shrubs appeared as the most intense dust source. Desert grassland also seemed to have a high potential for dust emission, even though wind speed in the monitoring period did not reach high values. The monitoring of an area (DG1 site), representative of a desert land where an intense and long-lasting aerial seeding reforestation project was promoted by Chinese government more than 30 years ago, showed that such an intervention is effective in reducing dust emission. Indeed, even with high wind speed, no dust emission was observed.

One of the goals of the validation monitoring was to assess relative importance of dust emission from natural desert sites and degraded sites (i.e., sites where erosion occurs mainly because of human activities). Thus, two representative sites in the surroundings of Beijing were monitored, namely a maize field (AS1 site) and an abandoned rubble pit (AS2 site). Results showed that, in terms of dust emitted per unit area, a rubble pit can be a source as strong as a desert area. Tables were produced linking wind friction velocity and dust emission fluxes, thus providing reference datasets for the DSS modeling.

A more extensive measuring effort, foreseen for spring 2006, could lead to the identification of all the most relevant soil types to dust emission, both in Alashan and in Beijing areas, with final goal of producing an “Emission Inventory” of the soil types.

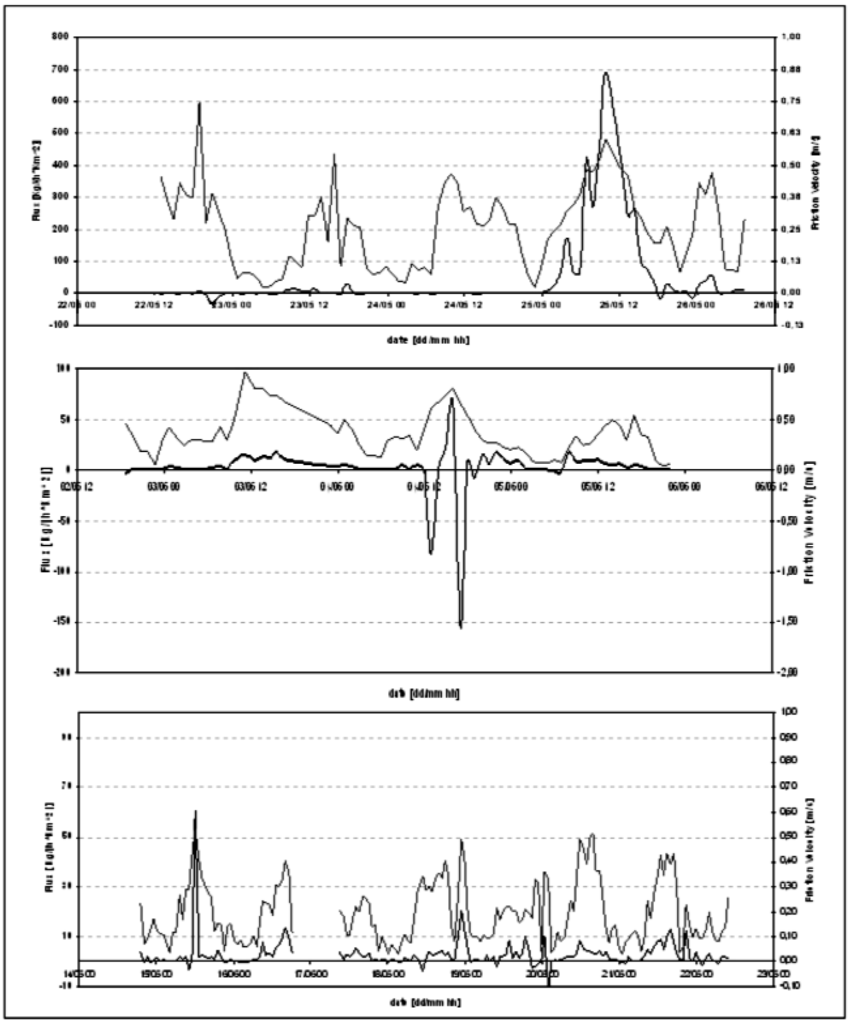

Fig. 4. Time series of net PM7 fluxes (black lines) and friction velocity (grey lines), for GB1, DG1 and AS2 sites corresponding to a Goby-type soil land in Alashan (top), an aerial-sown area in Alashan (center), and an abandoned rubble pit in Beijing (bottom).

Dust sandstorms dynamics

Based on Northern Hemisphere EASE-Grid Weekly Snow Cover for the period 1979-2004, it was observed that during spring season, due to the Indian Monsoon, the snow cover is extended throughout most potential sources for dust/sand, except for the Alashan and few other areas. Since the presence of snow cover is relevant to the inhibition of dust/sand emission, the area of Alashan could play an important role during spring season in terms of dust/sand emissions. The analysis of the Reanalysis daily data (1979-2004) showed that the pattern of the wind field in northern China is favorable, especially during spring season, to transport dust/sand from the Alashan desert areas to the Beijing area. A direct corridor acting between Alashan and Beijing, related to the Asian Jet Stream, was observed especially in March and April.

The modeling activities provided a characterization of the DSS at regional and local scale by providing hourly map for the relevant atmospheric fields (e.g. geo-potential height, temperature, wind velocity and direction), dust/sand emissions and concentrations (Fig. 5). The adopted numerical prediction model allowed simulating the implementation of small and large scale interventions and, therefore, the quantitative evaluation of the mitigation effects produced by the intervention activities.

The results of the modeling activities showed that the contribution of local sources (abandoned rubble pits and degraded areas) to the DSS affecting the Beijing area, for the two case studies considered was negligible compared to the contribution of the remote sources. However, emissions from local sources, which were not found to strongly related to extreme meteorological events, likely affect the deterioration of the Beijing air quality on a more frequent and continuous basis than remote emissions.

Since the estimation of the dust/sand emission was based on global datasets, the emission modeling provided consistent results but affected, to some extent, by the low resolution of such datasets, i.e. small scale features could not be detected. Specific/high-resolution datasets could be implemented in the emission module given that the whole system architecture was designed to enable the ingestion of different datasets.

Dust sandstorm mitigation and control measures

Since the implementation of some pilot project is

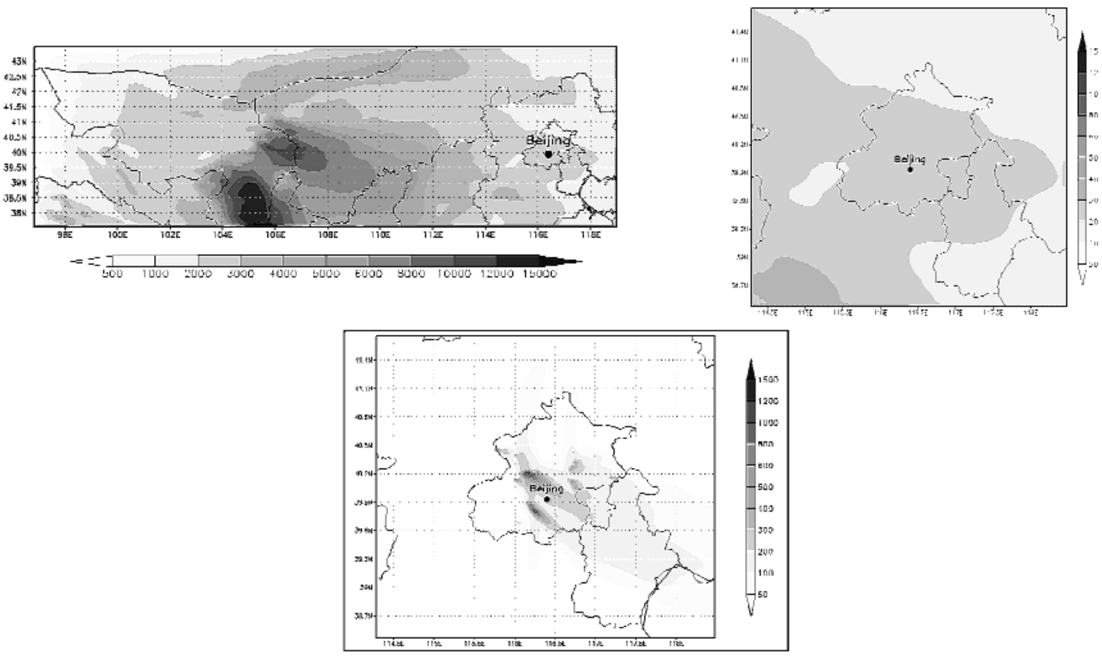

Fig. 5. March 2002 case study. Vertical integrated concentrations cumulated over the simulation period due to: (i) remote emissions at regional (top left) and local (top right) scale, and (ii) due to local emissions (botton). Concentrations due to local emissions (expressed in µg/m³) are negligible compared to the concentrations due to remote emissions (expressed in mg/m³).

still ongoing, a proper evaluation of the results has still to be made. However, some preliminary inferences can be drawn. In Alashan pilot projects, first implementation showed that considerable saving of water and energy is possible to sustain families' economy; when extended on a larger scale, it could result in a substantial reduction of the anthropogenic impact on the territory, thus indirectly, but effectively, contributing to mitigation of DSS causes. *In vitro* propagation of *Haloxylon ammodendron* seemed to be a promising technology for fast production of young plants for reforestation purposes in Alashan.

Rubble pit rehabilitation projects should be included in the definition of an integrated intervention plan as they can play a relevant role in the reduction of dust emission from local sources and, therefore, in the improvement of the Beijing air quality. In addition, first trial fields of conservation tillage technologies applied in the Beijing agricultural sites showed potential for reduction of dust emission through reduction of soil disturbance and increase in soil cover by vegetation residues. Rubble pits rehabilitation and innovative agricultural practice interventions should be based on a prior localization and exhaustive evaluation of the suitable sites.

Conclusion

In the framework of the WinDust project several activities were carried out toward the characterization of the baseline environmental conditions and DSS dynamics and, therefore, the identification of feasible and effective DSS control and mitigation measures. Providing updated information on topography and land cover of the study area, DSS characterization in terms of atmospheric, emission, and dispersion aspects, the performed activities, to some extent, bridged the knowledge gap about the phenomena involved in the DSS. The numerical prediction model was found to represent a practical and flexible tool to simulate and analyze DSS dynamics at different scales and could be considered a monitoring tool in the integrated management approach to DSS mitigation and control. Direct measures of wind erosion helped refining emission datasets and detecting relevant sources of dust both in Alashan and in Beijing; they also proved effectiveness of the aerial-sown reforestation programs undertaken by Chinese government in desert regions; nonetheless, more efforts in characterizing existing dust sources by a quantitative point of view have to undertaken.

Modeling activities showed that a reduction in the potential dust/sand emissions due to remote sources (i.e. mainly the Alashan area during spring season) should be considered as relevant in the mitigation of severe DSS events affecting the Beijing area. Reducing the dust/sand emissions from local sources should be considered towards the improvement of the Beijing air quality. Preliminary results of pilot projects encourage further efforts in introducing state-of-the-art techniques and methodologies both in the agricultural sector and in the recovery of degraded lands, with the aim of turning development into a sustainable perspective, reducing anthropogenic impacts on the environment, thus indirectly contributing to mitigation of DSS.

Acknowledgements

The present work was developed within the framework of the WinDust project, established and funded by the Italian Ministry of Environment and the Beijing Municipality Environmental Protection Bureau, with the aim of studying formation of the dust sandstorms affecting Beijing and proposing mitigation actions. Thanks go to the whole Chinese staff that made the implementation of such an ambitious project possible. The active cooperation and continuous suggestion by the Chinese experts is also greatly appreciated. Special thanks go also to the colleagues from the Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI) of Lanzhou for their scientific contribution and assistance during the field work.

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Land degradation and wind erosion in Tunisia – causes, processes and control measures

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Abstract

Large parts of Tunisia are arid, with soil and climatic conditions allowing only sparse natural vegetation. Overuse of these fragile areas due to high population pressure has led to severe land degradation. Lands formerly used only for seasonal and nomadic grazing have been converted to arable use for the settlement of formerly nomadic people. This loss of grazing reserves is leading to serious overgrazing of the remaining rangeland. Clearing large tracts of land using heavy machinery and clean-tillage is resulting in severe wind erosion. Research on soil protection against wind erosion in Tunisia focuses on preventive and curative measures. Good ground cover has been shown to be the most effective measure against wind erosion. Strip cropping is very efficient in controlling erosion in the cereal cropping system on sandy soils. Mulching is also effective, but materials to be used for mulching cannot usually be produced locally in sufficient quantity. More realistic measure is the use 10-20m wide strips of natural vegetation across the main wind direction. The strips can also be utilized as a source of feed for animals. Appropriate soil tillage is important for protecting the soil. Use of narrow tines and sweeps helped in reducing wind erosion, as compared to the disk harrow but the yields were lower. In the olive plantations that are vulnerable to sand encroachment by small sand dunes, the flattening of the dunes and mulching of the ground surface with shrub and palm leaves proved to be effective. Mechanical fixation of sand dunes is an effective but expensive measure. Local materials for dune fixation are being tested. Preliminary results show that dune fixation also encourages the re-establishment of natural vegetation on the stabilized lands.

Introduction

The zone adjacent to the Sahara in Tunisia covers approximately 30,000 km^2. The annual rainfall ranges between 100 and 200 mm. According to the lower end of the Mediterranean arid climate, the rainfall is highly variable, and occurs mainly between May and September, during the cold period. The thermal regime has large temporal variation. The average maximum temperature of the hottest month (July) varies from 32 to 36°C. Because of low soil fertility, loss of much of the rainfall through runoff, and overgrazing the steppe vegetation has become sparse.

Since the beginning of this century, and in particular during the last few decades, rapid changes in the landscape in southern Tunisia have been observed, due mainly to population growth and resettling of people. Changing style of living and rural development are accompanied by changes in the land tenure system and the quantitative and qualitative use of natural resources (Floret and Pontanier, 1982; Le Houerou, 1969 and 1990; Talbi, 1993).

Causes of land degradation

In the past, communal rangelands in this area were used for extensive grazing by sheep, goat, and camel and the traditional system of cereal cultivation was mainly in the higher rainfall zones. The recent rapid settlement of nomadic people and the change in the ownership of collective lands have resulted in a new form of natural resource use and management. This is illustrated by the gradual abandonment of transhumance systems, establishment of home gardens, and rapid extension of tree-and cereal-crop cultivation at the expense of pasture lands. This process has been accelerated by the introduction and general use of heavy tillage machines (such as disc plough), which permit rapid and less expensive clearing of large areas of steppe (Khatteli, 1981; 1984). Adoption of this aggressive technology for cultivating the sandy steppe lands, which are most attractive for the production of cereals and tree-crops, promotes accelerated wind erosion. It has also led to a decrease in the traditional pasture area. Sheep, still found in significant numbers, are progressively pushed to graze on marginal lands with reduced palatable species and low biomass, which leads to further land degradation. This process is of serious concern, as the topsoil on these lands is particularly prone to wind erosion that leads to the formation of dunes (Ben Dali, 1987; Akrimi et al., 1988; Akrimi and Abaab, 1991).

Settlement of nomadic people is leading to the abandonment of the system of large flocks. These are being replaced by smaller units that graze year-round close to the inhabited areas. This also results in localized overgrazing and an accelerated degradation of the environment in the vicinity of the settlements (Floret and Pontanier, 1982).

Sheep grazing is more or less a semi-nomadic practice, easily adapted to a spatial and temporal variability of rainfall and grazing resources. The deterioration of the ancient system of management of rural areas is leading to changes, sometimes irreversible, in the ecological equilibrium that existed in the traditional system. Natural resource degradation process has increased as is demonstrated by the decreased biological productivity of the ecosystems and resulting lower standard of living for the inhabitants (Floret et al., 1976).

Research on wind erosion processes

The research undertaken by the *Institut des Régions Arides, Médenine* and other Tunisian research centers has provided several useful results concerning the fundamental processes of wind erosion and the development of practical solutions, both curative and preventive, to counter wind erosion. Studies carried out at different research stations (Ben Gardane, Dar Dhaoui, Sidi Maklhouf, Menzel El Habib, and Nouiel) demonstrated that desertification in the form of sand encroachment, which poses the most serious problem, should not be considered as an unstoppable progression of sand mass from the Sahara. In fact, it is more a local phenomenon - discontinuous, diffuse, and nongeneralized - that occurs at all places in a vulnerable and marginal environment where the delicate equilibrium is disturbed by excessive and indiscriminate use by human populations (Khatteli, 1981; 1983).

In fact, the movable sand dunes that are encountered frequently near oases, cultivated lands, and villages are formed following the destruction of vegetative cover due to multiple anthropogenic effects (eradication of woody species, overgrazing, crop cultivation, etc). Their progression in the direction of the Sahara in general, and the Erg Oriental in particular (and not the other way as was previously believed), is due to the dominance of active winds that blow from the east, southeast, and the north over the winds that originate from the west and the south (Khatteli, 1981; Khatteli and Bel Haj, 1993).

At the planning level, the results of our study on wind dynamics and sand movement have provided practical solutions for efficient control of movement of sand dunes on the local scale. Mechanical windbreaks can be oriented perpendicular to the axis of sand displacement, and the implementation of mechanical stabilization of sand dunes can be undertaken when winds are relatively quiet. However, regular maintenance operations and the re-erection of the fences installed should be done during the windy periods in order to avoid their burial under the mobile sands (Khatteli, 1996). Low wind breaks (maximum height of 1 m) with a homogeneous permeability and without an opening at the base, are highly recommended to combat moving sand dunes.

Combating wind erosion

The research conducted in the arid region of Tunisia has demonstrated that the wind erosion in our zone is an anthropological phenomenon which, once initiated, tends to become more extensive and even encroaches on the more stable environmental zones. The experiments carried out at the research stations have demonstrated that it is possible to combat this degradation at the curative as well as the preventive level.

Curative control of wind erosion

Olive crops affected by sands: The sand encroachment of olive crops results from excessive cultivation of soil with a disk harrow, which pulverizes the soil and renders it more vulnerable to wind erosion. This is manifested by the disappearance of olive crops where the deflation and formation of movable sand dunes occurs, or where sand deposition occurs. To combat this phenomenon, mulching was employed, consisting of spreading plant residue over the soil surface after levelling the dunes (Khatteli, 1984). The erosion process has slowed down markedly, and no new dune formation has occurred at this site since then. Three types of plant residues were tested. The twigs of *Artemisia campestris* were found to be more suitable for the fixation of the mobile dunes than the other material (*Rhanterium suaveolens* and palm leaves). This was due to their application efficiency, pastoral and economic value, and availability in sufficient quantities on the degraded and fallow lands in the zone of study. It is also strongly recommended that the disk harrow be replaced by a tooth-harrow plough-share, or blade-harrow, all of which result in less degradation. The maintenance of natural plant strips between the olive trees and their utilization as wind breaks is also highly recommended.

Land covered by degradation:
The research done at Menzel El Habib on a degraded steppe covered by *Rhanterium suaveolens* under multiple anthropogenic effects (overgrazing and removal of woody species) illustrates the positive impact of measures taken to combat wind erosion. The ecological evolution of the study zone under the effect of the protective measures is demonstrated from a geomorphologic stand point in terms of (a) a spatial extension of *nebkas* at the expense of mobile dunes and the denuded zone; (b) a decrease in the susceptibility of the land to wind erosion; and (c) a general tendency towards the establishment of an eco-pedomorphological equilibrium. The protection of degraded land subjected to intense wind erosion processes can be envisaged as an efficient and less expensive method to combat wind erosion, provided the limit of its irreversibility has not yet been reached.

Mechanical fixation of mobile dunes:
A trial at the Sidi Maklhouf station examined the use of dry wattling (living brushwood) for rapid and effective stabilization of mobile dunes. Five treatments (including a control) were studied. The results showed that wattling arranged either in 20 m squares (continuous pattern) or in rows spaced 20 m apart (across the main wind direction) were the most effective treatments in terms of the quantity of sand trapped and the stability of soil surface inside each plot. The 40 m squares were less effective, but still resulted in improvement. Wattling rows planted 40 m apart were the least efficient, although they were significantly superior to the control (no intervention). In terms of cost/benefit, the 20 m parallel rows were better than the 20 m squares because they were only half as expensive. This allowed us to evaluate the actual cost of mechanical stabilization of dunes carried out by the regional technical services of the General Directorate of Forestry. The first six months of the trial were characterized by instability inside the different plots, which damaged the fixed plants. It is thus advisable not to begin tree planting during this period to avoid the burial of young plants due to sand deposit, or their removal due to deflation. Work during this period should be oriented towards the cleaning and care of the fence. Replanting should not be started until after the second year, or, at a minimum, six months after the installation of the plots. The dune soil, especially when it is a little mobile, generally provides a favorable environment for the development of natural vegetation, thanks to its capacity to retain soil moisture at shallow depths. It responds well to protective measures and may be sufficient for soil-surface fixation. This procedure will avoid the need for re-afforestation, resulting in reduced expenses for the fixation of the mobile dunes and the restoration of the degraded lands.

Preventive measures

The results of the experiments carried out in Dar Dhaoui on the implements used for soil cultivation, as well as natural plant strips for the prevention of wind erosion on lands under cereal cropping, clearly pointed out the extreme fragility of the arid ecosystems, notably those on sandy soils. Inappropriate exploitation of the natural resources in this zone (water, soil, vegetation) provokes wind erosion which, once initiated, feeds on itself and intensifies due to anthropogenic as well as climatic factors.

Crop cultivation can be regarded as a factor of soil degradation in south Tunisia because wind erosion is provoked on soils that are cultivated. This erosion is at its highest when the land is cultivated by disk harrow. Utilization of the disk harrow on sandy soils is inappropriate unless the soil roughness is improved by the addition of plant residues or by keeping uncultivated natural vegetation strips between the cultivated strips. If the first solution cannot be achieved, because it requires an investment to provide plant residue (hay, straw, or any other natural residue available locally), the second solution of natural vegetation strips is attractive to the farmers because it does not require any major investment. It can be easily implemented on a large scale. Strips 10-20 m wide were more efficient than strips 5 m wide, because they were more effective in decreasing wind erosion, and also helped in achieving a small increase in the yield of barley grown in between the strips. In addition to the ecological benefits (conservation of natural vegetation, which is nearing extinction because of land clearing), the uncultivated strips also provide livestock feed.

The tooth harrow (tiller) and the blade (sweep) significantly reduce wind erosion in comparison to the disc harrow. However, they cannot substitute disc harrow in the cereal zone because the yield of barley is reduced by using these kinds of tillage. Therefore, their utilization is recommended only in horticultural fields (i.e., for land cultivation in olive plantations). The tooth-harrow plough-share is the most appropriate tool because it results, on average, in a three-fold reduction in soil loss compared to the disk harrow, while producing an annual harvest closer to the mean yield.

Adoption of results on field scale

The research results achieved on wind erosion control in the arid Tunisia have been utilized at several locations as indicated below:

- The Regional Technical Services of the Directorate General of Forestry made use of these results to select the most permeable mechanical windbreaks and their orientation relative to the dominant active winds. These are being implemented at Mednine, Gabes, and Kebili.
- The farmers at Ben Gardane and at Zarzis used our recommendation about the maintenance of uncultivated strips between cultivated lands and the progressive replacement of the disk harrow by the tooth harrow, particularly in olive fields.
- Dune fixation in olive fields encroached by sand using the mulching technique has started to interest some olive farmers in the Zarzis region.

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Climatic characteristics of sandstorm in Gansu Hexi corridor

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Abstract

The spatial distribution characteristics and temporal variation laws of the sandstorm frequency in Gansu Hexi Corridor were analyzed using the observations from weather station during the past 50 years, and the atmospheric circulation conditions that favor the occurrence of the sandstorms in North China were investigated based on the NCEP/NCAR reanalysed climate data. The results show that the spatial distribution of the sandstorms in Gansu Hexi Corridor is the product of arid unstable transition zone on the edge of deserts. It means that under the same atmospheric circulation conditions, the underlying surface status mainly determines the spatial distribution of sandstorms. The temporal variation laws of the sandstorms in Gansu Hexi Corridor are related to strong winds. That is, on a certain underlying surface, the atmospheric status determins the temporal variation of sandstorms. The pattern of the atmospheric circulation composed by Mongol low (trough) and Ural high (ridge) is a typical background during sandstorms for all temporal scales (daily, annual, inter-annual and inter-decadal). The EOF analyses for the sandstorms in Gansu Hexi Corridor show that the sandstorm frequency regained an upward trend evidently from the end of 20th century to the beginning of this century.

Introduction

Gansu Hexi Corridor, which is to the north-east of the Qinghai-Tibetan Plateau and where Gobi and desert are crisscross and oases irrigated by high mountain runoffs are scattered, is an arid region of interior Asia. As a result of lack of water resources, the ground vegetation is extremely instable and it makes Gansu Hexi Corridor one of the most important sources of North China sandstorms (Wang et al., 2001; Wang et al., 2000; Zhou et al., 1999; 2002; Li et al., 2002) under the control of variations of atmospheric circulation.

Sandstorms are product of specific geographical and meteorological conditions. The ground in deserts and desertified areas around deserts under the instable vegetation condition are sources of sandstorms. The atmospheric circulation adjustment triggers forces for a series of processes during sandstorms. These two factors make up the necessary and sufficient conditions for the occurrence of sandstorms. In this paper, based on the observation data from weather station during the past 50 years and the NCEP/NCAR reanalysed climatic data (Kalnay et al., 1996), the spatial distribution characteristics and temporal variation laws of the sandstorm frequency in Gansu Hexi Corridor as well as the atmospheric circulation conditions that favor the occurrence of the sandstorms in North China are analyzed, in order to enhance our understanding of sandstorms and provide theoretical basis for improving the accuracy of sandstorm forecasting.

Spatial distribution of sandstorms

The distribution of long-term average annual number of days of sandstorm in different parts of Gansu Province is given in Fig. 1. It can be seen that, there are three high frequency sandstorm areas where the frequency is higher than 10 days per annual (d/a), and all of these are in Gansu Hexi Corridor. The first one is at the west end of Gansu Hexi Corridor and it borders in the west with Kumutage Desert in Xinjiang. Dunhuang, where the average sandstorm frequency is 10.7d/a, is the representative station of this area. The second one is in the middle of Gansu Hexi Corridor and it borders in the north with Badanjilin Desert in Inner Mongolia. Dingxin, where the average sandstorm frequency is 18 d/a, is the representa-

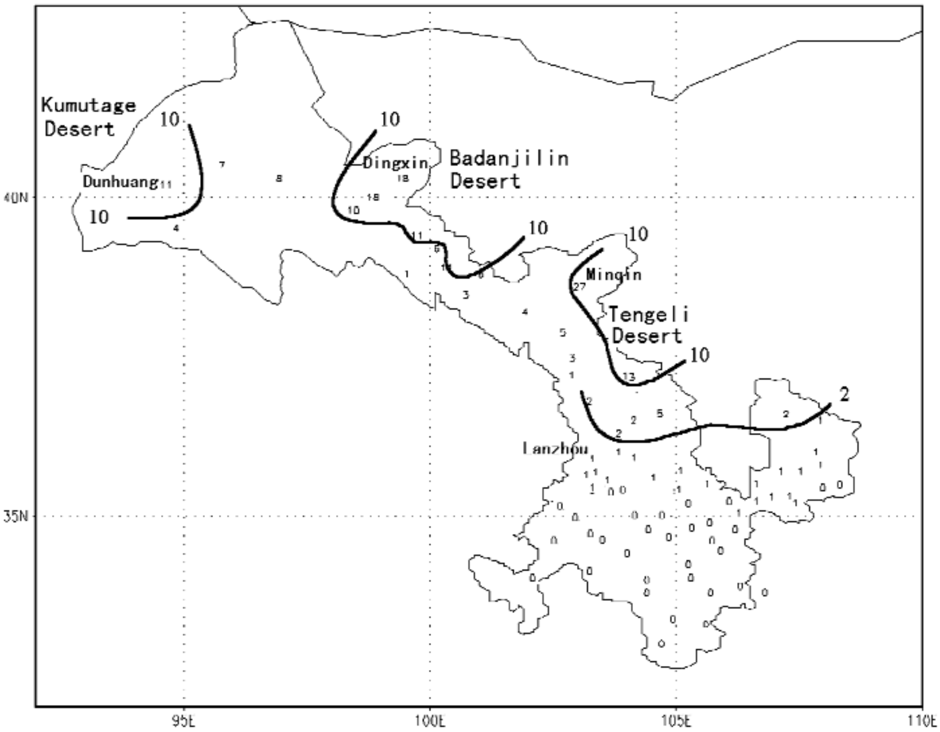

Fig. 1. The distribution of sandstorm number in Gansu province (day/year).

tive station of this area. The last one is in the east of Gansu Hexi Corridor and it borders in the east with Tengeli Desert in Inner Mongolia. Minqin is the representative station of this area, and its average sandstorm frequency is up to 27.4 d/a, which is the maximum in whole of Gansu Hexi Corridor. The average sandstorm frequency declines quickly in the east of Yellow River, and in the regions south of 36°N, the frequency is below 2 d/a.

The results show that the spatial distribution of the sandstorms in Gansu Hexi Corridor is related to the arid unstable transition zone on the edge of deserts. Regions near the deserts have more sandstorms, while regions far from deserts have less. This shows the importance of underlying surface conditions for sandstorm occurrence. Under the same atmospheric conditions, the underlying surface conditions determine the spatial distribution of sandstorms.

Characteristics of annual variation of sandstorms

The annual variation in the frequency of sandstorms in Gansu Province is given in Fig. 2. Five regions with high sandstorm frequency are shown there. The general characteristic of these regions is the same: more sandstorms in spring, less in autumn. However, the annual variations of sandstorm are different in the three areas. During the period between March and May, the sandstorm frequency of Dunhuang reaches maximum, and the frequency in each month of this period is almost the same. In June and July there is a hypo-maximum, which is in the shape of step. Although the maximal sandstorm frequency of Dingxin also appears in April, there are two sub-maximums, one is in January and the other is in June. The highest sandstorm frequency is in Minqin, which is nearest to deserts among the three regions. Only one peak appears in April is Minqin, and in June and July there is a hypo-maximum. Lanzhou also suffers from sandstorms although it is far from deserts, and there are fewer sandstorms. The annual variation of sandstorm frequency shows a single peak in spring while the frequency is low in autumn, and this typical structure represents the situation around high frequency sandstorm areas. The second highest peak value in the Fig. 2 is shown by Jingtai, which is in the south of Tenggeli Desert, but the pattern of its annual variation is different from that for the other locations: the single-peak typical structure is almost the same as around Lanzhou, and this shows the characteristics of the transition from central zone to the surroundings.

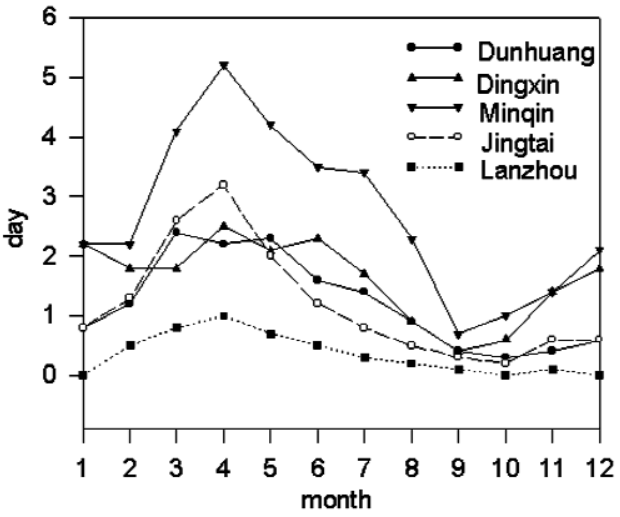

Fig. 2. The annual variation in the frequency of sandstorm in Gansu province (day/month).

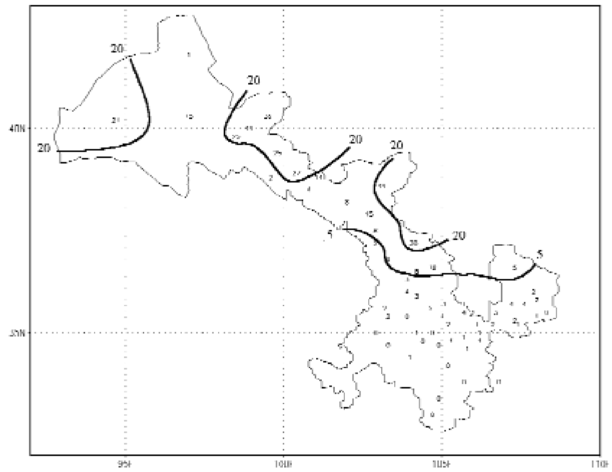

Fig. 3. The EOF first eigenvector field of sandstorm.

The general characteristic of the variation in the frequency of sandstorms is that there are more sandstorms in spring and less in autumn, and this pattern tallies well with the characteristic of annual variation in the number of gale days. From the above it is clear that under the condition of the same underlying surfaces, the general characteristic of annual variation of sandstorms is determined by the characteristic of annual variation in the atmospheric conditions. The actual changes in each region are determined by local factors.

Characteristics of inter-annual and inter-decadal variation of sand storms

The empirical orthogonal functions (EOF) analyses for sandstorm frequencies show that the spatial distribution of the first eigenvector field and distribution with long-time average observation values in 61 stations are almost the same: the distribution of three maximal centers and their surroundings is very distinct (Fig. 3). The variance contribution of the first eigenvector field is above 63%, and this indicates that the first eigenvector field represents the characteristics of basic spatial distribution of sandstorms and also the main form of the annual variation of sandstorms.

The annual variation of the first eigenvector field of sandstorms is given in Fig. 4. It can be seen that the frequency of sandstorms declined during the 40 years, and especially there is a conspicuous falling-off from the beginning of 1970s to the middle and late 1990s. The results of inter-decadal variation show that the frequency is low in 1960s, and reaches the maximum in 1970s; from 1980s it begins to decline and drops to the minimum in 1990s, but from the beginning of this century it has begun to rise again. From the record of every station where long-term observations were available (Fig. 5) it can be seen that the 1950s is the period with high sandstorm frequency.

The 50-year changes of sandstorm frequencies in Dunhuang, Dingxin and Minqin are given in Fig. 5. Although some details of the changes of the three stations are different, the general trends of them are just the same, which can be described as being high in 1950s, low in 1960s, high again in 1970s, low again in 1980s, lowest in 1990s and then getting high again at the end of this century. The results of spectral analysis of the time coefficient of the first eigenvector field of the EOF shows that, around 41.0, 6.8 and 3.4 years there are notable quasi-period with high reliabilities, and the quasi-period of 41 years is most notable of them all. From Fig. 4, it can also be seen that the form of the principal wave is obvious. And in 1960s and 1970s, minor-cycle waves of sandstorms vary within wider limits, and then they decline with the total sandstorm frequency getting down, and at the beginning of this century, they are not obvious.

Fig. 5 shows that the sandstorm frequencies of each station regain an upward trend from the end of 20th century to the beginning of this century, and this trend is more obvious in the Fig. 4. The continuous upward trend lasts from 1998 to 2001, and the increase is approximately equal to a quarter of the total decrease after the maximum in 1970s and also equal to one third of the total decrease after the 1960s. Such an obvious rising trend of sandstorms should be treated seriously.

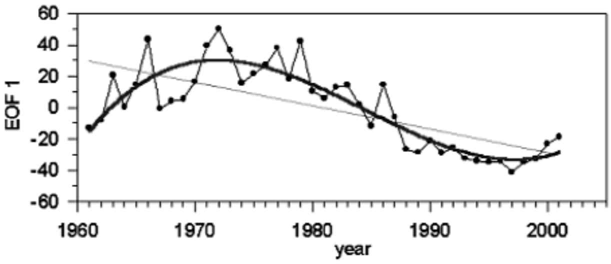

Fig. 4. The inter-annual variation of EOF first eigenvector of sandstorm.

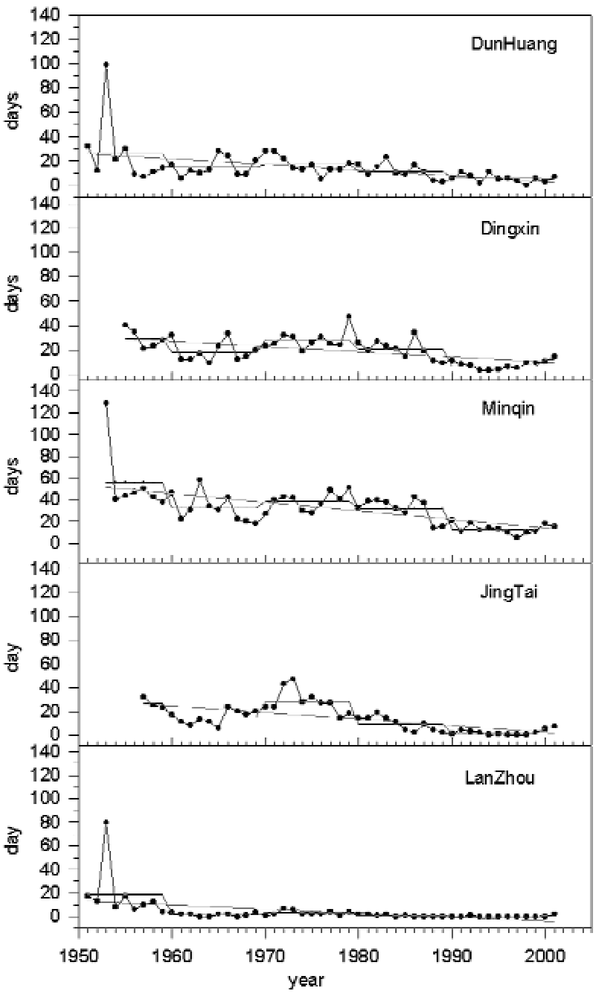

Fig. 5. The annual variations of sandstorm number in some stations.

Atmospheric circulation background of sandstorms

Strong winds are the most direct and important reason for sandstorms occurrence. This is shown obviously by data on daily, annual and inter-annual variations. The relationship between gales and sandstorms is very good, as many researchers have analyzed the phenomena (Zheng et al., 2001; Wang et al. 2002). In this paper, therefore, only the conditions of gale and circulation background that are favorable for sandstorm occurrence have been discussed from the aspect of atmospheric circulation.

In Fig. 6, from the field of 50-year average 500hPa height for spring, we can see that contour lines are relatively straight, and the westerly wind is stable. However, from the field of 500hPa height departure from normal for spring during the 1950s to 1990s, it can be seen that the field of departure is high in the west while low in the east, with the minus departure vortex in the center of Mongolia, and the positive departure ridge in Ural. The powerful pressure gradient force between the high and low centers destroys the straight northwest wind, enhances the longitudinal degree of the circulation, and the cold air is led to the south by the northerly wind resulting in strong surface winds in large areas. The pattern of the atmospheric circulation composed by Mongol low (trough) and Ural high (ridge) is usually a typical background during sandstorms, and if the pattern appears in a long-time climatic average state, we can say that the circulation of this kind was common in this period. As a result, synoptic processes favorable for sandstorm occurrence are also usually easy to be found in the period, and this leads to the rising of sandstorm frequency.

Contrary to the above situation, there is minus departure in the middle latitudes during the 1960s, and the departure in Ural is stronger than that of Mongolia. Positive departure center appears in Mongolia and the northwest of our country during the 1980s, and the departure of Ural is lower. In the 1990s, there is a strong positive departure center in Mongolia, while at the same time, the departure of Ural has become minus. Under the situation above, the westerly wind becomes weak, and the circulation gets stable; as a result, the synoptic processes favorable for sandstorms are not easy to be triggered, and hence the sandstorm frequency gets lower and lower.

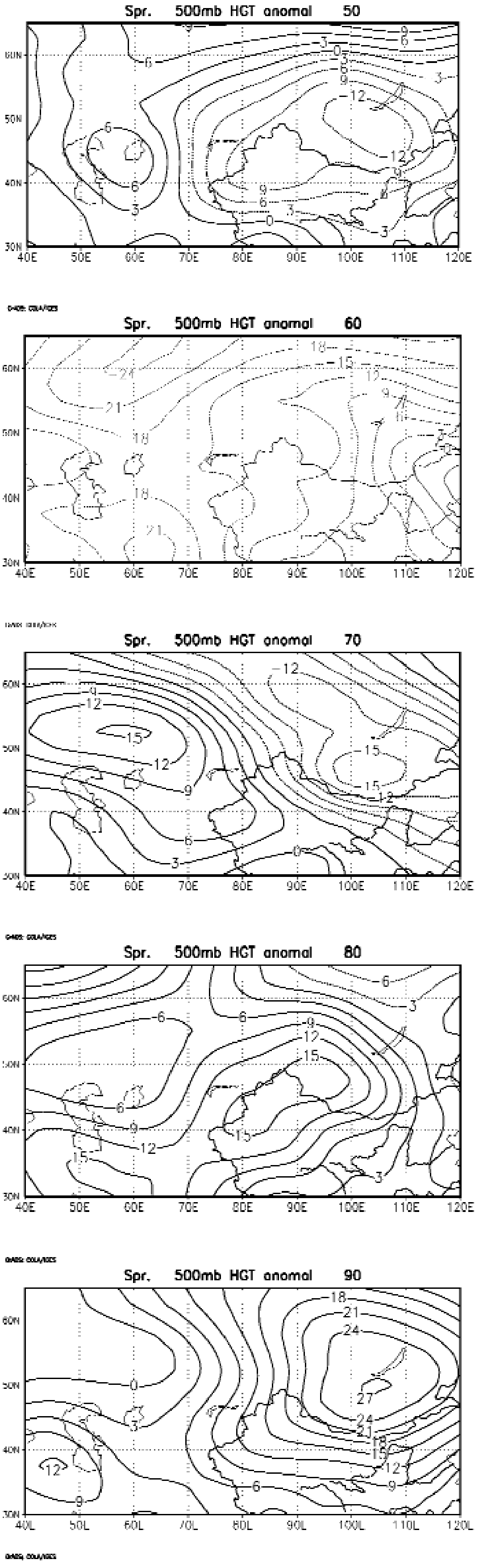

Fig. 6. The 500hPa height departure in spring during 1950s to 1990s: (a) 1950s, (b) 1960s, (c) 1970s, (d) 1980s, (e) 1990s.

It can be inferred from the above analyses that the inter-decadal variation of 500hPa height departure and the inter-decadal variation of sandstorms are in accord with each other, and the changes in the circulation status provide climatic background conditions for sandstorm occurrence.

Conclusions

The spatial distribution of the sandstorms in Gansu Hexi Corridor come into being mainly with the arid unstable transition zone on the edge of deserts, and this indicates that, under the same atmospheric circulation conditions, the underlying surface conditions determine the spatial distribution of sandstorms. The temporal variation laws of the sandstorms in Gansu Hexi Corridor are related to strong wind, and it is true for daily, annual, inter-annual and inter-decadal variations. Thus, under certain ground surface conditions, the atmospheric circulation status determines the temporal variation of sandstorms. The pattern of atmospheric circulation composed by Mongol low (trough) and Ural high (ridge) is a typical background during sandstorms, and this is true not only for synoptic scale but also for annual, inter-annual and inter-decadal scale. The EOF analyses for sandstorms in Gansu Hexi Corridor show that the sandstorm frequency regains an upward trend evidently from the end of the 20th century to the beginning of this century, and the rise approximately equals to a quarter of the total decrease after the maximum in 1970s, and is also equal to one third of the total decrease after the 1960s.

Acknowledgements

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Integration of advanced remote sensing technologies to investigate the dust and sand storm source areas

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Abstract

Advanced Remote Sensing (RS) technologies have an important role in the development of effective strategies to reduce and combat the dust sandstorms (DSS) phenomena that frequently affect the north-eastern China. An integration of the available remote sensed data allowed the development of an extensive multi-source and multi-temporal analysis to identify the base line environmental conditions in the area of interest and to detect the potential dust sources at regional and local scale in northern China. The dust sources characterization was carried out by means of the Spectral Mixture Analysis (SMA) for the Beijing and Alashan (Inner Mongolia) areas using Landsat ETM+ imagery. The Normalized Difference Vegetation Index (NDVI) profile, obtained by the low resolution AVHRR images, was adopted as an important statistical indicator to evaluate the land cover evolution during the seasonal, annual, and decadal changes over the area from Alashan to Beijing. The construction of a complete dataset for the investigated areas included the study of the topographic response to acquire detailed and recent landscape morphology from SRTM data, describing the elevation features of the considered surface, i.e. Digital Elevation Model (DEM). The integration of different RS technologies, supported by the Geographical Information Systems (GIS) capabilities for the environmental inventory, allowed assessing the present physiographic conditions in northern China and analyzing the causes of the man-induced land cover changes.

Introduction

Under the influence of global climate change, warm winters and dry springs dust sandstorms (DSS) occur more seriously in the northern China. DSS involve strong winds that blow large quantity of dust and sand particles away from the ground and over long distances, producing severe environmental damages in the affected areas. Remote Sensing (RS) provides a quick landscape-level visualization of the long-term evolution of the territory, representing a primary monitoring tool to support the environmental management at regional and landscape level.

Advanced RS techniques were efficiently applied, in tandem with on-the-ground field activities, to support the DSS characterization and the identification of effective mitigation and control measures to the DSS affecting Beijing. The adopted methodology allowed developing an extensive multi-source and multi-temporal analysis and, therefore, identifying the baseline environmental conditions to detect the potential dust/sand sources at regional and local scale in northern China. Spatial extents of spectrally distinct rock and soil substrates for the Beijing and Alashan target areas were mapped by means of the Spectral Mixture Analysis (SMA); changes in the vegetation cover in the past two decades were investigated by analyzing Normalized Difference Vegetation Index (NDVI) time series; the topographic response to DSS was studied by developing a Digital Elevation Model (DEM). The effectiveness of advanced RS interpreting techniques to monitor and assess the trend of many relevant environmental variables, such as those controlling the DSS phenomena, was evaluated.

The performed activities were carried as a part of the 'WinDust' project to combat DSS in northern China, a Sino-Italian cooperation project launched in 2005 in the framework of the Sino-Italian Cooperation Program for Environmental Protection (SICP) by the Italian Ministry for the Environment and Territory (IMET) and the Beijing Municipal Environmental Bureau (EPB).

Multi-source and multi-temporal dataset

To investigate the DSS source areas, a multi-source and multi-temporal dataset was employed. The most suitable data to the purpose of the present study were selected and acquired.

The soil was characterized by the imagery acquired by Landsat 7 satellite, the latest in the series, equipped with the Enhanced Thematic Mapper (ETM+) sensor, multispectral radiometer able to measure the reflected solar radiance. The surface reflectance is measured in six spectral bands at 30 meters of spatial resolution, one panchromatic band at 15 m, two thermal infrared bands at 60 m, over a swath 183 km wide. The circa 2000 imagery, composed of 25 Landsat scenes covering from the Alashan to the Beijing area (i.e. study area), was acquired from the Global Land Cover Facility (GLCF) at the University of Maryland (Landsat Technical Details Website). Six Landsat scenes acquired on spring of 2004 were selected to cover four hotspots areas in Alashan, as indicated by the Chinese experts of Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI) of Chinese Academy of Science and the Beijing area.

Moderate Resolution Imaging Spectroradiometer (MODIS), a passive multispectral sensor onboard the orbiting Terra (EOS AM) and Aqua (EOS PM) satellites, was employed to obtain a regional land cover. MODIS collects images of the entire surface of the globe every 1 to 2 days in 36 spectral bands at three different spatial resolutions. To cover the study area, seven tiles of Terra MODIS Nadir Bidirectional Reflectance Distribution Function (BRDF), Adjusted Reflectance 16-day composite images (referring to the period 23 April - 8 May 2004) were employed. The BRDF adjustment corrects the reflectance effects of illumination and view-angle. This product includes seven spectral bands, organized in tiles, with 1-km pixels in a sinusoidal projection.

As a measure of the vegetation abundance, Multi-temporal Normalized Difference Vegetation Index (NDVI) series of the AVHRR Channels 2 and 1 were analyzed to monitor the changes in the physical characteristics of land cover. NDVI product derived from Advanced Very High Resolution Radiometer (AVHRR) images taken aboard National Oceanic and Atmospheric Administration (NOAA) satellites and processed at the University of Maryland in the Global Inventory Modeling and Mapping Studies (GIMMS) program were used. The GIMMS NDVI product provides a set of bi-monthly composite images, corrected for several errors, from 1 August 1981 to 31 December 2003 at 8 km spatial resolution (Tucker et al., 2004).

The Shuttle Radar Topography Mission (SRTM) data products were adopted to provide a detailed and recent characterization of the landscape morphology in the study area. The SRTM is the first mission to respond to the shortage of high-resolution Digital Elevation Model (DEM) of the Earth, significantly improving the global DEM at 1 km horizontal resolution (United States Geological Survey - USGS). SRTM data provides a consistent spatial resolution of 30 m and a vertical resolution of 10 m. The adopted SRTM DEM, available at the USGS - SRTM ftp site, is characterized by a horizontal resolution of 3-arc-seconds (approximately 90 meters).

Investigation of the sandstorm source areas

Spectral mixture analysis of soils

A detailed soil characterization was carried out in the Alashan and Beijing areas based on Spectral Mixture Analysis (SMA) of Landsat imagery. The objective was to represent the land surface reflectance as continuous fields of biophysical land surface properties, and, therefore, to obtain a discrete cover characterization by applying a decision tree classification.

The SMA is a methodology whereby an observed radiance is modeled as a linear mixture of spectrally pure signature, called ‘endmember’. If a limited number of spectrally distinct endmembers can be found, it is possible to define a mixing space within which mixed pixel spectra can be described as linear mixtures of the endmember spectra (Adams et al., 1993; Gillespie et al., 1990; Smith et al., 1990). The spectral feature space was represented with a three dimensional feature space of the principal components (PCs), where the 95% of the variance in the image is contained (Small, 2004), rather than the six dimension features space of the original six ETM+ bands. The linear mixing problem was interpreted as a linear inverse problem in which the system of mixing equations is inverted to estimates of the endmember fractions that best fit the observed mixed reflectance (Settle and Drake, 1993). The endmember fraction composite represents distributions and spatial variations in the aerial abundance of spectral endmembers representing the primary biophysical properties of the land surface. Starting from the endmembers and working inward to progressively mixed land covers, the endmember fraction space is successively divided into discrete classes corresponding to specific abundances of each endmember.

The spectral endmembers obtained for Alashan area were vegetation, dark surface (shadow and crystalline rock), and two high albedo substrates representing dry sand and fine grained silt and mudstone. On the basis of field observations carried out in October 2005, thresholds of 0.3 and 0.6 were set for sand and dark crystalline rock classes. Low threshold of 0.1 was set for vegetation to ensure inclusion of sparse desert vegetation. A higher threshold of 0.5 was set for dense vegetation associated with some agricultural areas. Decision trees allowed the user to specify the exact logical basis of class assignment in the form of a Boolean conditional of arbitrary complexity based on the fixed thresholds (Fig. 1).

The accurate soil characterization based on Landsat SMA and the field observations were employed as guidelines for the selection of training areas (i.e. *“a priori”* information) for the supervised classification of MODIS images acquired in spring 2004. After putting a mosaic of the original seven tiles into a single image and the selection of the training areas, a Maximum Likelihood classifier was applied to the MODIS mosaic (Fig. 2) to perform a decision rule, able to assign, based on the class statistic, the belonging class to the considered pixel. According to the USGS Land Cover classification system, a thematic land cover map was obtained.

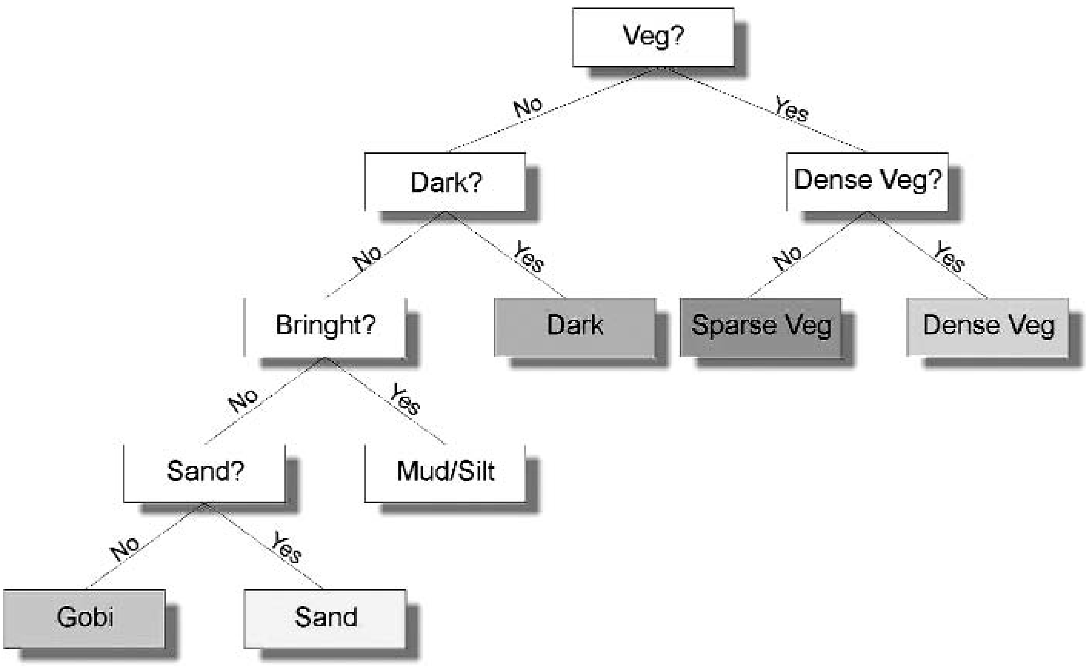

Fig. 1. The adopted decision tree for the classification of Alashan area.

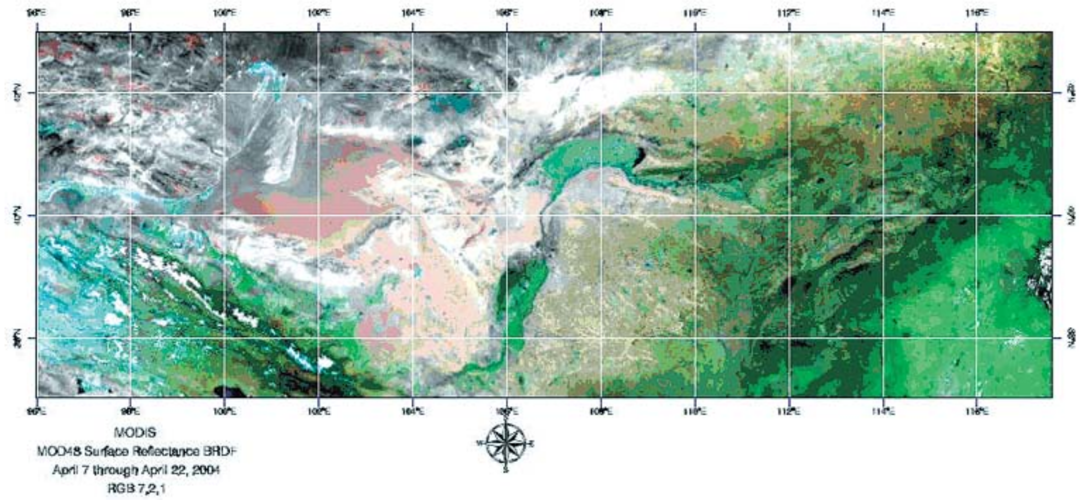

Fig. 2. RGB false color composite of the extended MODIS, mosaic of the seven original tiles.

Trend analysis from NDVI

The extended dataset, collected to analyze the evolution of the vegetation in the last twenty years, was pre-processed for the trend analysis (Weiss et al., 2001). Each global bi-monthly GIMMS image was clipped to the study region and joined to create a stack of 540 time slice images. Firstly, the NDVI dataset was used to identify the spatial distribution and temporal patterns of vegetation using Empirical Orthogonal Function (EOF) analysis. Any multidimensional database can be expressed as a linear sum of EOFs. The results of the orthogonal decomposition of the dataset can be used to identify independent spatial and temporal patterns, where the first EOF represents the dominant spatial pattern in the data. EOF analyses are computationally intensive, and the full resolution NDVI dataset could not be easily handled; thus each time slice image was re-sampled to an approximately 10 km of spatial resolution using a nearest neighbor assignment. Results indicate that 64% of the variance can be explained by the first EOF, which has a cyclical pattern suggesting that seasonality dominates. The spatial image of the first EOF shows the distribution of large seasonal values in the dataset (Fig. 3).

In order to quantify and compare the strength of the seasonal NDVI signal at each pixel through time, variance of the NDVI time series was calculated. Variance is the square of the standard deviation of NDVI over a specified temporal window of data. The variance of the time series at each pixel was computed using a five-year Hamming weighting function. The weighting function was used in this situation to prevent errors, such as spectral leakage or ringing that result from using a simple boxcar filter, and which essentially

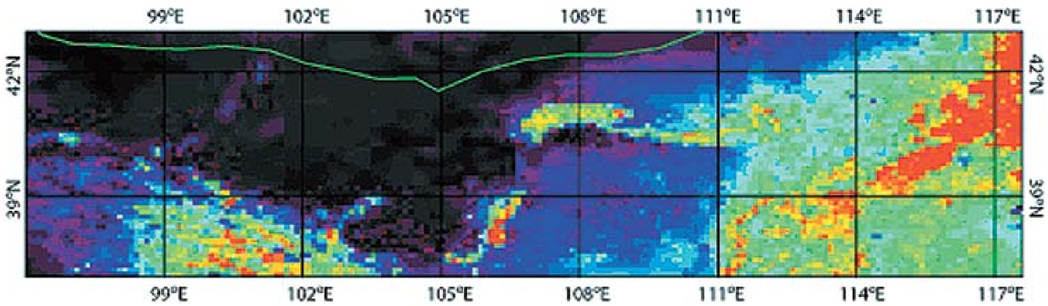

Fig. 3. Spatial component of the first EOF, showing high NDVI values in the eastern region of the sample area, between 105° and 109° East, and in the south western margin of the image in the Qulian Shan mountain range.

decrease the signal variance and introduce more noise to the results. Several filter sizes were tested on the data and it was concluded that a five year running variance filter most effectively suppressed seasonality. Given the five year window used, the resulting variance time series was curtailed at both ends and the total number of bands in the dataset decreased to 421 or 17 years

Digital elevation model (DEM)

SRTM data were processed to obtain a DEM of the study area. Since the SRTM dataset is not correctly geo-located, contains numerous regions with no data due to the geometric distortions in the acquisition, and radar backscatter results noise, several pre-processing steps were required. Firstly, all the SRTM tiles were merged into new single file. An interpolation procedure was applied in the overlapping areas by applying a 3 x 3 pixels window. The Geographic Projection with WGS84 Datum was chosen. A noise-free image was obtained from the extended and geo-located DEM by clipping out the sea, i.e. the noisy portion of the image. The coast delineation, provided by the National Geophysical Data Center NOAA Website, was employed as 'clipping boundary' and the sea-level backscatter anomalies were masked out.

Due to the presence of smooth surfaces, missing values, extending for about 3% of the study area, were found in the DEM. To overcome this problem, the missing values were filled by using a surface fitting technique and minimizing the curvature, so as to achieve a more natural-looking correction. A triangulation method was used for surface fitting, i.e. the missing pixels were fitted with triangles calculated from the surrounding elevation values (Fig.4).

Implementation of a GIS

The topographic, land cover and trend thematic maps provided by RS analysis defined the baseline environmental conditions in the study area. Such maps, along with the original RS imagery, were georeferenced and implemented in the GIS. The GIS database allowed managing all the relevant data that were employed in performed studies, but also implementing additional data, providing a useful support tool in the environmental management oriented to the DSS mitigation and control.

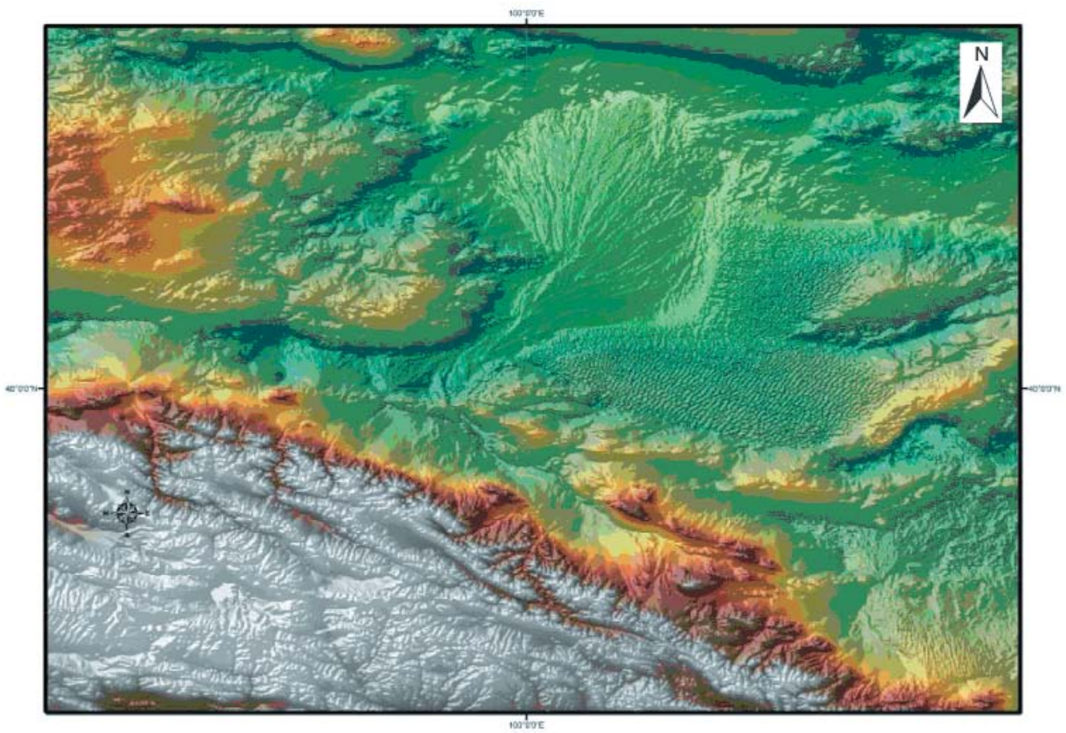

Fig. 4. The figure represents the gap filled DEM added of the slope information. An alluvial plain is distinguishable in the upper central zone.

Results

Soil type characterization

The results of SMA highlighted the reflectance properties of an urban/rural system in Beijing that was represented in a triangular mixing space very similar to that found for other cities around the world. For Beijing, three endmembers were spectrally distinguished: substrate (S), vegetation (V) and dark surfaces (D), where, the non-reflective dark surfaces represent both transmissive (e.g. clear water), absorptive (e.g. Fe rich rocks) and non-reflective (e.g. deep shadow) targets.

Because the characteristic scale of land cover units in urban/suburban areas is comparable to the 30 m resolution of the sensor, almost all pixels are thoroughly mixed. However, specific types of land cover classes were chosen for Beijing on extensive field validation experience but rather general observations. Because urban areas inherently contain a more heterogeneous and finer scale mosaic of land cover, and a wider variety of distinct but spectrally indistinguishable materials, than undeveloped areas, there is unavoidably greater ambiguity in the relationship between land cover and reflectance in urban areas.

For Alashan, selecting the endmembers one substrate (S1), vegetation (V) and dark surface (D), the agricultural areas and the contrast between high

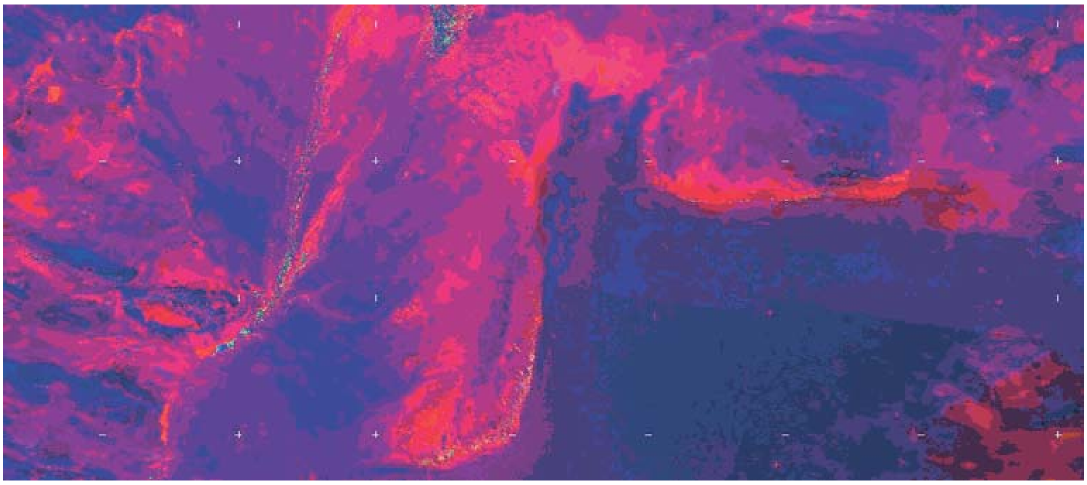

Fig. 5. Endmember fraction composite generated by assigning the substrate to the red, the vegetation to the green and blue to the dark surfaces.

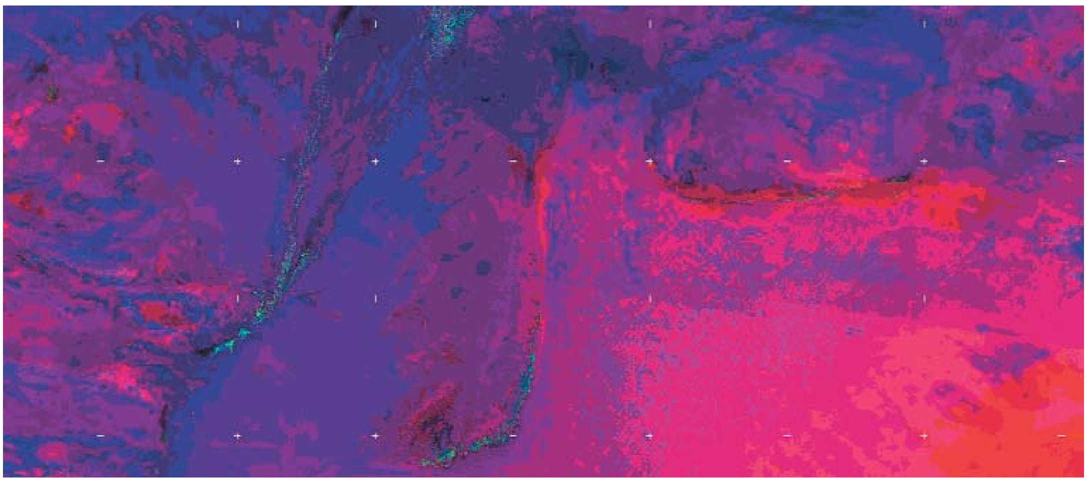

Fig. 6. Endmember fraction composite generated by assigning the mud/silt to the red, the sand to the green and blue to the dark surfaces.

and low albedo rock/soil substrates got highlighted. Using the two substrate endmembers mud/silt (S2) and sand (S1) as well as dark (D), lithologic differences between the low albedo of Ferrous rich and crystalline rocks, high albedo mud/silt deposits, evaporates and intermediate albedo sands got highlighted. Therefore, the Alashan area can be represented as a tetrahedral mixing space bounded by four distinct spectral endmembers. The endmembers, determined from the apexes of the spectral mixing space, correspond to green vegetation, non-reflective dark surface and two rock/soil substrates. In the SWIR wavelength rock/soil substrates and bright sands reflect higher albedo, more spectrally flat reflectance corresponding to both evaporates and mud/silt lithologies.

The results of the spectral mixture analysis indicate that the Alashan region is characterized by continuously varying substrate properties (Fig. 5

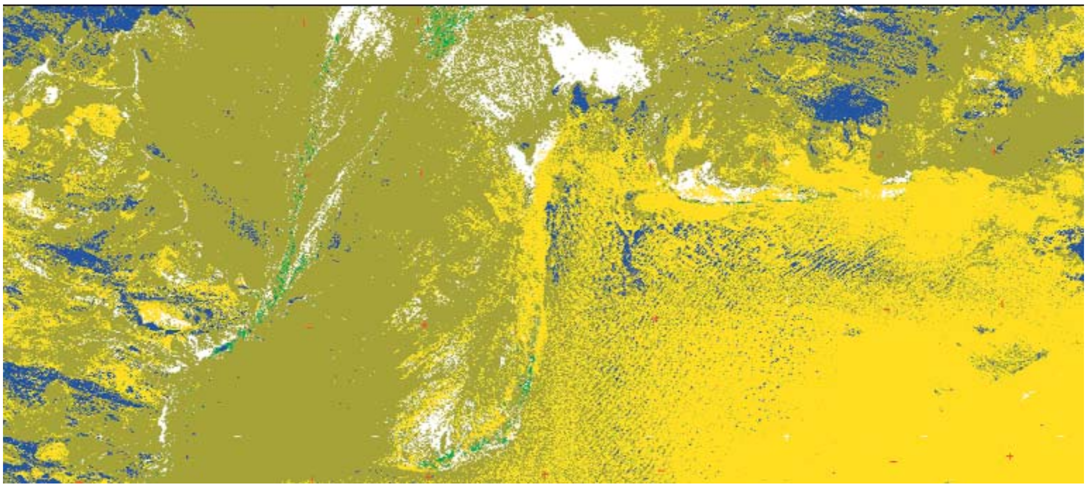

Fig. 7. Classification map obtained with the Decision Tree approach.

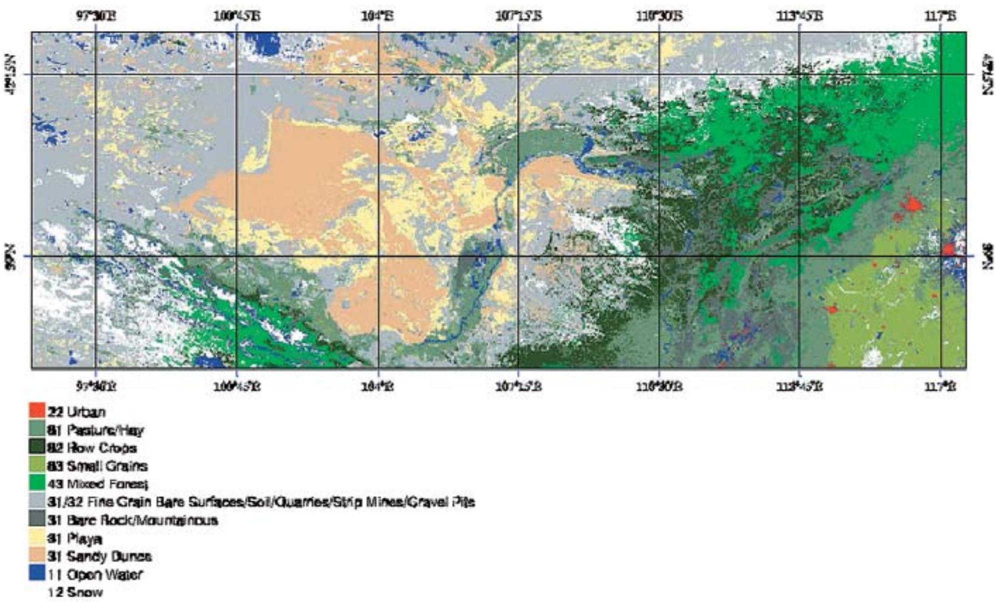

Fig. 8. Land cover obtained with the supervised classification on the MODIS mosaic, following the USGS classification system. The following classes are represented: Urban, pasture, row crops, small grains, mixed forest, fine grain bare surface/soil/quarries/strip mines/gravel pits, bare rock/mountainous, playa, sand dunes, open water, and snow.

and Fig. 6). The analysis of soil samples collected during the field verification allowed assessing the presence of a wide variety of crystalline rocks cropping out throughout the Alashan region and a widespread Gobi surface of strongly mixed composition, in addition to the relatively homogeneous sand and mud/silt substrates.

Mapping at-sensor radiances into endmember fraction abundances converts a physical measure of reflected solar radiance to a physically meaningful estimate of a basic biophysical property of the land surface. The advantages of endmember fraction abundances are: (i) physically meaningful quantities (e.g. vegetation fraction, albedo), (ii) greater accuracy, (iii) no loss of spatial variability information, and (iv) no introduction of error from class homogenization. The obtained cover information (Fig. 7) was used as a guideline during the selection of training areas in the supervised classification of the MODIS images. The classes distribution of the resulting Land Cover map (Fig. 8), following the USGS classification system (Table 1), allow to assess that the majority of the region is covered by bare rock/mountainous and playas (sandy areas).

Land cover evolution

Trend analysis was used to plot the evolution of NDVI through time in order to identify patterns of vegetation change within the study area. By relating these results to other information of the investigated area, it is possible to detect the meaningful causes of these vegetation changes.
To qualitatively assess how NDVI has changed over the past two decades, April averages for three years at the beginning (1982-84), middle (1992-94), and end (2001-03) of the time series were computed and converted to an RGB composite image (Fig. 9).

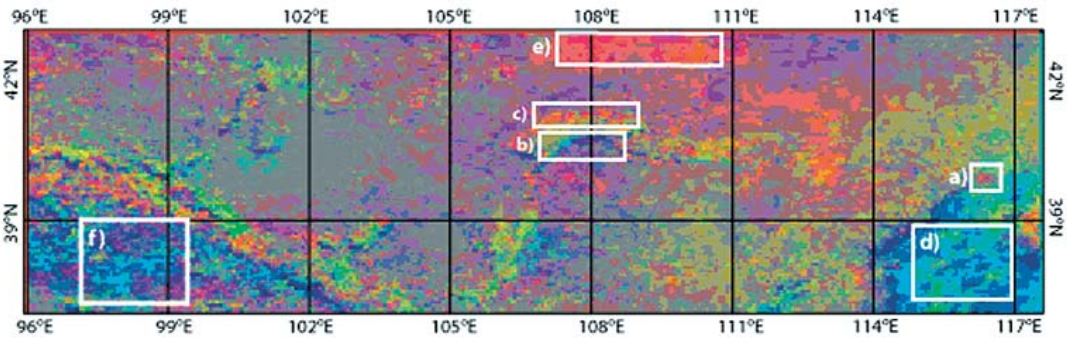

Fig. 9. Regions where noticeable changes were detected from the beginning to the end of the period of analysis (1981-2003). Red, Green and Blue (RGB) image of the NDVI averaged over the beginning, middle, and end of the time series. Red pixels indicate areas where NDVI was higher at the beginning of the time series, similarly, blue represents areas that have increased in NDVI in recent years.

Table 1. Adopted classes following the USGS National Land Cover system and the corresponding cover distribution in the classified surface

USGS ID	Class Name	Number of Pixels	Percent of Image	Area [m²]
22	Urban	2,341	0.16%	2.01E+09
81	Pasture/Hay	195,113	13.64%	1.68E+11
82	Row Crops	117,953	8.24%	1.01E+11
83	Small Grains	61,763	4.32%	5.30E+10
43	Mixed Forest	122,775	8.58%	1.05E+11
31	Fine Grain Bare Surfaces/Soil/			
32	Quarries/Strip Mines/Gravel Pits	414,790	28.99%	3.56E+11
31	BareRock/Mountainous	106,882	7.47%	9.18E+10
31	Playa	98,099	6.86%	8.42E+10
31	Sandy Dunes	152,785	10.68%	1.31E+11
11	Open Water	23,349	1.63%	2.00E+10
12	Snow	134,960	9.43%	1.16E+11
	Unclassified	0	0.00%	0

By displaying the early time period in red, the middle period in green, and the most recent time in blue, a qualitative understanding of how NDVI has changed over the past two decades was obtained. Running variance was then used to obtain a more quantitative perspective on how vegetation varies in time. Variance values ranged from 0.03 to 0.08 in highly vegetated areas and 0.0005 or lower in more arid regions. Variance was employed rather than mean to identify longer temporal trends in NDVI because variance gives a better indication of how vegetation abundance changes seasonally. Thus, if a region that initially has sparse vegetation becomes cultivated due to agricultural expansion, the amplitude of the seasonal NDVI signal would get larger and correspondingly the variance would increase. The applied Hamming filter was able to suppress seasonality and inter-annual signals in the data without masking longer-term decadal signals.

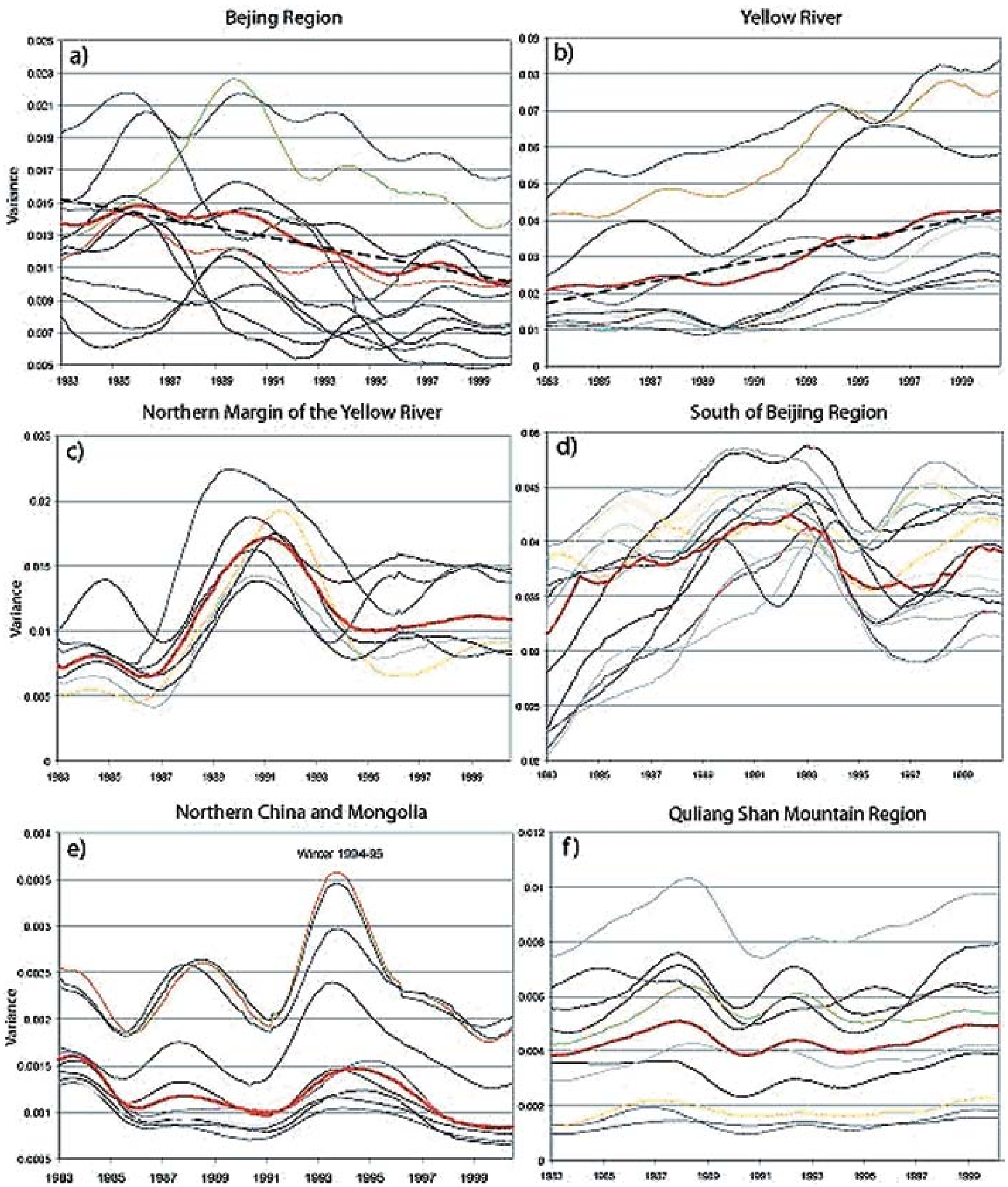

Fig. 10. NDVI trends for the different pixels in the selected regions. The solid red line represents the averaged NDVI for each time slice within the selected region. The broken black line in 'a' and 'b' showed the regression function.

The NDVI features of the significant regions were evaluated on a pixel-by-pixel basis and the relative trends are reported in the Fig.10. Increasing or decreasing variance was apparent from the plots of individual pixels within six different regions. The Beijing region (region a) has experienced a consistent decrease in NDVI variance from the early 1980s to 2000s, corresponding to a reduction in seasonality. The region south of Beijing in the Hebei Province, region (d), appears to have experienced an increase in variance until the early to mid-1990s, whereupon the variance values dropped and then regained a positive trend. This could either be due to a multi-year climatological influence or anthropogenic effects such as changing agricultural practices or urbanization. The Yellow River also exhibits some interesting NDVI variance trends, increasing variance along the Yellow River (b) and decreasing variance to the North (c). This study shows that regional land cover change can be effectively evaluated using variance measurements of AVHRR NDVI from 1981 to 2003.

Topographic characterization

The obtained DEM, along with the field verification activity, allowed conducting a preliminary study of alluvial deposits and lacustrine depositional environment features for Alashan. A standard fuzzy-logic technique, based on two topographic parameters (altitude and curvature), was applied to identify the alluvial areas characterized by a specific range of altitudes and curvature values. It was observed that the detection of landforms on deposits is connected to the bedrock slopes and the lower alluvial plain. These landforms were found to be complex, large and well established, implying that alluvial areas and lacustrine depositional environment were stable for extended periods. The lacustrine features appeared to be eroded-cut features carved on unconsolidated slope materials or on bedrock in some locations.

Conclusion

RS analysis of different remote sensed data provided a satisfactory knowledge on baseline environmental conditions in the study area. The delineation of landscape morphology and the identification of the land surface properties, in terms of extent and localization of land cover types and potential dust sources, were provided. The effectiveness of advanced RS interpreting techniques to monitor and assess the trend of many relevant environmental variables, such as those controlling the DSS phenomena, was demonstrated. RS should be further employed in the characterization and monitoring areas where the DSS originate.

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A study on threshold wind velocity of particles on slope

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Abstract

Bagnold's typical equation expressing relationship between the threshold wind velocity and particle diameter for the initiation of sand particles on the flat bed has been widely accepted in sand saltation researches. Because the dune is the most basic aeolian landform in deserts, the slope has a great influence on particle saltation in the dune windward slope and leeward slope. This paper establishes a threshold wind velocity formula for the initiation of sand particle according to the forces on the particle and based on a rolling model. By means of 'ANSYS' software, this paper simulates the distribution of wind speed when a stable wind is blowing over a dune slope, and quantitatively analyzes the effects of both slope gradient and particle position on the initiation of sand movement. The results show that the slope angle and particle position influence the initiation of sand particles.

Introduction

In recent years the disasters due to the wind-blown sand movement have attracted much attention in China. It is considered crucial to profoundly study the wind-blown sand movement mechanism for overall understanding and preventing wind-blown movement. For example, some interesting studies have been carried out on the aspects of initial velocity distributions (Zheng et al., 2006), wind-sand electricity influence (Zheng et al., 2004 b; Zhou et al., 2005) and vertical profiles of mass flux (Zheng et al., 2004 a). They have yielded a series of substantial results in quantitative simulation of wind-blown sand movement. However, the threshold wind velocity, which is defined as the minimum friction velocity required for the aerodynamic forces to overcome the retarding forces, is also a key variable to be determined in the studies of wind-blown sand transport and soil-erosion (Shao, 2000). Many scholars have conducted research on the threshold wind velocity through theoretical analysis, wind tunnel experiment as well as field survey (Bagnold, 1941; Greeley and Iversen, 1985; Phillips 1980; 1984; Shao and Lu, 2000; Wu, 1987; Qi et al., 2001).

Although several theories for threshold wind velocity have already been developed for sands or soils with uniform and spherical particles spread loosely over a dry and flat surface, the widely accepted expression of the threshold wind velocity (Bagnold 1941) can be expressed as following:

$$u_{*t0} = A\sqrt{\frac{\rho_P - \rho}{\rho} gd} \qquad [1]$$

where u_{*t0} is the threshold friction wind velocity on the level surface, ρ_p the quartz density, ρ the air density, d the grain diameter and A an experiential constant.

Equation [1] describes the relationship between the threshold friction wind velocity and particle size under ideal conditions. In practice threshold friction wind velocity is essentially a property of the sand (or soil) surface, rather than that of a sand (or soil) particle (Shao, 2000). The sand wave and the dune are the most basic aeolian landforms in deserts. Windward and leeward slope of the dune may stretch several meters to hundreds of meters in length with obvious effects on wind velocity and initiation of sand particles. In wind erosion research soil ridges are common in cultivated lands. Therefore, slope is an important factor that has to be considered in the study of entrainment process of sands by wind.

Being cognizant of slope effects, researchers have studied the threshold wind velocity of particles on slopes. Based on the rolling model, Iversen and Rasmussen (1994) attempted to include an inter-particle force term in the expression for the effect of slope on static threshold, namely the threshold friction wind velocity is related to the diameter of particles, and is also closely related to the slope. He et al. (2003) developed a similar threshold wind velocity formula of the initiation of the uniform sand particle on the slopes and discussed how to select the values of the parameters in the starting shear stress formulae. However, the threshold wind velocity of particles on arbitrary slope is simplified so that its direction and magnitude are invariable, and the speeding-up effects of wind velocity on the windward flanks of the dune are neglected.

Analyzing the forces on particles on the slope and based on the rolling model, this paper establishes a threshold wind velocity formula for the initiation of sand particle. It simulates the distribution of wind speeds for a stable wind blowing over a slope by means of 'ANSYS' software. Then quantitative analyses are performed of the effect of slope gradient and particle position on the initiation of sand particles.

Threshold wind velocity formula

Sand (or soil) particles resting on the slope surface under the influence of an air stream experience several forces, including aerodynamic drag, F_D , aerodynamic lift, F_L , gravity, W_P , and inter-particle cohesive, I_P . These forces are illustrated in Fig. 1 and can be expressed mathematically as follows (Iversen and Rasmussen, 1994):

Drag force F_D
$$F_D = \frac{\pi}{8} C_D \rho d^2 u_{*t}^2 \qquad [2]$$

Lift force F_L
$$F_L = \frac{\pi}{8} C_L \rho d^2 u_{*t}^2 \qquad [3]$$

Gravity W_P
$$W_P = K_1 \left(\rho_P - \rho\right) d^3 \qquad [4]$$

Inter-particle force I_P
$$I_P = K_2 d \qquad [5]$$

where u_{*t} (*m/s*) is the threshold friction velocity, C_L the aerodynamic force coefficient, C_D the drag coefficient, d the grain diameter and $K_i (i=1.2)$ experiential constants.

For a particle of size d with a threshold friction velocity u_{*t}, its initiation is determined by the balance of F_D, F_L, W_P, and I_P. At the instant of particle motion the combined retarding effects of W_P and I_P will be overcome by the combined lifting effects of F_D and F_L. The particle will tend to pivot about point A of Fig. 1 in a downstream direction (particle diameter here is that of an equivalent sphere). The balance of forces at the instant of particle lift-off can be obtained by the summation of moments about the pivot point A,

$$F_D \cdot a_1' d + F_L \cdot b_1 d = \cos\theta W_P \cdot b_1 d + \sin\theta W_P a_1 d + I_P c_1 d \qquad [6]$$

When the expressions for lift, drag, weight and inter-particle force are substituted into the preceding equilibrium equation, we have the following results:

$$u_{*t} = \sqrt{\frac{8K_1\left(\rho_P - \rho\right)gd}{\pi\rho}\left[\frac{\cos 0 + \frac{a_1}{b_1}\sin 0 + \frac{K_2 c_1 / K_1 b_1}{\left(\rho_P - \rho\right)gd^2}}{C_D \frac{a_1'}{b_1} + C_L}\right]} \qquad [7]$$

If the influence of inter-particle cohesive force and the effects of Reynolds number variation are neglected, the ratio of threshold on a sloping surface to that on a level surface is (Howard, 1977; Iversen and Rasmussen, 1994; Allen, 1982; Dyer, 1986; Sarre, 1987):

$$\frac{u_{*t}^2}{u_{*t0}^2} = \cos\theta + \frac{\cos\theta}{\sin\alpha} \qquad [8]$$

Namely

$$u_{*t} = A\sqrt{\frac{\rho_p - \rho}{\rho} gd}\sqrt{\cos\theta + \frac{\cos\theta}{\sin\alpha}} \qquad [9]$$

where the angle is defined as (see Fig. 1) is the static friction angle and its value is usually taken as according to Iversen's experimental results.

Equation [9] presents the local threshold friction velocity (LTFV) of wind for the initiation of sand

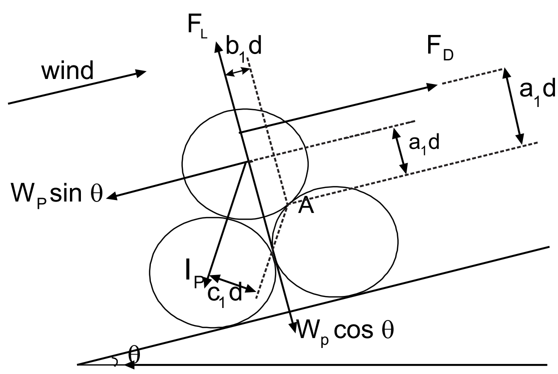

Fig. 1. Schematic diagram of the force system at the threshold of motion.

particles on the slope with angle. The so called local threshold friction velocity in this paper means that a particle at a given position (for example point A) on slope will move when the wind velocity at the position of point A attains it. The local threshold wind velocity is different from the threshold wind velocity of upstream air flow, because the wind velocity accelerates along the slope (Liu, 1995).

The effect of slope angle on the threshold wind velocity

With equation [9], we can get the predicted results of the relationship curve between the threshold wind velocity and different slope angles. To compare the predicted results with experimental results (Iversen and Rasmussen, 1994), the diameter of sand particles is taken as d=0.242 *mm*. The relationship curve $f(\theta)$ between the local threshold friction velocity and the slope angle θ is shown in Fig. 2. It can be seen from Fig.2 that the predicted results agree well with of the experimental values (Iversen and Rasmussen, 1994) and the local threshold friction velocity of sand particles (for a given diameter) increases with the slope angle.

Fig.2 only presents the relationship curve between the local threshold wind velocity and the slope angle. To get the threshold velocities of free upstream air flow corresponding to the sand particles at the different positions of the slope, we must analyze the distribution of wind speed for a stable wind blowing over a dune slope.

ANSYS analysis on airflow over a slope

The model

According to the characteristics of the crescent dune, this paper establishes a right triangle model with slope angles and uses FLUID141 unit to carry on two-dimensional analysis.

The boundary condition

The velocity profile of upstream inflow is employed as the logarithmic distribution (see Fig. 3**)**. The no slip boundary condition is employed, namely all velocity components are taken as zero. The fluid is assumed to be incompressible. In this case, the pressure is the relative value, so the boundary condition of the exit can be taken such that the pressure is fixed at zero for all exit cells.

Results and analysis

By means of ANSYS software, the distribution of wind speed when a stable wind is blowing over a slope is simulated where the friction velocity of the stable wind is 0.20m/s and the value of the slope angle is 10 (see Fig. 4). From Fig. 4 it can be seen that the wind velocity varies greatly on the slope, and the wind velocity begins to accelerate from the bottom of the slope and attains a maximum value at the top of slope then decreases on the leeward slope. Therefore, the position of particle on slope must be considered when establishing the upstream threshold friction velocity formula.

To characterize the position of particle on fixed slope θ, the value of coordinate x, namely the con-

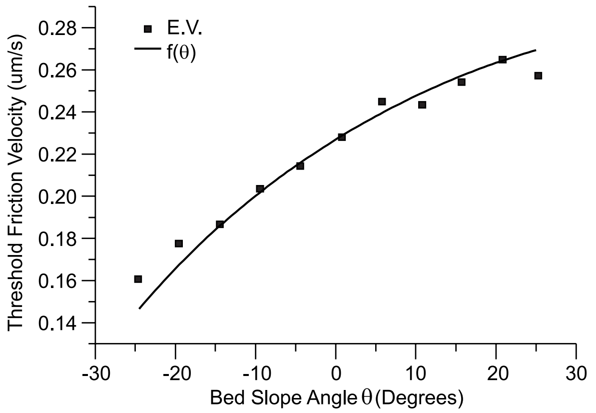

Fig. 2. Threshold friction velocity versus bed slope angle.

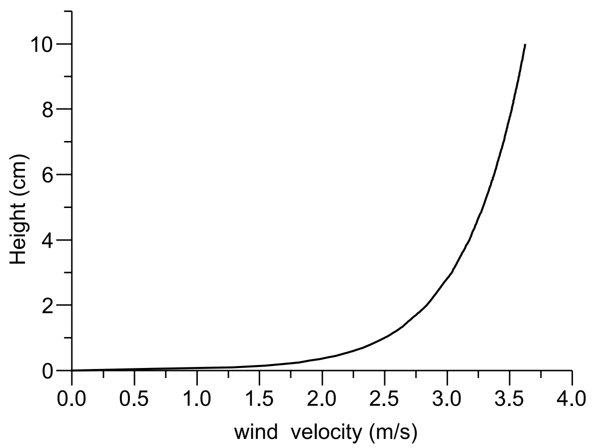

Fig. 3. Simulated incoming plane bed velocity profile.

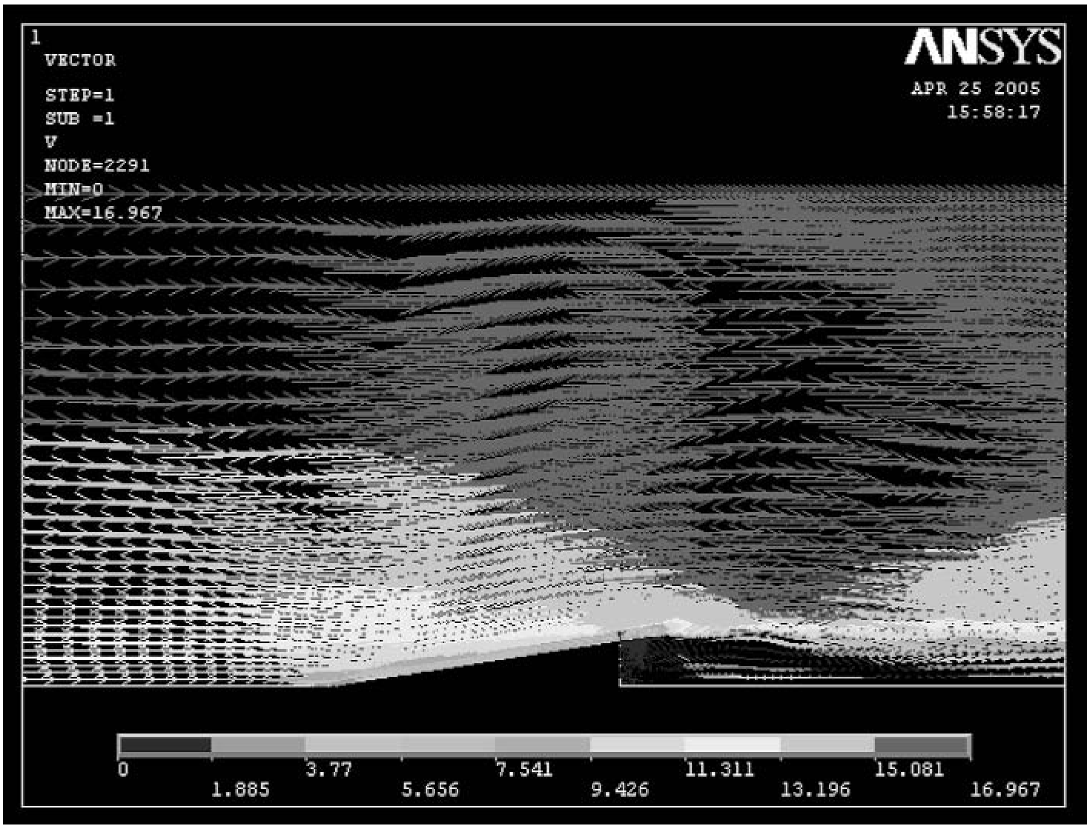

Fig. 4. The distribution of wind velocity when a stable wind is blowing over a dune slope.

crete position of particle expresses o(x,x tanθ) is used in this paper (see Fig. 5). To clearly denote the variation of wind velocity along the slope, we present the numerical results of the wind velocity profile along the slope in Fig.6. The curve presents the relationship between the wind velocity and particle position for the friction velocity of 0.258 m/ s and the slope angle of 20°. It can also be seen from Fig.6 that the wind velocity varies greatly and it consistently increases from the foot to the head of the slope. The wind velocity is the minimum at the foot of slope and it attains the maximum at the top of slope. For example, the wind velocity near the toe of slope (x=1cm) is only 3.16 m/s, but at the top of slope the wind velocity is 4.83 m/s when x=5 cm. This is a 52.8% increase. When the friction velocity of the stable upstream air flow and the value of slope are constant, and the wind velocity slightly exceeds the local threshold velocity for particles at the top of slope, the wind velocity at the foot of slope will be below the threshold velocity. Therefore the position of particles must be taken into consideration while studying the threshold friction velocity for particles on the slope.

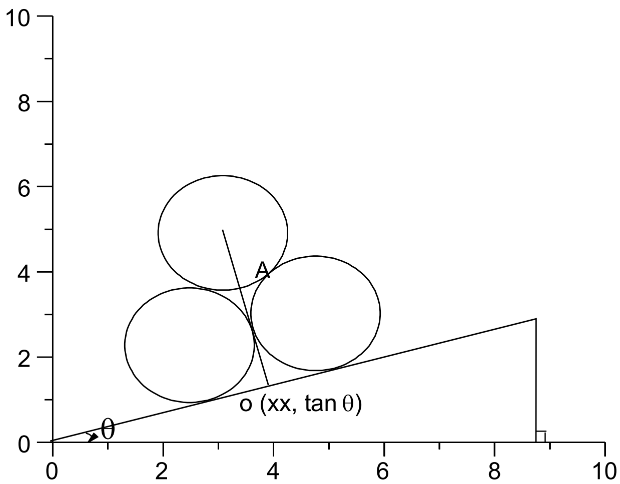

Fig.5. "The coordinates" to characterize the position of particle on fixed slope θ

The relationship between slope position and threshold friction velocity of the stable upstream air flow where the particle diameter is 0.125mm and the slope angles are 10°, 15° and 20° are illustrated in Fig. 7. When the slope angle is 10°, the threshold friction velocity of the stable upstream air flow needed for the initiation of particles at the toe of slope is 0.2 m/s where x=1 cm. Threshold

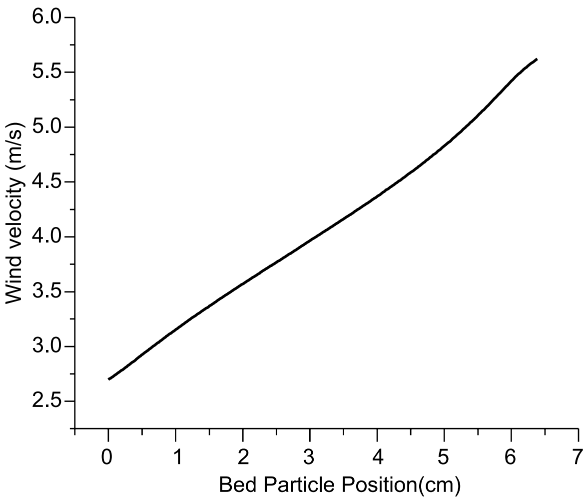

Fig. 6. The wind velocity versus bed particle location.

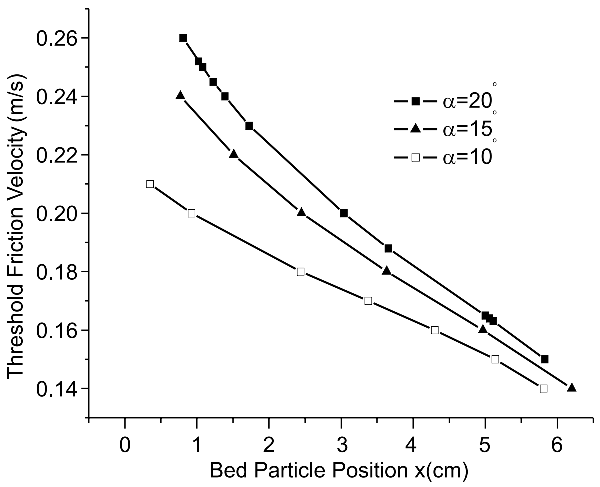

Fig. 7. The relationship between slope position at three slope angles and threshold friction velocity of the stable upstream air flow for the particle diameter of 0.125 mm.

friction velocity is only 0.15 m/s where x=5 cm, which decreases 25% compared to that for particles at the foot of slope. Similarly when the particle diameter is same and the slope angle is 15°, the threshold friction velocity is 0.23 m/s where x=1 cm, at the toe of slope, but for particles at the top of slope (x=5 cm), the threshold friction velocity is only 0.16 m/s, a decrease of 30.4%. When the particle diameter is same and the slope angle is 20°, the threshold friction velocity is 0.252 m/s where x=1 cm, at the foot of slope, but for particles at the top of slope (x=5 cm), the threshold friction velocity is only 0.165 m/s, or a 34.5% decrease. These results illustrate that the threshold friction velocity of stable air flow needed for particles on slope decreases rapidly for particles

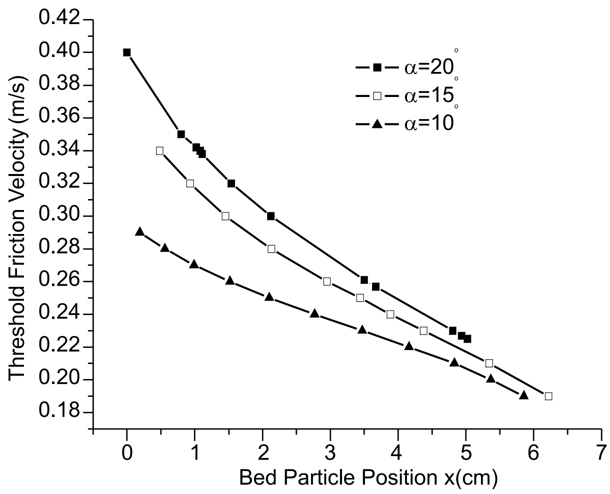

Fig. 8. The relationship between slope position at three slope angles and threshold friction velocity of the stable upstream air flow for the particle diameter of 0.242 mm.

along the slope. Therefore, sand movement will begin at the top of a slope before movement at the toe of the slope. Sand movement is not easy to initiate at the foot of slope, whereas the particle at the top of slope are almost ready to saltate. Simultaneously the threshold velocity increasing by the slope is substantiated on the same position.

The curve between the slope position and the threshold friction velocity of the stable upstream air flow, where the particle diameter is 0.242 mm and the slope angle are 10°, 15° and 20° is presented in Fig. 8. For the particles at the toe (x=1 cm) of a slope, the threshold friction velocity of the upstream air flow is 0.27 m/s, threshold friction velocity is 0.205 m/s for the particles at the top of slope (x=5 cm), or a 24.1% decrease. For 0.242 mm particle and the slope angle is 15°, the threshold friction velocity of the upstream air flow is 0.32 m/s for particles at the toe of slope (x=1 cm). The threshold friction velocity is only 0.22 m/s for particles at the top of slope (x=5 cm), or a 31.25% decrease. For 20° slope the threshold friction velocity near the toe of slope is (x=1 cm), but at the top of slope the wind velocity is 0.226 when x=5 cm, or a 51.3% decrease. The threshold friction velocity of the stable upstream air flow decreases rapidly as the position of particles on slope rises.

The relationship curves between the position of particles on slope and the threshold friction velocity of the upstream air flow, where the particle diameter is 0.32mm and the slope angles are 10°, 15° and 20° are presented in Fig.9. For a 10° slope, the threshold friction velocity of the upstream air flow is 0.31 m/s for the particles at the toe of slope (x=1 cm), but for particles at the top of slope (x=5 cm) the threshold friction velocity is only 0.235 m/s, or a 24.2% decrease. For a 15° slope, the threshold friction velocity at the toe of slope (x=1 cm) is 0.36 m/s, but at the top of slope (x=5 cm), the threshold friction velocity is 0.25 m/s, or a 30.6% decrease. For a 20° slope, the threshold friction velocity near the foot of slope (x=1 cm) is only 0.395m/s, but at the top of slope (x=5 cm) the wind velocity is 0.256 m/s, or a 35.2% decrease.

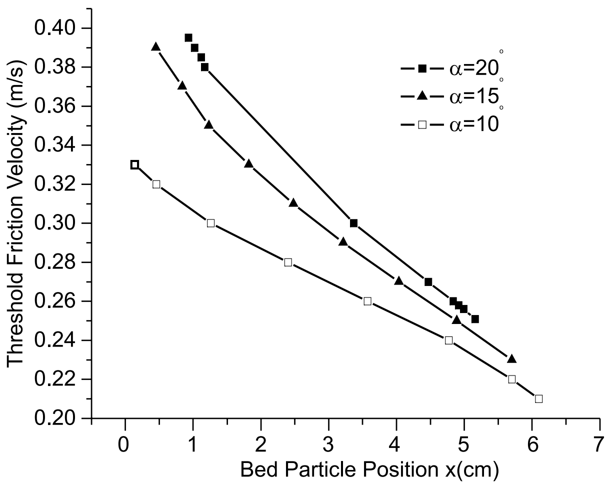

Fig. 9. The relationship between slope position at three slope angles and threshold friction velocity of the stable upstream air flow for the particle diameter of 0.32mm.

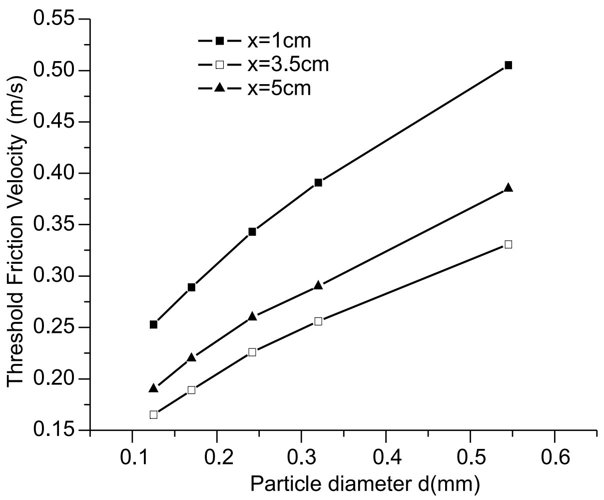

Fig. 10. The relationship between the threshold friction velocity and the particle diameters for particles on the positions of x=1, 3.5 and 5cm with the slope angle θ of 20°.

Three curves in Fig. 10 present the relationship between the threshold friction velocity and the particle diameters for particles on the positions of x=1 cm and x=5 cm respectively with the slope angle θ of 20°. From Fig.10 it can be seen that the threshold friction velocity on the different position of particles on slope increases with increasing particle diameter, but the value of the velocity on the slope toe is 50% more than on the crest region. These once more denote that the slope has a great influence on the initiation of particles on the slope.

Conclusion

An equation is developed to simulate the local threshold wind velocity of the sand particles on slope. The calculated results show that the local threshold wind velocity of the sand particles increases with the slope angle. The local threshold wind velocity of the sand particles increases with the diameters of sand particles on a given angle slope. These results are in agreement with experimental results (Iversen and Rasmussen, 1994) for sand particles on a slope and the experimental results (Bagnold, 1941) for particles on flat bed (slope angle is zero). The distribution of wind speed is simulated when a stable air flow blows over a slope by means of ANSYS software. Based on the numerical results of the distributions of wind speed on the slope, the effects of both slope angle and particle position on the initiation of sand particles are quantitatively analyzed. The results show that the slope has a great influence on the initiation of particles on the slope and the threshold friction velocity of the stable upstream air flow decreases rapidly as the position of particles on slope rises. Therefore, the effects of both slope angle and particle position have to be taken into consideration in the theoretical analysis on the threshold friction velocity of the upstream air flow corresponding to the initiation of particles on a slope.

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Dust and sand storms in NE Asia - a transboundary environmental problem

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Abstract

Dust and sandstorm (DSS) is the generic term for a serious environmental phenomenon in Northeast Asia. DSS involves strong winds that blow a large quantity of dust and fine sand particles away from the ground and carry them over a long distance with severe environmental impacts along the way, and often with serious impacts in the countries downwind of the DSS source. Both the Korean Peninsula and Japan are the recipients of this dust that can, under some circumstances, go as far as North America. The major sources of DSS in the region are believed to be the desert and semi-desert areas of the People's Republic of China (PRC) and Mongolia. DSS causes considerable hardship, loss of income, disrupts communications, affects peoples' health and, in extreme cases, leads to death of people and their livestock and crops over large areas in the affected countries. Since DSS has no regard for national boundaries, it is typically viewed as trans-boundary pollution. When DSS particles are finally deposited in their destinations, their environmental impacts are felt in areas far removed from their sources. The various forms of dust and sand storms are discussed and the forces that favor the onset of DSS are outlined. DSS are the result of the interaction of climate, geography, soil type and human actions. Climate and weather patterns play a major role. Southern Mongolia and northern PRC, the source of most dust and sand, have a continental climate and are located far from the influence of oceans. Prevention and control of DSS will be a long and difficult task and one that requires cooperation between several countries in the region. The present article reviews some of the measures and outlines a strategy to combat DSS in Northeast Asia.

Introduction

The Northeast Asian countries suffer from severe dust and sand storms (DSS), including the effects of entrainment and transport of materials from the source areas and the accumulation in rural and urban areas downwind, and desertification threats. Long distance transport of dust aerosols occurs over distances of from 1000 to 4000 km. Dust aerosols are usually <20 µ and many are <10 µ. It is useful to distinguish between DSS that affect communities close to the source of uplift and those that are carried downwind for long distances. Local DSS events are comprised of larger dust particles up to 60 µ and fine sand and cause considerable damage and loss of human life, livestock and crops.

Dust and sand storms are primarily in the form of sand encroachment on arable land, steppes, desert steppes, rangelands, pastures. However transport, communications systems and all other infrastructures are also under threat (Yang et al., 2001). Worsening dust devils blow across large areas via the Mongolian Plateau, northern parts of Peoples Republic of China (PRC), the Korean peninsula to the Pacific Ocean (Kar and Takeuchi, 2004; Wang et al., 2000). The frequency and severity of DSS has increased in north-east PRC over the past 50 years (Fig. 1) and by 2002 another 32 major dust storms had occurred.

DSS are the inevitable consequence of desertification. Taking the case in China as an example, since the 1950s, sand drifts and expanding deserts have taken a toll of nearly 700,000 hectares (ha) of cultivated land, 2.35 million ha of rangeland and 6.4 million ha of forests, woodlands and shrublands. At present, as many as 2.674 million km^2 of land in China are already desertified (Wang, 2003) as manifested by sand encroachment, dune movement, soil and water erosion, denudation and deflation, salinization, deforestation and downstream sand accumulation (Ci, 1997).

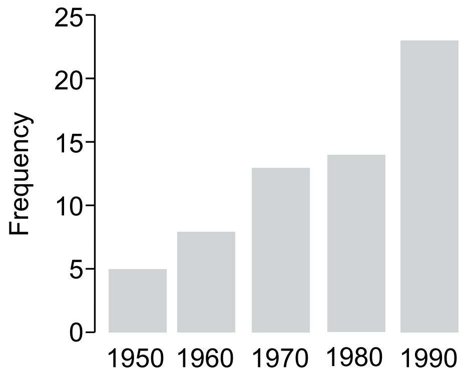

Fig. 1. Frequency of sand-dust storms in each decade, from 1950s to 1990s.

The estimated annual rate of spread of desertification-prone land, particularly from the mid-1990s to 2000, is 3,436 km^2 of land that has been turned into deserts, compared to an annual expansion rate of 1,560 km^2 in the 1970s and 2,100 km^2 in the 1980s. A considerable number of villages have been lost to expanding deserts, sand drifts, dune movement and sandstorms. It is estimated that some 24,000 villages, 1,400 km of railway lines, 30,000 km of highway, and 50,000 km of canals and waterways are subject to constant threats of desertification. With up to 58% of China's land area being classified as arid or semi-arid nearly one third of the land suffers from the effects of desertification.

The two most severe DSS events in decades took place in March and April 2002. They swept across Mongolia and hit 18 provinces in China, and then the Korean peninsula and Japan. The total suspended particles (TSP) content in the air, which reflects the air quality levels, was 10 to 1000 higher in the affected areas than the national standards in these countries. Mongolia had to close its international airport in Ulaanbaatar for three days and the Republic of Korea (ROK) had to close schools and cancel more than 40 flights from Kimpo airport in Seoul.

Causes of DSS outbreaks

The root causes of an environmental problem are often located in a non-environmental sector. It is useful to distinguish between "drivers of change" and the subsequent actions in response. The solution to controlling desertification lies in relieving the pressure and allowing people, the main cause of desertification, to adopt alternative lifestyles and pursue more sustainable land uses.

Mostly desertification is caused by human activity and as such can to be addressed through natural resource management techniques. Such human activity is often part of people's coping mechanism. Overgrazing, over-cultivation, excessive fuel wood collection, harvesting wildlife, digging medicinal plants and other such activities that are often listed as the causes of desertification are in fact both symptoms of desertification and agents of change that can accelerate the process of land degradation.

Economic and ecological impacts of DSS

The damage that DSS causes in Northeast Asia each year is enormous. In China alone it is estimated at 54 billion Yuan RMB (approximately 6.5 billion US dollars) annually, which accounts for 16% of the overall damage of worldwide desertification (Zhang and Ning, 1996).

The ecological deterioration of the wind-sand-impacted regions in Northeast Asia should not be underestimated. Of the factors behind the under-development of the region, adverse natural conditions may be the most fundamental limitation. It has been recognized that none of the grand plans for development in this region will materialize unless the ecological problems are given due emphasis. Dust storms sweep across northern China and the Korean peninsula each spring, thanks to seasonal wind patterns (Yang et al., 2001).

In early April 2002, as an immense cloud of sandy dust blew in from China, polluted air raised health concerns in the Republic of Korea (ROK) where authorities swiftly issued a "yellow dust" warning. As a result, schools were called off, and clinics were overflowed with patients suffering respiratory problems.[1] DSS events have become so frequent and intense that Koreans grimly call the period of yellow dust "a fifth season" of the year.[2] In recent years, Seoul has witnessed an increase in the number of DSS days, specifically, 6 days in 1999, 10 in 2000, and 27 in 2001.[3] Table 1 provides a chronology of a severe DSS event that occurred in April 2001.

[1] See "Sand smothers Mongolia to Korea," *www.cnn.com/2002/WORLD/asiapcf/east/04/08/skorea.sand/index.html.*
[2] "China's growing deserts are suffocating Korea," by Howard W. French, The New York Times, April 14, 2002.
[3] See a report carried by *sports.creaders.net/news Pool/24O100412.html.*

Since DSS has no regard for national boundaries, it is typically viewed as transboundary pollution. When DSS particles are finally deposited in their destinations, their environmental impacts are felt in areas far removed from their sources. DSS can be thought of as nonpoint source (NPS) pollution. Unlike pollution from industrial and sewage treatment plants, pollution from DSS comes from many diffuse sources. In environmental management literature, NPS pollution often refers to those problems caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, and so on. DSS represents a NPS pollution problem. Because our knowledge about the sources and movement paths of sandy dust is incomplete, it is difficult to pinpoint the exact point source of the dust.

To control the spread of transboundary pollution, the United Nations Economic Commission for Europe implemented the Convention on Long-Range Transboundary Pollution (1979). Since then, emissions of sulphur dioxide across Europe have been lowered dramatically, but increases in the volume of traffic have meant that emissions of nitrogen oxides have not fallen as quickly. At a regional level, useful experiences have been gathered in Europe and the Confederation of Independent States (CIS) (see McGlade, 2000) and the Nile Basin (Anon., 2001). Two other initiatives are the ASEAN Agreement on Transboundary Haze Pollution in Southeast Asia, and a capacity building program aimed at building national capacities to address the issues of transboundary air pollution in South Asia.

The upwind and downwind relationship

Dusts originating from desertified land in north-western and northern PRC and southern Mongolia reach as far as PRC's eastern seaboards, and even the Korean peninsula and Japan. Sedimentation occurs when strong winds carry soil particles from DSS source areas and pathways, and finally deposit them to sites downwind. Therefore, apart from the need to assess the damage that DSS causes, it is highly important to be able to identify the sources, transport routes, and destinations of the dusts. There is an obvious relationship between the welfare of downwind residents and upwind DSS prevention and control efforts. Mongolia and the PRC are fighting against desertification. The effectiveness of the two countries' efforts to restore sound ecosystems in the upwind areas has a direct bearing on the continued prosperity in the areas thousands of km downwind.

From an economic perspective, one major issue with environmental problems is the disparity between private costs and social costs; the social costs tend to greatly exceed the private costs. In the case of DSS, aside from climatic factors that are beyond human control, anthropogenic activities have led to land degradation and, in turn, DSS. The resultant negative externality impacts millions of people in downwind areas even beyond national boundaries. DSS prevention and control efforts in sandy dust source areas and along the dust transport routes will yield positive benefits not only for local residents in these areas but also for people living downwind.

Table 1: Chronology of a severe DSS event, April 2001

Date	Movement
5 April	Cyclone emerged in the Xinjiang basin of north-western China and in southern Mongolia.
7 April	The resulting dust storm, stretching 2,000 km in length and 800 km in width, moved eastward over northern China and the Korean peninsula.
8 April	Storm was visible over eastern China, Japan, and Russia's Far East.
10 April	Dirty yellow cloud left Asia and continued moving eastward.
15-16 April	Whitish haze from the storm reached North America, the cloud stretching from Calgary, Canada, to Arizona. Air particulate concentrations in Aspen, Colorado were measured as four times higher than the week before.
17 April	Air samples taken by NASA plane over Boulder, Colorado, revealed a dust plume about 6.4 km thick, stretching from roughly 4,500 to 10,700 m above Earth's surface. Skies over Florida were white with dust.
20 April	Cloud covered New England, in the eastern US.
21 April	The entire dust cloud moved over the Atlantic Ocean.

Source: Compiled by Janet Larsen, Earth Policy Institute, www.earth-policy.org.

The notion of externality

Externality is defined, simply, as a secondary or unexpected consequence. In economics this term is used to describe costs or benefits not accounted for in the price of goods or services. Often externality refers to the cost of pollution and environmental impacts. In the context of DSS, externality arises because DSS causes incidental damages to downwind areas way beyond the actual DSS source areas. Solution to an externality requires putting in place mechanisms that ensure proper compensation provided to or paid by those who generate the externality, in the cases of positive and negative externalities, respectively.

The indirect damage costs are believed to be in the neighborhood of 4.5 times that of the direct costs. Indirect damage costs of DSS include, for example, the increased medical costs that arise from the impact of sandy dust on public health, the costs of cleaning the glass of residential and commercial buildings and the interior, the repair and reconstruction costs, the wear and tear on machinery and equipment due to DSS, and so on.

First and foremost, the impact of DSS on human heath is the greatest concern in DSS source areas, along DSS transport routes downwind, and the dust destinations. Given the high population density of metropolitan centers, health concern with DSS is particularly high in big cities. On DSS days, clinics tend to receive a greater number of patients suffering respiratory problems than on non-DSS days. It is reported that, in Seoul, the number of deaths on "yellow sand days" is higher than the daily average of non-yellow-dust days. In particular, deaths due to cardiovascular and respiratory problems rise dramatically. Definitive studies regarding the damage costs of dust storms to public health in NE Asia are lacking but work in Australia suggests that the costs are very high.

A regional strategy to prevent and control DSS and mitigate the impact

Given the proximity of the countries in the Northeast Asian region and the pervasiveness of the transboundary environmental problems such as DSS, bilateral cooperation quickly turned into a regional effort, can create favorable conditions for addressing the issues in an integrated, multilateral manner. At present, prospects for addressing transboundary environmental issues from a regional perspective are gaining momentum. DSS prevention and control is precisely a "Regional Commons" issue among the various efforts to protect the shared environment in the interests of promoting the welfare of citizens in respective countries.

Specifically, a DSS monitoring and early warning system in Northeast Asia is one of three initiatives undertaken in 2003 to tackle transboundary atmospheric pollution. This system was initiated by the ADB, the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), the Asian Regional Office of the UNCCD and UNEP, together with the governments of Mongolia, the PRC, Japan, and the ROK.

Public pressure from Korean citizens played an important role for the ROK government to push for the launching of an annual PRC-ROK-Japan trilateral ministerial consultation on the environment in 1999 and for establishing a 5-year joint research program on DSS and regional transboundary air pollution (Baker, 2000). The Environment Ministers Meeting of the PRC, Japan, the ROK, and Mongolia serves as a forum for researchers from the four countries to exchange information regarding DSS.

In 2000, the ROK, Japan and the PRC launched a joint program to study transboundary pollution from a variety of sources, including the effects of airborne yellow dust that "clogs Korean lungs". The project features computer modeling of the flow of pollutants as well as the identification of their major sources. Of the three countries, the ROK is the largest financial contributor to this particular initiative. To a certain extent, the project may be viewed as an extension of Japan's Acid Deposition Monitoring Network in East Asia (EANET), which involves 38 monitoring sites in 10 countries from Indonesia to Mongolia.

The Northeast Asian Sub-Regional Program on Environmental Cooperation (NEASPEC) plays an important coordinating role in promoting collaboration with UNEP and UNCCD concerning DSS prevention and control. During the 8th Meeting of the Senior Officials of NEASPEC on Environmental Cooperation in Northeast Asia held in Ulaanbaatar, June 20, 2002, delegates stressed the need for enhanced collaborative efforts of international and regional organizations as well as national agencies in the preparation of a GEF project on DSS prevention and control in Northeast Asia.

The Asia-Pacific Environmental Innovation Strategy Project (APEIS) is a concrete regional initiative, which aims at assisting developing countries to enhance the capacity in their efforts to address issues pertaining to environmental protection. The APEIS has two main objectives: (i) to develop scientific knowledge-based tools and innovative strategy options to promote informed decision-making for sustainable development as a common asset; and (ii) to promote regional cooperation and capacity building, so as to enable Asia-Pacific countries to formulate and implement their own policies for environmental management and protection that take into account their national circumstances. The APEIS is composed of three sub-projects, namely, Integrated Environmental Monitoring (IEM), Integrated Environmental Assessment (IEA), and Research on Innovative and Strategic Policy Options (RISPO). Of particular relevance to DSS prevention and control in the Northeast Asian region is the IEM which seeks, among other things, integrated monitoring of environmental disasters such as dust storms, transboundary air pollution, floods and forest fires, and integrated monitoring of environmental indices and degradation including salinization, deforestation as well as land use and land cover change.

Participatory approach and community involvement

DSS is a transboundary pollution problem affecting the countries in Northeast Asia, but this problem requires a concerted regional approach as well as local action. The strategy should build on the initiatives of local communities and their traditional knowledge, combined with the application of modern sciences and technologies.
Environmental risks are often expressed as a function of biophysical disturbances. Hence, assessment of natural disaster risks is usually approached from a technical or expert perspective. Public or community input on how the risks are identified and perceived is often excluded until the implementation phases of management schemes. Communities are at the interface between the environment and society where environmental disturbances and risks are keenly experienced.

The strategy will comprise specific projects that are participatory and inclusive, aimed at internalizing DSS control measures and promoting sustainable practices. New research findings recognize the importance of understanding socioeconomic vulnerability. Clearly understanding the linkages between natural hazards like DSS and community response to the risk will help ensure the target outcomes and cost-effectiveness of investments.

Programs are needed to provide cost-share, technical assistance, and economic incentives to implement DSS prevention and control management practices. Some communities use their own resources to adopt technologies and practices to limit the impacts caused by DSS.

Public education is an essential component of a successful DSS prevention and control program. A number of tools can be used to educate local farmers and herders: announcements in the news media, workshops, booklets, posters, and the distribution of DSS control devices. Public school education is also an important means for instilling DSS control awareness.

Finally, DSS highlights the underlying roots of land degradation. One of the root causes is poverty. Desertification control and anti-DSS measures will be a long battle. Therefore, long-term ecological, economic and social benefits must be taken into account, at a scale surpassing the local level, and these considerations should receive greater attention in the process of justifying investments for DSS prevention and control in the context of Northeast Asia.

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Ground-surface conditions for sand-dust event occurrences and soil conservation of Aibi Lake region in Xinjiang, China

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Abstract

Comparing with other regions, the factors reducing the erosion-resistance and causing the formation of sand-dust event in the Aibi Lake region are the bare land cultivated in spring season and desert landscape with low vegetation cover. The positive factors of strengthening the ground surface stability are mainly the high vegetation cover, more abundant plant community diversity and coarser soil texture. On the basis of the ground surface conditions of sand-dust event occurrences, the paper brings forward some biological, physical and chemical approaches that improve the capability of erosion-resistance of the top soils in the region.

Introduction

The Aibi Lake region is one of the areas in the western Junggar Basin of Xinjiang, China where the frequency of sand-dust events is high (Qiu et al., 1996; Wang et al., 2003; Qian et al. 2004). Although the frequency and strength of the events is less than that of Taklimakan Desert of the southern Xinjiang, the contribution of local materials to sand-dust events should not be neglected. In the process of the sand-dust storm event of 18 April, 1998, SeaWiFS satellite images showed that the sand-dust cloud originated from this region and passed across Japan and arrived in North America (He et al., 2001).

In comparison with the neighbouring regions of the southern Junggar Basin, the Aibi Lake region does not have the climatic condition which would make it extremely susceptible to sand-dust events. As a result, some researchers have focused on the ground conditions during the periods of spring and early summer seasons (Li Xialing, 1997; Jilil and Mu, 2002; Zhou, 2003). In fact, the ground conditions have great influence on the resistance of the soil to erosion by wind. Therefore, during the springtime periods of frequent sand-dust event occurrences, the characteristics of the vegetation and the physical-chemical properties of the soils in this region and the adjacent mid-southern Junggar Basin of Xinjiang were investigated and measured systemically. Then, the positive and negative factors of soil erosion-resistance were determined to provide a basis for soil conservation.

Study area and methods

Study area

The Aibi Lake region, located in the south-western Junggar Basin, is a graben basin surrounded by mountains in the north, south and west. In the east, the basin is joined to the Gurbantunggut Desert. This region, with a typical temperate continental arid climate, is characterized by low rainfall, high evaporation and abundant solar energy. The Aral Mountain pass in its west is a main wind pass for cold air (the north-westerly winds) to intrude. In Jinghe County located at the leeward area of the Aibi Lake region, the gales of wind velocity of more than 17 ms^{-1} occur on an average 26.3 days and sand-dust events 49.2 days per year (the number is a mean annual value from 1961 to 2001, including sand-dust storm, drifting dust and blowing sand). The Gurbantunggut Desert is located in the center of the semi-closed Junggar Basin with abundant solar energy, high evaporation, and low precipitation. In the southern part of the desert, the gales occur 15.2 days per year and the sand-dust events 19.3 days per year. Almost no runoff occurs on the ground surface and groundwater is very deep in this desert.

Methods

During the springtime (April of 2001 to 2004), when the sand-dust event occurrence is frequent, field investigations and sampling in the Aibi Lake region and a contrasting region (the mid-southern Gurbantunggut Desert) were conducted. Specially, on the day of the sand-dust event (19 April of 2004) and the following day data were collected in the study region. At each site 1 to 4 quadrats were used to determine the characteristic parameters of plant distribution, using quadrats of 10 m×10 m for communities of shrubs, 20 m×20 m for communities of low trees, and 3 quadrats, each of 1m × 1m for herbs. The 'herb' quadrats were arranged along a diagonal, nested within the shrub and low tree quadrats. The species presence, frequency and abundance (herbs), vegetation cover, plant height and crown diameter were recorded. Within each quadrat, soil samples from surface layer (0-10 cm) were collected for physical and chemical analyses. Topsoil water-content, texture, organic matter, nutrients, salts, and pH were measured using routine methods (Nanjing Institute of Petrology, 1978). The particle size was measured by Malvern Laser Analyzer, and the parameters were computed based on the formula of Folk and Word (Shanbei Team of Chengdu Institute of Geology, 1976).

The data for plant distribution parameters and discriminate analyses of ground-surface characteristics for these sand-dust source regions were processed by Excel and SPSS10.0 software package. The relevant meteorological data were obtained from Xinjiang Meteorological Bureau.

Results and discusses

Sand-dust events and landscape characteristics

According to the frequencies of the mean annual sand-dust events (Table 1), Jinghe County, as a representative of the Aibi Lake region, had a high-frequency of sand-dust events and high numbers of days with drifting dusts. In this region, on the alluvial-fluvial plain with fine gray-brown and gray desert soils, agricultural is intensive, and the area of bare land cultivated in spring seasons continues to expand. The bare cultivated land and the dry clay lakebed become the source of sand-dust events, especially on the days when drifting dusts frequently occur. In contrast, the Gurbantunggut Desert is a region with medium frequency of sand-dust events, and where the stable and semi-stable aeolian sandy soils with a coarser soil texture are dominant; the vegetation cover is high with good biodiversity; and the soil crust is well developed; thus, the drifting dust events were less frequent (Table 2).

According to the work of Counihan et al. (cited by Liu and Dong, 2003; Jia et al., 1999) and our investigations, if the bare land or desert land with low vegetation cover is present as a single patch of landscape or is compartmentalized by shelter forest net of farmland, the aerodynamic surface roughness (Z0ef) can rise. That is, the larger the degree of the separation or fragmentation in bare cultivated lands and desert lands with low vegetation covers, there is lesser likelihood of the breakout of sand-dust event.

Zhou (2003), using the data of Landsat TM, analyzed the landscape pattern of the Jinghe Basin and observed that the separation of the grasslands and the desert lands with low vegetation covers is 0.468, the lands-cultivated 1.761, and the fragmentation of total landscape 0.371. There, because of the natural state and the existence of cultivation on big farms, the fragmentation of its cultivated land (bare land in spring) and desert land with low vegetation cover is not high. This landscape characteristic makes the aerodynamic roughness Z0ef decrease significantly, which provides an underlying surface condition for blown wind sand in the Aibi Lake region.

In the mid-southern Gurbantunggut Desert, the stable and semi-stable sand dunes dominate, so, the bare lands without vegetation cover are only distributed on the top of the mobile sand dunes in small sections, with a limited area. Although the vegetation cover among the micro-landforms shows some differences, the macro-distribution of the vegetation still shows a high homogeneity. Differing from those bare cultivated lands and desert lands with low vegetation cover, the smaller separation or fragmentation of sandy lands with medium-high vegetation cover (over 20%) increases the aerodynamic roughness of complex ground-surface, and the Z0/Z0ef is high.

Table 1. Types and frequencies of sand-dust events (d a^{-1}, 1961-2001)

	Aibi Lake region (Jinghe County)	Southern Gurbantunggut Desert (Caijiahu)
Gale (≥17 ms^{-1})	26.3	15.2
Drifting dust	28.5	3.0
Blowing sand	16.3	12.7
Sand-dust storm	4.4	3.6
Total	49.2	19.3

Table 2. Main types of landform, vegetation and soil

Regions	Number of samples	Geomorphologic landscape	Types and covers of vegetation	Types of soils
Aibi Lake region	20	Alluvial/fluvial fan	*Kochia prostrata* and *Artemisia* spp. community and *Haloxyon ammodendron* community, vegetation cover of 10%~15%	Gray-brown desert soil
		Alluvial plain	*Seriphidium borotalense* and ephemeral plants community, vegetation cover of 15%	Gray desert soil
		Lakeshore/dried lakebed, shrub sand dunes	*Limonium suffruticosum*, *Halocnemum strobilaceum* and *Kalidium capsicum* community, vegetation cover of about 30%; *Nitraria sibirica* sand dune and *Tamarix* sand dune, vegetation cover of 7%-50%	Solonchak
		Mobile/	*Tamarix* sand dune, vegetation cover of 7%; *Haloxyon persicum* community, vegetation cover of 20%	Aeolian sandy soil
		Lands of interdunes	*Halostachys caspica*, *Phragmites communis* community, vegetation cover of over 70%; *H. persicum* and *Calligonum leucocladum* community, vegetation cover of over 30%; *Seriphidium santolinum* and ephemeral plants community, vegetation cover of about 35%	Saline soil, aeolian sandy soil, gray desert soil
		New cultivated land on alluvial plain	Bare cultivated land	Gray desert soil
		New cultivated land on interdunes	Bare cultivated land, original vegetation is *Phragmites communis* meadow	Meadow soil
		Oasis cultivated land	Bare cultivated land	Irrigated-cultivated soil
Gurbantunggut Desert	26	Fluvial-alluvial plain in the northern desert	*Ceratoides lateens*, *Salsola arbuscula* and *Stipa glareosa*, vegetation cover of over 45%	Gray-brown desert soil
		Great longitudinal dunes in the northern desert	*H. persicum*, *Ephedra distachya*, *C. leucocladum* and herb plants, vegetation cover of about 25%~35%	Aeolian sandy soil
		Complex longitudinal dunes	*E. distachya*, *Seriphidium santolina* and ephemeral plants community, vegetation cover of about 40%-60%	Aeolian sandy soil
		Mobile belt on the top of sand dunes	*H. persicum*, *Artemisia arenaria* and ephemeral plants community, shrub cover over 30%	Aeolian sandy soil
		Stable sand dunes of checker board-shaped form	*H. persicum* and ephemeral plants community, vegetation cover of about 35%-70%	Aeolian sandy soil
		Transitional belt between desert and oasis	*H. ammodendron*, *Reaumuria soongorica* and annual halophytes, vegetation cover of 30%-80%	Salinized gray desert soil
		Lands of interdunes	*E. distachya* and ephemeral plants community, vegetation cover of over 30%, soil crust developed	Aeolian sandy soil
		Alluvial-fluvial plain in the northern desert	*H. ammodendron* and *Reaumuria soongorica*, vegetation cover of 32%	Salinized gray desert soil

Ground-surface characteristics of sand-dust events

The vegetation cover, ecological dominance and diversity index of the vegetation structure and the internal factors of soil erodibility (including soil texture, soil organic mater, total salts and pH, and topsoil water-content) were taken as the chief ground-surface parameters that affect the process of blowing sand-dust. With Canonical Discriminant Analysis (CDA), the ground-surface conditions of the Aibi Lake region and the Gurbantunggut Desert were analyzed. The results show that the parameters that decrease the stability of the surface are the ecological dominance of vegetation (C), the sorting index of soil particle sizes, the organic matter and pH of soils. The factors that increase the ground surface stability are mainly the vegetation cover, plant community diversity and coarser soil texture.

Among the negative factors, the soil pH is significant. The soil pH is affected by many factors (Dai 1997; Qi 1994) and the most direct factors are the contents of carbonate (mainly CO_3^{2-}/HCO_3^-), organic matter and some soluble salt ions in soils. In a previous study (Qian et al., 2004) we noticed that there is a significant correlation between the soil pH and the contents of soluble salts (Ca^{2+}, Na^+, HCO_3^-, CO_3^{2-}) and organic matter. The soil pH for the Aibi Like region shows a direct relationship with the content of CO_3^{2-} with a correlation coefficient of 0.76 ($P>0.01$). The higher pH value, corresponding with higher carbonate content in the soil, reduced the stability of the sandy soil in this region (Qian et al., 2003; Chepil, 1956a).

The ecological dominance of vegetation, C, is also a negative factor, whose influence on ground-surface stability is clear. In the study regions, the ecological dominance of the vegetation was generally high because of the bare cultivated land in the spring season or the farmland with mono-cropping and the natural desert land with single type of shrub and semi-shrub species. The content of organic mater, acting as an important parameter with a significant discriminant effect (15.9% contribution), has both positive and negative effects on soil erosion-resistance. Generally, if an increase in the organic mater in the topsoil is caused by development of bio-crust of plant litter or deadwood and defoliated leaves, this will undoubtedly increase soil erosion-resistance (Eldridge and Leys, 2003; Li et al., 2001). However, if the organic mater in the soil is decomposed, this will make the soil susceptible to erosion (Chepil, 1954b; Singer et al., 2003). The type of organic matter existing in these regions is not clear, and the content of organic mater ranges from 0.09% to 2.04% with a negative impact.

The discriminant value of the soil sorting index (*s*) is not large, with contributing ratio of 1.1% only, and the impact of this parameter on soil erodibility is clear. We found that the samples with high values of *s* were mainly distributed in the sections susceptible to sand-dust event occurrence, which are the bare farmland and the desert land with poor sorting indices (Fig.1).

The vegetation cover and plant community diversity are the most positive aspects of strengthening the stability of soil surface. The high vegetation cover and abundant community diversity increase the aerodynamical roughness Z0 and reduce the wind speed (Zhang et al., 2004). Then, plant residues can effectively cover the soil surface to reduce wind-erosion (Eldridge and Leys, 2003). Comparison of two parameters shows that the plant community diversity is more significant, and the herb and woody structure of multi-layers reduces the aerodynamical porosity of vegetation, further reducing the flux of sand-dust (Lancaster, 1998). Secondly, the soil texture indicated by mean particle size, Mz, is one of the internal factors influencing soil stabilitys with a contributing ratio of 8.3. According to our observations, a soil with a high Mz has a strong erosion-resistance (Fig.1). The

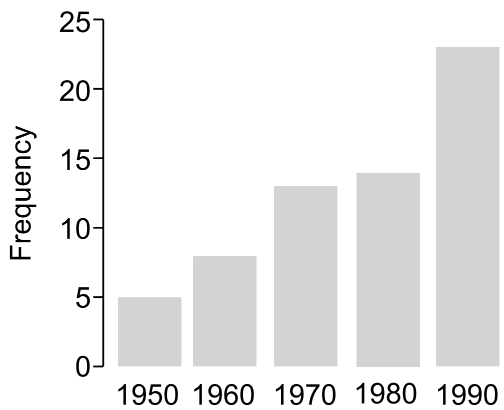

Fig. 1. Mz-s diagram for the typical samples in the study regions.

topsoils with a high fine silt and clay content are most likely source for sand-dust events. Singer et al. (2003) and Orlovsky et al. (2005) came to this conclusion in their study of the Aral Sea in central Asia, which has environment very similar to the Aibi Lake region, and Liu and Dong (2003) also proved it in a wind tunnel experiment.

A high content of topsoil salts (TS) in some studies is usually understood as a negative factor, which makes not only the vegetation degrade but also decrease the air quality (Qian et al., 2004). Singer et al. (2003) noticed however that the generation potential of fine silt soil, PM10 dust, with a high salt-content is low when they studied the southern Aral Sea. The reason is that salt crystals and fine soil particles form a stable crust preventing the soil from erosion. However, the erosion-resistance of salty soil crust is sensitive to soil particle size, that is, the salty crust of a sandy soil or sandy loam is easily broken so that the soil generates the sand-dusts (Singer et al., 2003). The results show that the soils of the Aibi Lake region consist of gravely fine silt and clay silt soils, so the action of salts benefits the soil stability; the particle size of aeolian sandy soil in the Gurbantunggut Desert is coarse, and the stabilizing action of salts is limited.

Many researchers suggest that the topsoil water-content is the most positive factor for soil stability (Wang et al., 2001). However, Wiggs et al. (2004) showed that under a certain wind speed a lower topsoil water-content (4%-6%) has no significant influence on the soil anti-erodibility. Since the study region belongs to arid and semi-arid lands, the topsoil in the spring season, when gales are frequent, is especially dry with soil water-content of less than 2%; therefore, the contribution of soil moisture to the anti-erodibility of topsoil is very small.

Conclusions and recommendations

Comparing the ground-surface characteristics between the Aibi Lake region, that has high frequency sand-dust events, and the Gurbantunggut Desert, with medium frequency of sand-dust events, the results show that in the Aibi Lake region, where gray-brown desert soil and gray desert soil are widely distributed and agricultural operations are intensive, the factors impacting its ground-surface stability negatively are mainly the higher pH, salts, organic matter of soils and the ecologic uniformity of vegetation. However, in the Gurbantunggut Desert, where stable and semi-stable aeolian sandy soils are dominant and are less disturbed by human activities, the erosion-resistance of the topsoil is benefited from the higher vegetation cover, larger plant community diversity and coarser soil texture.

Based on the above-mentioned biological, physical and chemical characteristics, the ground-surface conditions can be changed to restrain sand-dust event occurrence and prevent soil erosion. Firstly, by applying organic fertilizer, pH value because of high carbonate content can be reduced. Secondly, while turning cultivated land to grassland and woodland and building forest shelter belts, parallel vegetation cover can be raised with an increase in the diversity of plant community. Thirdly, by selecting alkali-salinity-tolerant plants and appropriate irrigation methods, good cover can be achieved. By mixing sand into heavy clay soil, the soil can be ameliorated thereby decreasing the source of sand-dust events.

Furthermore, since the aerodynamic roughness of a ground-surface (Z0ef) affects the number of transporting sand-dust events and the formation of sand-dust events, the measures for increasing Z0ef should be adopted. For the large areas of cultivated land (bare land in spring season) or desert land with low vegetation cover, measures should be taken to return the cultivated land to grassland and woodland according to a certain spatial pattern, and include rationally built shelter forest belts, in the main wind direction, which can increase Z0ef. They should also rotate the crops of winter and spring in order to reduce the area of bare land in spring season for increasing Z0ef.

Lastly, considerable capital should be invested for advanced water-saving techniques, maintaining the entropy of soil water in spring season so that the capability of soil erosion-resistance in the region can be greatly improved.

In conclusion, soil conservation in these regions of high frequency sand-dust events is a key factor for controlling sand-dust event occurrences.

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Desertification in Otindag Sandy Land region, northern China: processes and causes

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Abstract

Aeolian desertification in Otindag Sandy Land has expanded dramatically during the past 50 years. This research based on remote sensing images and field investigations explored processes and causes of aeolian desertification in the study area. The results showed that aeolian desertification development in Zhenglan Qi, a typical region located at the center in the study area, can be divided into three stages including rapid occurrence before 1987, parts of rehabilitation and most of deterioration from 1987 to 2000, and little rapid rehabilitation from 2000 to 2005. Gradually declining sand mobility index (MI) indicated that climate change was not the major cause of aeolian desertification in the last 40 years, and increasing population should be the underlying cause. Irrational human activities including unsuitable reclamation in the 1960s and over-grazing after 1980 are direct causes whose adverse affect was accentuated by repeated drought events. Over-grazing and undesirable climate have different functions during the whole aeolian desertification process. Over-grazing gradually changed grasslands to slightly desertified lands at the initial stage, while climate with windy days or droughts often accelerated formation of seriously desertified lands. Aeolian desertification in the study area can frequently occur but there is great potential to rehabilitate such lands. Integrated countermeasures combating local aeolian desertification should be developed.

Introduction

Aeolian desertification is one of the most serious environmental and socio-economic problems at the global scale, and especially in arid, semi-arid and dry sub-humid areas of Africa, Central Asia, Australia and North China. The Otindag Sandy Land is an important ecological barrier to block dust storms, originating in the steppe of the Mongolian Plateau and western China, from coming to Beijing.

With aeolian desertification occurrence at the end of 1950s (Chen and Gou, 1960; Yang, 1964) rehabilitation mainly occurred at that time (Zhu and Liu, 1981; Zhu, 1999). Since then rapid aeolian desertification has occurred in this region (e.g., Wulan et al., 2001; Liu and Wang 2004). In addition, frequent dust-storms in the end of 1990s were considered to be a result of rapid aeolian desertification occurrence in North China (Ye et al., 2000), and anthropogenic factors were considered to be the main contributors of aeolian desertification in this region (Li et al., 2002; Wu et al., 2003; Dong, 2000). At present, however, the results are still unclear because researchers used different classifications to evaluate the degree of aeolian desertification in this region. Although significance of coupling and feedback mechanism in aeolian desertification development had been recognized (Charney, 1975; Sun and Li, 2002; Chang et al., 2005), Zhu and Liu (1981) had proposed that the period of aeolian desertification occurrence often related to major historic events mostly accompanied with droughts; coupling and cumulative impacts were ignored in many cases.

In fact, aeolian desertification is a complex process which involved many factors. To enhance awareness about the threats of aeolian desertification and to encourage willingness to combat it requires better knowledge about its distinct causes in order to take actions to achieve most efficient and sustainable control. Based on vegetation information, attempts have been made to discriminate between climate or human-induced degradation in Syria (Jason and Roland, 2003) and Otindag Sandy Land (Zheng et al., 2006). Analyzing the results of previous studies (Wang et al., 2003; Xue et al., 2005; Liu and Wang, 2004), with proxies for human activities and variations in climatic indices, Wang et al. (2006) identified the relative role of climatic and human factors in aeolian desertification in semiarid China.

In this paper aeolian desertification situation in the Otindag Sandy Land over the past 30 years is explored, and the causes of aeolian desertification are discussed.

Study area and aeolian desertification status in 2000

Otindag Sandy Land is located in the eastern Inner Mongolian Plateau, between 112°30´ to 118°**E** and 41°30´ to 44°30´**N** with elevation between 1,100 and 1,400 m (Fig. 1), and is dominated by arid and semiarid continental climate. The rainfall is 350-400 mm in the southeast and 100-200 mm in the northwest, and about 70% of annual rainfall events occur in June to August due to activity of southeast monsoon. The annual evaporation is 2,000-2,700 mm; annual mean temperature 0-3°, sunshine hours 3,000-3,200 hours, and the frost-free season about 100-110 days. There is high wind activity in winter and spring, especially in April and May; the annual mean wind velocity is 3.5-5.0 m s^{-1}, and the number of windy days (instantaneous wind speed exceeding 17.2 m s^{-1} within a day) is 50-80 days in this region. Many lakes are scattered in the Otindag Sandy Land. In the middle and eastern parts of this Sandy Land, elms grow on the surface of fixed and semi-fixed dunes, and grasses cover most of the interdunes. In contrast, the west is occupied by semi-fixed and few mobile dunes. Aeolian soils with different steppe characteristics have developed in this region, and usually in the eastern Sandy Land 4-6 and 3-5 layers of sand and dark brown paleosols can be easily found in dune profiles. The grain size of sands is about 1-4 μ , which is easily eroded by wind. Traditionally the northern Otindag Sandy Land was used as rangeland and the southern part, such as Duolun County, Taipusi Qi and the south of Zhenglan Qi, was reclaimed for rain-fed croplands. Vegetation cover is low in dry and windy seasons. As a result, wind erosion occurrence has become common and aeolian desertified lands have been expanding once land surface has been disturbed by human activities.

Aeolian desertified lands are up to 40,766.85 km^2 in 2000, which occupied 27.04% of total areas of Otindag Sandy Land. Areas of aeolian desertified

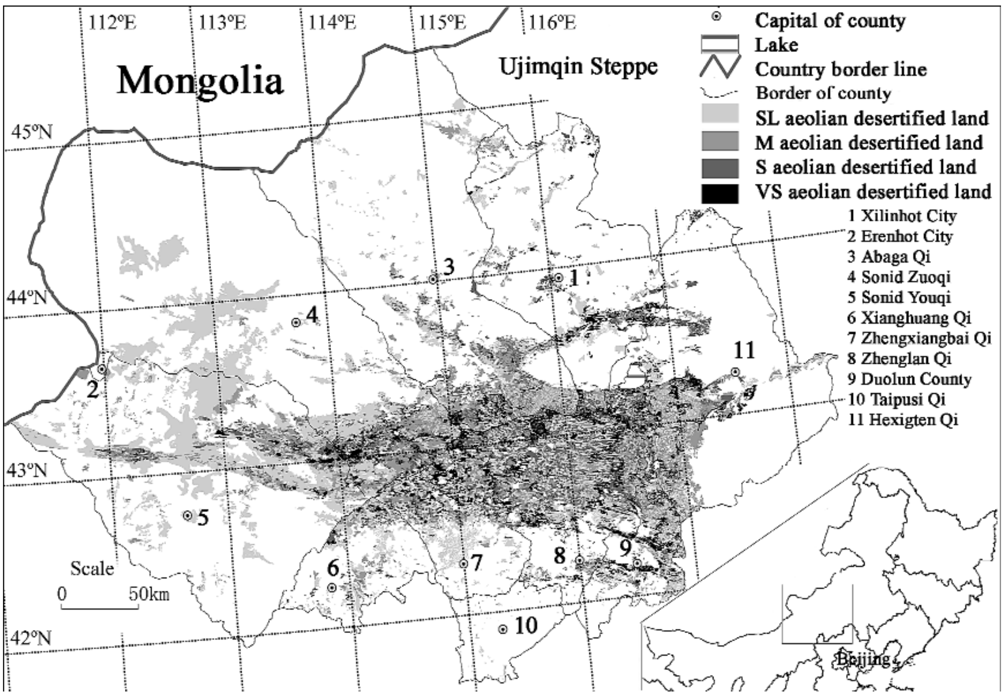

Fig. 1. Study area: location of Otindag sandy land and distibution of aeolian desertified land.

lands in Zhenglan Qi and Zhengxiangbai Qi both exceeded half of its administrative area (Liu and Wang, 2004). Four aeolian desertification types (Chen, 1991) can be classified in the study area: surface of grasslands in northern Sonid Zuoqi and Sonid Youqi were eroded by winds and were accumulated by coarse sands (Fig. 2-G); reactivation of fixed dunes and shifting dunes in patches were changed into stripe or sheet ones in the middle Zhenglan Qi, Zhengxiangbai Qi, Hexigten Qi, as well as the south part of Abaga Qi and Xilinhot City (A-E in Fig. 2); farmlands in the south suffered from soil erosion by wind (Fig. 2-I); and many shrub-coppice dunes and wind-eroded badlands were developed in the region (Fig. 2-F and H).

Materials and methods

Aeolian desertification information in the 1950s was obtained from aerial photographs taken in the late 1950s and previous studies (Chen and Guo, 1960; Yang, 1964). Data obtained from the false color composites made up of bands 4, 3, 2 (R, G, B) of Landsat 5 Thematic Mapper (TM) images in September 1987, 2000 and 2005 and Landsat MSS image in 1977 were used as the primary information. Zhenglan Qi, located at the center of Otindag Sandy Land (a typical county-level administrative area in Inner Mongolia), was selected for detailed analysis on aeolian desertification process from 1977 to 2005, where reactivation of fixed and semi-fixed dunes was the main aeolian desertification processes. Spatial resolution of the TM images was 30×30 m, and MSS images 60×60 m. The images were corrected by using the Erdas Imagine provided by ERDAS. Referring to 1/50,000 topographic maps and lots of digital photos by camera with accurate GPS data during field investigation, remote sensing images were interpreted by adopting man-machine conversation method under ArcView 3.2 and ARC/INFO 8.0 software, accord-

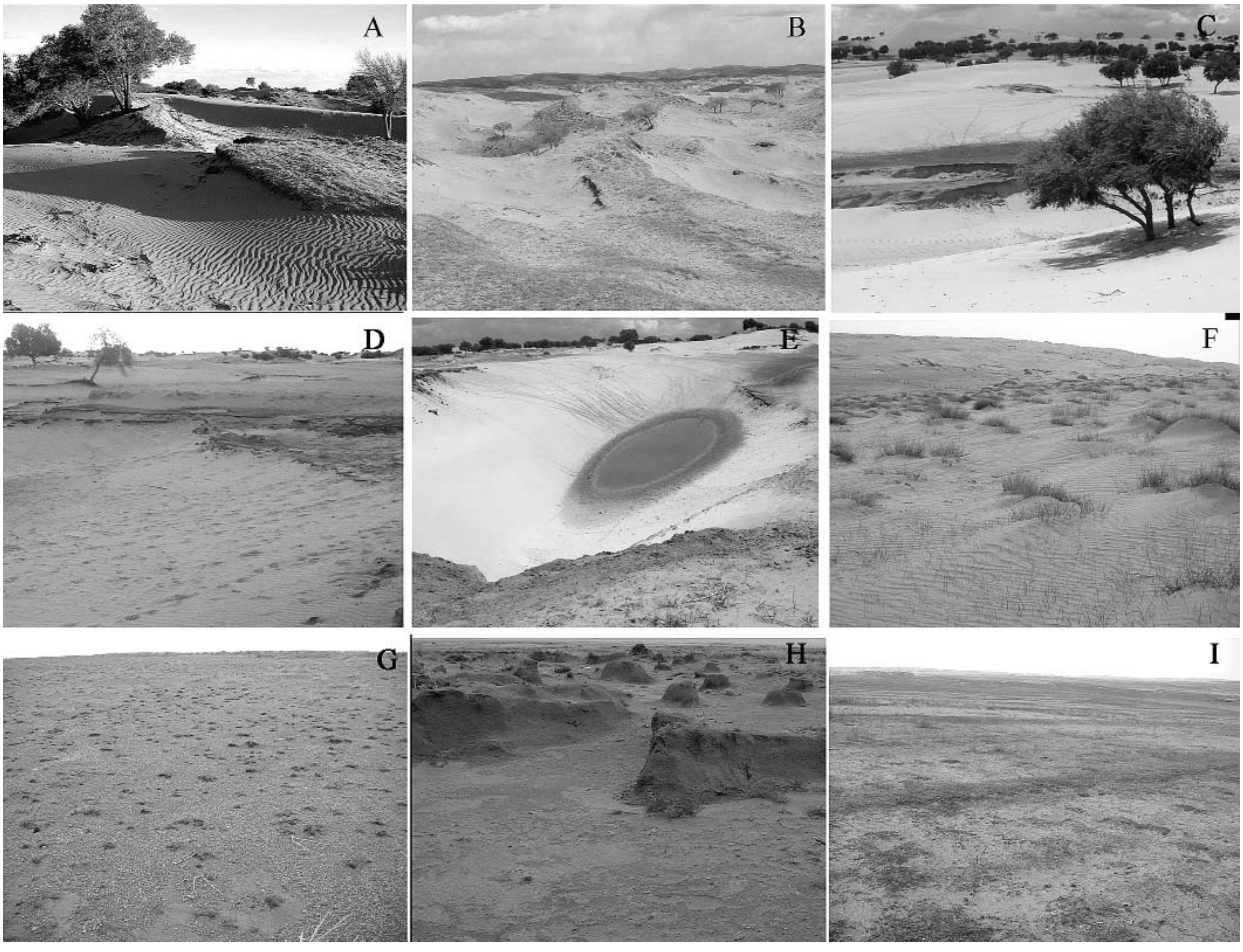

Fig. 2. Main types of aeolian desertified lands in Otindag Sandy Land (A-E. Reactivation of fixed and semi-fixed dunes; F. Coppice dunes in leeward; G. Bare coarse surface eroded by strong wind; H. Wind-eroded badlands; I. Abandoned farmland due to aeolian desertification).

ing the same classification criteria (Table 1; Wu, 2005). The investigation was conducted continually from 2002 to 2006 in the study area, and local 104 farmers and herders were interviewed for analyzing the causes of desertification. From April to May, in 2004 and 2006, field experiments were performed, on soil erosion by wind on sand dunes with different levels of stability and marking, for assessing annual expansion area.

Table 1. Classification and indicators of aeolian desertification degrees

Degree of desertification	Percent of blown sand area in total	Percent of annual expansion	Percent of vegetation cover
L (*slight*)	<5	<1	>60
M (*moderate*)	5-25	1-2	60-30
S (*serious*)	25-50	2-5	30-10
VS (*very serious*)	>50	>5	10-0

Because aeolian desertification evaluation includes not only the assessment of the total desertified area but also the severity of aeolian desertification, very serious aeolian desertified lands were explored additionally.

In the arid and semi-arid regions many studies (Nicholson and Farrar, 1994; Li et al., 2000), including Otindag Sandy Land (He and Lv, 2003) have indicated that NDVI is highly related with precipitation. But Chepil (1962) and FAO (1979) proposed that a wind erosion climatic factor containing key erosion factors such as mean wind velocity, monthly mean rainfall and mean temperature or potential evapotranspiration can reflect the role of climate change in aeolian desertification better. In addition, Tsoar (2005) argued that vegetated dunes can develop when wind power is sufficiently low.

Lancaster (1988) proposed a sand mobility index (M), which, although developed for dunes in desert environments, has been widely used to characterize dune activity in sub-humid to semi-arid environments (Jorgensen, 1992; Wolfe, 1997; David et al., 2005). Considering the fact that soil wind erosion in the study area mainly occurred in spring (Liu and Wang, 2004), in this paper we modified this index to explore the role of natural factors in aeolian desertification process of the study area as shown below:

$$MI = Vs^{*} PE^{*}R^{-1}$$

where MI is modified sand mobility index, Vs is the mean wind velocity in spring (March to May), PE is the annual potential evaporation and R is the annual rainfall. In addition, multi-temporal VGT-S10 (10-day synthesis product) radiometric data for the period April 1, 1998 to December 31, 2004 were downloaded from the free VGT products website (http://free.vgt.vito.be), and annual maximum NDVI during 1998-2004 deriving from SPOT images with maximum value NDVI composite (MVC) method were used to explore relationship between vegetation and drought. An easy to operate drought index (DI), defined as the ratio between annual potential evaporation (PE) and annual rainfall (R) was selected.

The livestock number and area of farmlands were counted year by year to explore the role of human activities in aeolian desertification processes. Aeolian desertified lands, climate change and anthropogenic factor change were compared in different periods, to analyze the causes for local aeolian desertification.

Results

Processes of aeolian desertification in the study area

The temporal and spatial distributions of aeolian desertified lands from the mid-1970s to 2005 in Zhenglan Qi are shown in Table 2 and Fig. 3.

Over the past 50 years aeolian desertification strongly occurred in Otindag Sandy Land (Fig. 4). Three periods could be clearly recognized: (a) Before 1987, rapid aeolian desertification occurred in this region, including slight, moderate, and very serious levels, and especially during 1977-1987 very severe desertification developed with a rate of 112 km^2 a^{-1}, (b) from 1987 to 2000, the rate of aeolian desertification decreased and part of the shifting dunes got rehabilitated; and (c) from 2000 to 2005, rehabilitation occurred of all the aeolian desertified lands. Before 2000, rate of aeolian desertification was 40-50 km^2 a^{-1} and only in recent years parts of aeolian desertified lands were rehabilitated and parts of lands with very serious aeolian desertification (VS grade) changed into lands with slight level of desertification from 2000 to 2005.

In 1977, aeolian desertification with VS grades was found only at a few places and on limited area in the east and west of Sandy Land, but it developed at an alarming rate throughout the Sandy Land during 1977 to 1987. In 2000, lands with VS grades converged on an irregular belt (Fig. 3) and total area occupied was 59.3% of Zhenglan Qi. Although there was some rehabilitation from the early 2000s to the present time in this region, aeolian desertification in 2005 was still very severe. Only parts of lands with VS grades of aeolian desertification in north-western and southern typical area were changed into grasslands and woodlands, while other lighter aeolian desertified lands basically did not get amelioration (Table 2 and Fig. 3). Control of VS grade land revealed that

Table 2. Aeolian desertification development in Zhenglan Qi over the last 30 years

Zhenglan Qi	1977(km^2)	1987(km^2)	2000(km^2)	2005(km^2)	Development rate in 1977-1987 (km^2 a^{-1})	Development rate in 1987-2000 (km^2 a^{-1})	Development rate in 2000-2005 (km^2 a^{-1})
SL	1,131.4	1,060.1	1,762.3	1,808.4	-7.13	+54.02	+9.22
M	1,683.4	1,103.2	2,005.6	1,977.4	-58.02	+69.42	-5.64
S	1,570.3	1,498.4	1,210.8	1,366.7	-7.19	-22.12	+31.18
VS	582.4	1,705.1	1,059.9	807.2	+112.27	-49.63	-50.54
Total	4,967.5	5,366.8	6,038.6	5,959.7	+39.93	+51.68	-15.78

Note: "+"for spread of aeolian desertified lands; "-"for rehabilitation of aeolian desertified lands

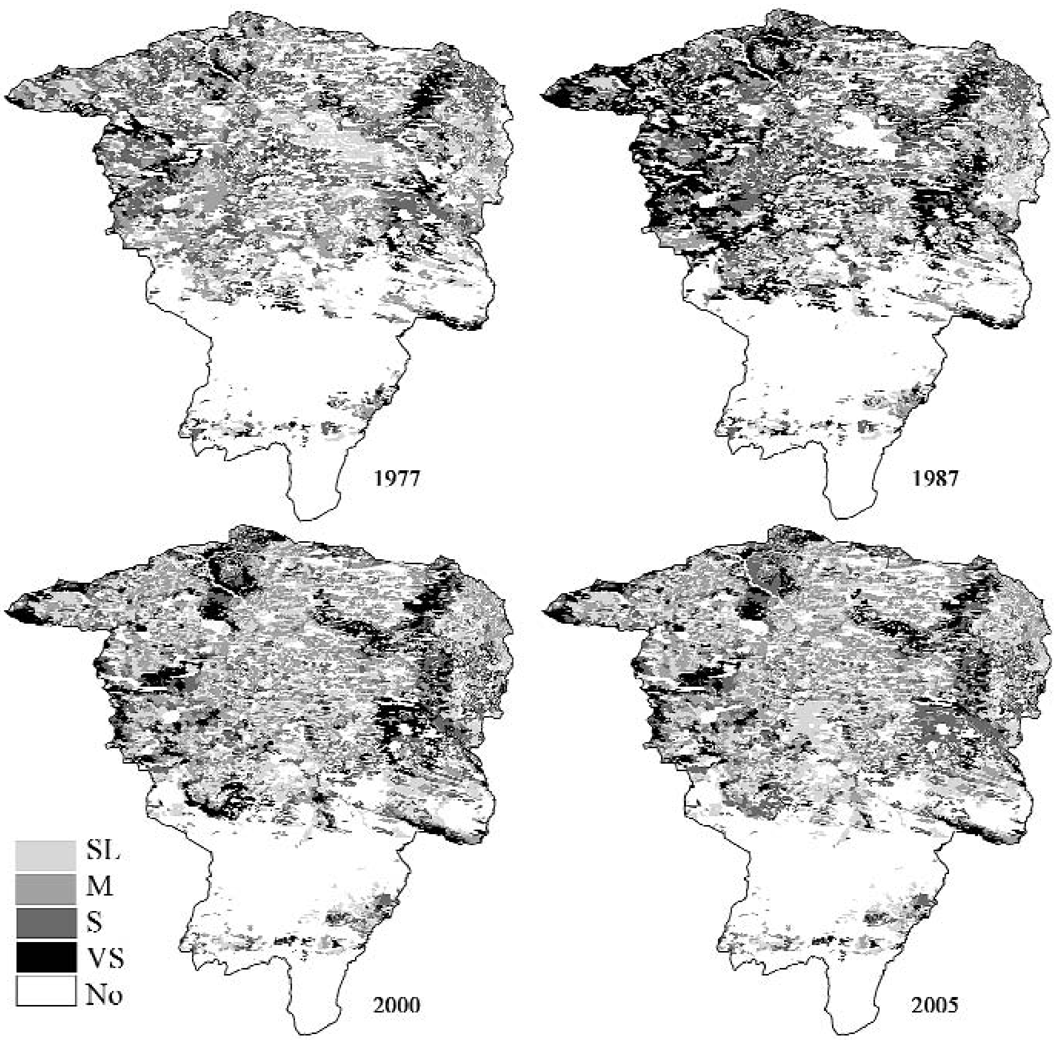

Fig. 3. Spatial distribution of various aeolian desertified lands in Zhenglan Qi over time.

aeolian desertified lands in the study area possesses great rehabilitative potential, while unaltered L, M and S aeolian desertified lands prone to reverse at the same period revealed that aeolian desertification is a complex process.

Causes of desertification in the study area

Climatic factors:

Climate change trend contributing to reverse aeolian desertification: Aeolian desertification occurrence mainly depends on association of wind and vegetation cover in areas with abundant sandy materials. Sun and Li (2002) proposed that the combination of drought, high wind erosion, poor crop and large livestock would make an area most prone to aeolian desertification. Climate change is widely thought as one of the major aeolian desertification causes and even as the main factor, especially droughts (El-Baz, 1983; Chen, 1986). Although drought has important influence on vegetation in the study area (Li et al., 2000; Table 3), drought index (DI) changed little during the last 40 years (Fig. 5), while MI, which directly affects sand mobility, decreased in the same period (Fig. 5).

In addition, heavy snow disaster in 1977 reduced the number of livestock over the last 40 years, which helped in the rehabilitation of desertified land although it caused economic loss. Therefore, climate change was not the main driving factor of aeolian desertification in the study area during the last 40 years.

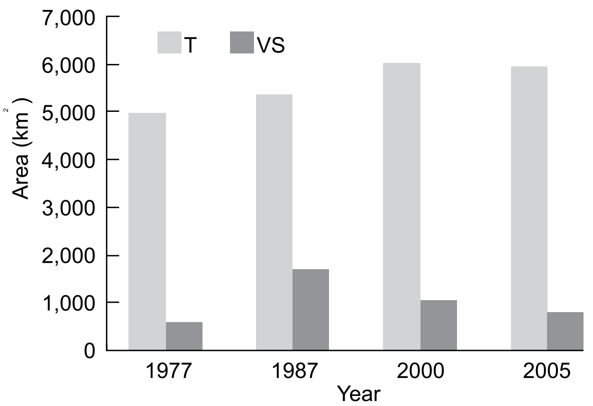

Fig. 4. Change of T and VS in Zhenglan Qi from the mid-1970s to 2005 (T is for total aeolian desertified lands; VS is for very serious aeolian desertified lands).

Drought events occurrence accelerating aeolian desertification process:

Although climate did not change to become dryer, drought events occurred during the last 40 years, such as droughts in 1980, 1989, 1997 and 2001 (Fig. 5). The droughts and frequent windy weathers in the 1970s directly resulted in wind erosion of farmlands and reactivation of partly fixed or semi-fixed sand dunes. As a result, areas of aeolian desertified lands reached 5,367 km^2 in 1987, and the areas of VS aeolian desertified lands reached the maximum of the past 50 years (Table 2 and Fig. 4). Another drought event, from 2000-2002, also resulted in rapid aeolian desertification process and also induced frequent sand-storms (Wang et al., 2002).

Anthropogenic factors:

From 1947 to 2002 the population increased by 4 times and grasslands per household decreased. The trends of livestock and farmland in the other regions of Sandy Land were similar to that of the Zhenglan Qi (Fig. 6, Zheng et al., 2006). The extensive reclamation program, implemented during the early 1960s, largely increased the areas of farmlands in 1960s-1970s. The direct result was the loss of high-grade grasslands, and an increase in the pressure on the remaining area (Zheng et al., 2006). During the early 1960s to 1977, area of aeolian desertified lands reached up to about 4,968 km^2 and many farmlands and high grade grasslands experienced rapid aeolian desertification in 1977 (Table 2).

Nomadism changed to settlements in the early 1980s, as enhanced humans' resistance to natural disasters especially snow damages (Begzsuren et al., 2004), but it caused prolong disturbances on adjacent grasslands. Nomadism has proved over the centuries to be sustainable rangeland management practice and suited to the ecosystem carrying capacity (MEA, 2005). Due to reform of using grasslands

Table 3. Relationship between DI and NDVI in Zhenglan Qi in recent 7 years

Zhenglan Qi	1998	1999	2000	2001	2002	2003	2004
DI	0.178	0.147	0.232	0.208	0.174	0.137	0.146
Mean NDVI	0.266	0.274	-0.144	-0.035	0.008	0.195	0.147

system and implementing Double Contract Policy (both livestock and grasslands be managed by households) about grassland and livestock since 1982, livestock began to steadily increase again (Fig. 6) and grassland per unit sheep declined rapidly (Liu et al., 2004), and pressure from population and livestock exceed the carrying capacity of the land (Han et al., 2002). Settlements of nomads and overgrazing resulted in wide aeolian desertification during this period. As a result, when parts of lands with VS grades of aeolian desertification were controlled and rehabilitated, slight and moderate aeolian desertification occurred on more grasslands till 2000 (Table 2 and Fig. 3).

Hahn et al. (2005) pointed out that in semi-arid and arid areas livestock and vegetation are usually not at equilibrium because of highly variable climatic conditions. High pressure on grasslands partly comes from decrease of grasslands area due to reclamation and aeolian desertification, and partly from livestock increases. Even if we take the livestock size in 2002 as the baseline (because this number is a more reasonable carrying capacity after implementing grass-animals balance policy, though

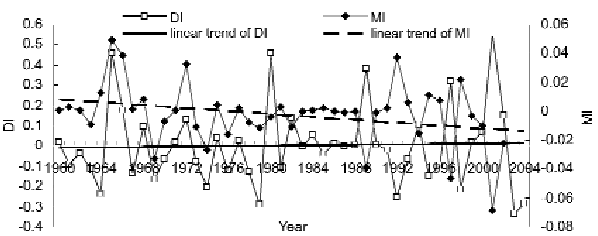

Fig. 5. Change of main climatic factors in Otindag Sandy Land over the last 40 years.

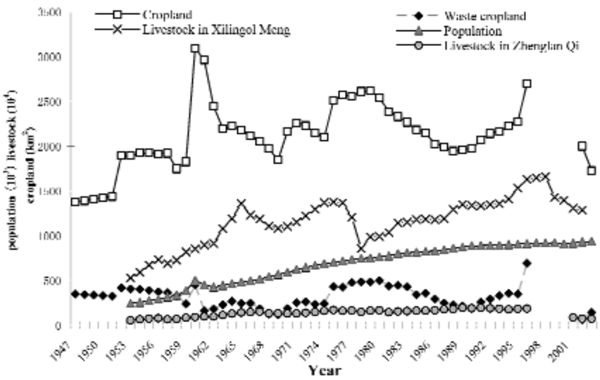

Fig. 6. Change of main anthropogenic factors in Otindag Sandy Land over the last 50 years.

it was still higher than the theoretical one), there were 20 years during the past 50 years, including 1965, 1973-1976 and 1988-2002, when overgrazing occurred. Overgrazing by domestic livestock has been widely accepted as an important cause of land degradation in rangelands (Sullivan and Rohde, 2002; Zhao et al., 2005). Besides, other economic activities such as mining, road building, traffic-off and recreation strongly destroyed grasslands. For example, only in Xilingol Meng, the number of vehicles increased from a few in 1949 to 104,000 in 2005, which also induced desertification. Field investigation showed that vehicles destroyed the vegetation by linear-blowouts along roads with 10-40 m wide and 0.5-2 m deep.

In addition, investigations and interviews showed that although more than 80% of local herdsmen supported present policies (SBXM 2006), other households still continued to overexploit grazing lands against local government. In fact, 82% of them also had known that overgrazing and other irrational human activities easily caused aeolian desertification, but they had no alterative means for surviving. Thus, latent factors inducing aeolian desertification, for example low income, still require further attentions and more sustainable management means.

The trend of change in total aeolian desertified lands in Fig. 4 is inconsistent with the MI (Fig. 5), while consistent with proxies of human activities such as population size, areas of farmlands and numbers of livestock. Field investigation and correlation analysis showed that human activities (particularly overgrazing) mainly transformed grasslands to slightly desertified lands and should be the main contributor to aeolian desertification occurrence. Another interesting observation was that VS change had higher correlation with MI, probably indicating that climatic conditions magnified the desertification, especially in the last 20 years in the study area.

Management practices to promote rehabilitation of aeolian desertified lands

Increase in the frequency of dust storms in the early 2000s compelled humans to carry out many protective projects and undertake countermeasures, such as Enclosure and Migrating Policy, for combating aeolian desertification in this region. There was increase in the mean NDVI in

Zhenglan Qi since 2001 (Table 3), partly because there was much rainfall but mainly because of better management. Many field quadrat investigations proved that the rehabilitation potential of aeolian desertified lands is very large.

Conclusions

Aolian desertification process in the studied area has shown three stages: rapid occurrence before 1987, partly rehabilitation and mostly of deterioration from 1987 to 2000, and partly rapid rehabilitation from 2000 to 2005. There is great potential for Rehabilitation of the desertified area. The role of climate change and human activities in causing aeolian desertification varied with time. In general, population increase was the underlying cause of aeolian desertification. Irrational human activities such as extensive reclamation during the 1960s and steady increase in livestock number, resulting in over-grazing, after 1978 was responsible for aeolian desertification, while climatic change was not the main cause, and it only helped in revealing the adverse affect of irrational human activities through undesirable drought events. It would be difficult to avoid aeolian desertification by depending only on the current protective methods such as fence building and the reduction in the livestock number to match the carrying capacity, and more sustainable management means that improve the livelihoods of the people would be needed.

Acknowledgments

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Experimental study on the characteristic of wind-sand movement on bare furrow

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Abstract

Soil erosion has become a very serious problem all over the world since man began cultivating the land. It is affected by a large number of factors such as soil surface characteristics, rainfall, runoff, and so on. This study focused on the experiment on the wind velocity, the ground temperature and the amount of erosion on bare furrow in an agricultural area in north Yin Mountain of Inner Mongolia. It analyzed the factors affecting the wind-sand movement based on measuring the amount of wind erosion at different wind velocities. The basic data on sand starting velocity, variation in height, wind velocity and the amount of wind erosion, which can show the law of wind-sand movement, were obtained. Based on the study on the wind-sand movement law the difference in wind-sand movement between the bare furrow and the desert was quantified. The study provides foundation for dynamic wind-sand movement characteristic of a bare furrow.

Introduction

Soil erosion has become a major environmental, agricultural and social problem all over the word. Especially in China wind erosion is recognized as an increasingly serious hazard in the arid and semiarid regions. Generally, the wind erosion is controlled by a large number of factors, including soil surface characteristics, rainfall, runoff, wind forces, soil type and texture, slope, vegetation, the conservation measures adopted, etc. (Chepil, 1954; Houghes and Baker, 1977). Soil surface characteristics include soil aggregate stability and random roughness of soil (Bronick and Lal, 2005; Chepil, 1942b; Jianjun and Bergsma, 1995; Layton et al., 1993) which strongly affect the resistance to wind erosion.

Many studies have been conducted on wind erosion over last several decades and several new techniques have been developed. The physics of blown-sand movement was studied by Bagnold (1954), Chepil (1942a & b; 1954; 1956), Chapel and Bisal (1943), and Shao (2000) who brought forward concepts for quantifying wind erosion in different ways. Nowadays, with new technological developments, there have been accelerated efforts in the study of laws governing the blown-sand movement. This paper focuses on an experimental study on the characteristic of wind-sand movement on bare furrow in north Yin Mountain.

Materials and methods

Materials

The study was conducted on a bare furrow in the region of north Yin Mountain, Inner Mongolia. Yin Mountain extends from Wolf Mountain in the west to Hua Mountain in the east, and includes Wulatehou, Wulatezhong, Guyang, Damao, Wuchuany, Siziwang, Chayouzhong, Chayouhou, Shangdu, and Huade counties. The area is a typical ecotone between agriculture and animal husbandry and is one of the regions most seriously affected by wind erosion. The wind erosion affected area is about 97,914 km^2 which is about 85% of the total area.

Methods

The study involved field measurements and laboratory analysis.. Wind velocity, the ground temperature, the amount of erosion and shear strength were respectively measured by using hand anemometer, JY222-geo-thermometer, SC-I sediment collector and crossed shear device in the field. The sediment collector was arrayed as a triangle. The grain-size distribution analysis was conducted in laboratory.

Results and discussion

Measurement and analysis of soil parameters

In order to study the wind erosion status, we studied the soil grain-size composition for six seasons in 2003 and 2005. A bare furrow ploughed after crop harvest was chosen for studies. Samples were collected in both pre-frozen and post-thaw period.

Soil mechanical composition: Based on 100 observations, a mathematic model was set up to describe the local topsoil particle distributions as shown below:

$$p = \frac{1}{1 + 1.08^{103.4336} \cdot e^{-8.1312 D^{0.1241}}}$$

where D is grain-size, and p is the cumulative percentage of the corresponding type of particle. Moreover, in order to study the fractal characteristic of soil particle, a fractal model was built up based on the fractal theory. The fractal dimensions were simulated as follows.

$$D_p = -0.1839x^2 + 0.5162x + 2.0574$$

$$D_s = -0.2437x^2 + 0.5090x + 2.4384$$

$$R^2 = 0.9153 \quad R^2 = 0.9181$$

Crust structure of topsoil: Soil crust is a natural safeguard and it contributes to stabilization of the topsoil and prevents the soil from wind erosion. The following pictures of the top soil were taken using a scanning electron microscope which magnifies super-surface and infra-surface 500 times (Fig. 1- 4). As far as the crust of the furrow topsoil is concerned (Fig. 3), the bigger particles were more than the smaller ones, the latter distributed in the space between the bigger ones. The surface of crust in the furrow was not as smooth as the crust on the surface of general grassland. In the infra-surface, the number of big particles was larger and the space between them bigger than and not as uniform as in the grassland, which had an obvious stratification structure.

Relationship between the topsoil shear strength and soil water content, ground temperature, and vegetation cover: In the unfrozen soil, the cohesion and shear strength increased linearly with increase in soil water content in the range between

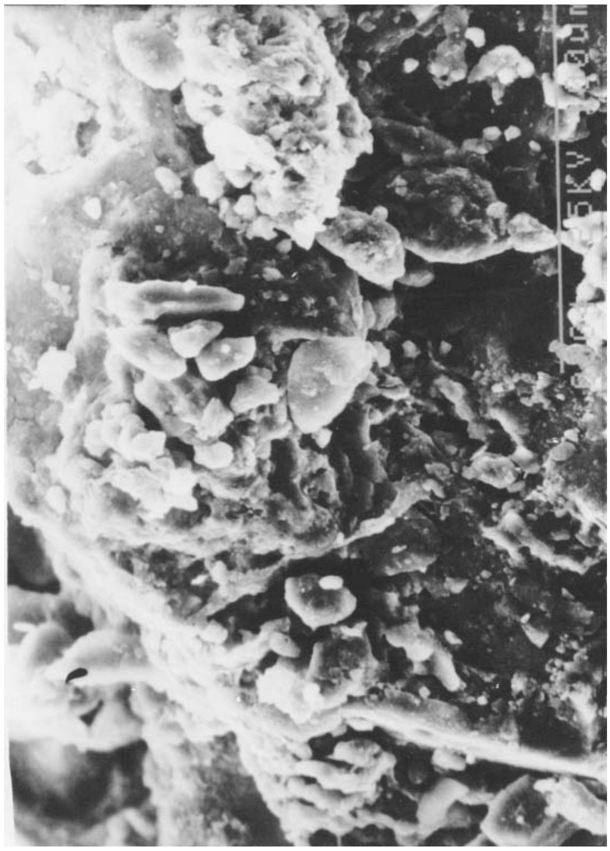

Fig. 1. Super-surface of crust in general grassland.

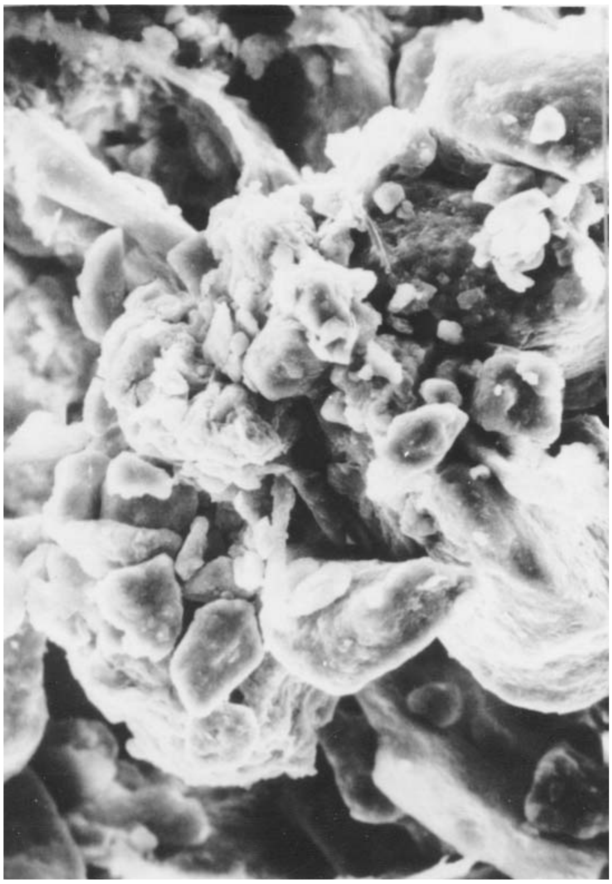

Fig. 2. Infra-surface of crust in general grassland.

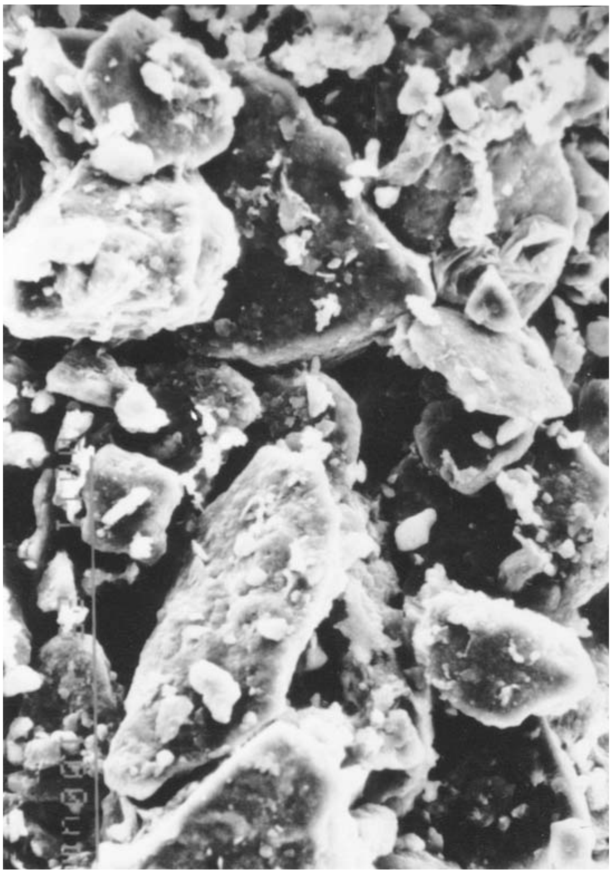

Fig. 3. Super-surface of crust in the furrow.

Fig. 4. Infra-surface of crust in the furrow.

3% and 7%, while it decreased linearly with the increase in temperature in the tested range (2 to 22). The cohesion and shear strength in the frozen soil increased parabolically with the increase of initial soil water content in the range between 4%-14%, while it decreased linearly with the rise of absolute value of the negative temperature in the experimental range(-15 to -2). In spring, the number of fine particles in the bare furrow was more than the ones in general grassland. Because the fine particle is easy to be eroded, wind erosion was more serious in furrow than in general grassland. The soil water content dropped significantly from pre-frozen-thawed to post-frozen-thawed periods and the temperature went up dramatically, which made the topsoil loose and the shear strength to collapse. Therefore, the resistance of soil to wind erosion fell and that is the reason why the sand storms happen frequently in spring.

Wind erosion prediction equation

The meteorological data were analyzed over a period of 30 years and the relationship between the number of the sandstorms and the meteorological parameters was built up as:
where h_a is the number of sand storm days, and *T*,

$$h_a = 0.125 + 0.0231T - 0.136W + 1.02a$$

W, and *a* are ground temperature, rainfall and windy days, respectively.

Wind-sand movement

Threshold velocity: According to the field experiment, the particles of size ranging between 0.1~0.25mm start to move when the wind speed is up to 9.5m/s in 1m.

Wind speed variation: In order to know the law of wind speed variation, the principle of maximum entropy was adopted in the observed data. The probability density entropy function of maximum wind speed can be expressed as:

$$p(x) = \exp(-1.8636 - 0.5850\times10^{-4}x - 0.5873\times1$$
$$\times10^{-4}x^2 - 0.5878\times10^{-4}x^3 - 0.5663\times10^{-4}x^4 +$$
$$0.0072\times10^{-4}x^5)$$

Based on this, the percentage of the days that the wind speed was over 9.5m/s accounted for

28.2%. It shows that the soil frequently suffered from the gale forces, which is the original driver of sand movement.

Sand transport quantity: Based on the statistical analysis of the sand transport quantity in three collectors on 27 March 2003, we found out the relationship between the sand transport quantity and the height from the surface as shown in Fig 5. The sand in the air decreased exponentially with

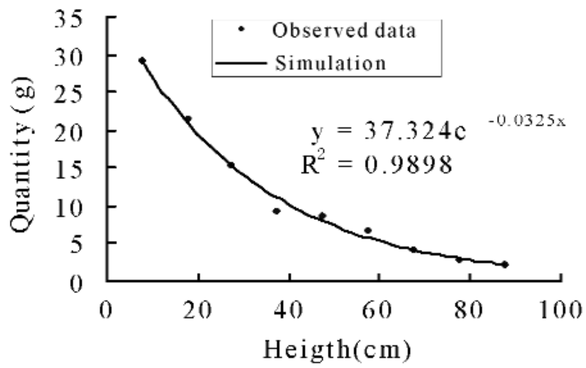

Fig. 5. Distribution of sand transprt quantity with height.

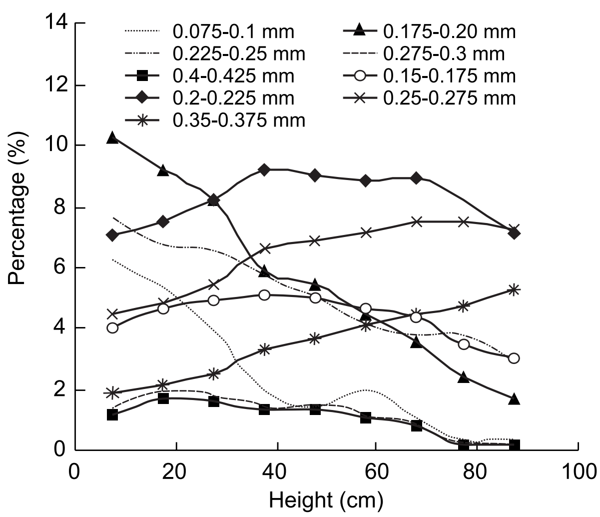

Fig. 6. Distribution of same grain size with altitude.

increase in the height. The particles in the height range 0~7.5cm accounted for 29.36% of the total collection, while 0~17.5cm height range accounted for 50.78% of the total collection. Nearly 90% of the total quantity was collected below the height of 50cm. Therefore, the sand transport occurs in the height range of 0 to 50cm.

Characteristics of sediment distribution

Adopting cubic spline interpolation, we calculated the percentage of eolian particles at interval of 0.025 mm in 40 intervals. The sediment distribution is shown in Figures 6 and 7. In the height range of 5~90cm, the particles of size range 0.25~0.425mm tend to saltate (Fig.6). The distribution of different grain-size on the same elevation shows clearly double-peaks (Fig. 7).

Study on the wind erosion amount in Northern Yin Mountain

On 11 March 2004 and 10 April 2005 the wind-erosion amount was measured on iron pin in every

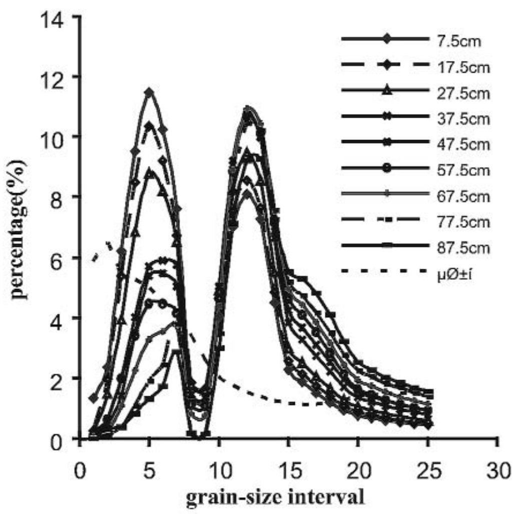

Fig. 7. Distribution of different grain size on same altitude.

Table1. Amount of wind-erosion in Siziwang County

Location		**Siziwang County**	
Time	**March 2004**		**April 2005**
Surface loss at every place (mm)	1.18		1.4
Mean loss (mm)		1.29	
Controllable area(m^2)	1000		1000
Mean aeolian modulus at every place (t/Km^2)	3186		3780
Mean aeolian modulus (t/Km^2)		3483	

Table 2. The total amount of wind-erosion in the high plain counties.

Location	Siziwang	Damao	Chahouyou	Shangdu	Huade
Soil loss (%)	98.5	97.9	75.7	99.0	94.5
Number of sand-storms per annum	9.3	4.4	4.8	7.9	6.4
Area of wind erosion (Km)	23664.7	17792.3	2877.8	4262.0	2427.9
Mean aeolian modulus per annum (t/Km^2)	32391.9	15978.6	17163.9	28395.5	622766.4

observation place. The results are shown in Table1. In the same way, the total aeolian amounts in four other Counties were calculated approximately (Table 2) based on the data of the sandstorm between 1971 and 1980.

The average aeolian modulus in high plain was 23339.27 t/km^2 per annum, while the largest was 32391.9 t/km^2 per annum in Siziwang County.

Conclusions

The study showed that the wind-sand movement differed between the bare furrow and the desert. The main reason was the difference in distribution of the topsoil particles. The threshold velocity in furrow was higher than in the desert. The study contributes to understanding the process of wind-sand movement, and provides a base for research on the dynamic characteristics of wind-sand movement in the areas.

Acknowledgements

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Theme: Range Management

Comparison of different range utilization methods and their effect on range condition: A case study from Damghan rangelands

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Abstract

Rangelands are the main stay of the livestock production in Iran. The utilization systems could be categorized as nomadic, village-based, public, and private. The aim of this study was to compare different utilization systems and identify the system that leads to the least range deterioration, and social and economic problems. For this purpose 31 range sites with different utilization systems were investigated. The results indicated that the contribution of range users in scientific range management, viz: range carrying capacity, grazing commencement and termination, range improvement practices etc. in each utilization system, had a direct effect on range condition. The lower the number of range users in a private section, better was the range condition. Sites where a scientific range management was practiced had a much better range condition. In general the range condition in sites with only one range user was better in all range utilization categories compared to public utilization (more than one range user in the same site).

Introduction

During the last decades utilization of the rangelands of Iran has undergone changes based on the social and political situations. One of the important factors affecting the range utilization was the land reforms introduced by the government after the Islamic revolution. Land reform resulted in the public access to the forests and rangelands, which consequently caused the forests and rangelands degradation. Because of sever rangelands degradation, the government decided to privatize the utilization of the rangelands in the recent years. This privatization was based on the premise that it would result in scientific management of rangelands. After 30 years since the land reform in Iran, most of the rangelands are still used under the public access system. So, it is necessary to compare the effect of two methods (public and private) of utilization on the sustainability of the rangelands.

The effects of land reform on rangelands in respect to their utilization and degradation has been studied from different view points. The results obtained in Semnan province revealed that the best way for allocation of rangelands to private section was renting them to the villagers for at least 10 years. Salmasy (1995) in his studies on public rangelands concluded that one of the problems in the use of rangelands is its public utilization and mismanagement by governmental organizations. He also indicated that the level of participation of villagers in rangeland improvement programs in such a system was very low. The Natural Resource Organization of Semnan Province (1998) reported that because of the lack of public contribution, about 35 different kinds of rangelands improvement projects could not be completed.

Mirzaolian (1999), working on a range site in Isfahan, concluded that scientific utilization of the rangelands had positive effects on rangelands conservation. Ansary (1996) stated that because of the ownership of the rangelands by the private sector before land reforms, the general conditions of the forests and rangelands were better than after the reforms. Azkia (1998) and Hajizade (1999) concluded that whenever the number of the users and managers of the rangelands were fewer, the rangelands conservation and production was better. Sepehrfar (1995), in his socio-economic studies of villagers depending on rangelands in central parts of Iran, concluded that allocation of the rangelands to the livestock producers would encourage them to have a more active role in rangeland improvement programs.

A significant difference in range production and sustainability was observed in the Chahar Mahal Bakhtiary province between the scientific and traditional utilization of rangelands (Sardary, 1999). Because of the lack of scientific information, villagers abused and mismanaged the rangelands, which had resulted in the degradation of the most of the public rangelands through out the country (Ghanbary, 1998). For the improvement and development of range it is necessary to practice a combination of scientific and traditional methods of range utilization (Arokhy, 1998). Seraj (1973) stated that poor utilization and lack of knowledge in range management during summer grazing of sheep and goats resulted in depletion of some meadows in Kholashkuh rangelands. He suggested changing the traditional system of range utilization and livestock management through a comprehensive management plan based on scientific methods of range analysis.

The goal of this survey was to investigate the effect of different kinds of management systems (public and private) on the condition of the rangelands as one of the economic resources for the villagers.

Materials and methods

This research was carried out in 31 range sites in Damghan, Semnan province, Iran. Different methods of range management were investigated for their effects on range production and sustainability. At the beginning, the history of all range sites was studied in respect to range conditions and range trend. A questionnaire was designed and served to the villagers to identify the level of their participation in range utilization in different management systems.

Results and discussions

Of the 31 range sites studied 18 were privately managed. Of these, 67% showed an upward trend and other 33% a fixed trend in the range productivity (Fig. 1). In the remaining 13 range sites studied a public utilization method was practised. Of these, 31% showed an upward trend, 54% a fixed trend, and 15% a downward trend in the range conditions (Fig. 1).

At 67% of rangeland sites in the private sector the villagers used a scientific rangeland management system while in the rest a traditional utilization system was used (Fig 2.). At public rangelands the scientific management ratio reduced to 15% and the rest of 85% sites received a traditional management practice (Fig. 2). The private sector thus applied a better management system on the rangelands. There was a negative correlation between number of ranchers and their contribution in range improvement and development programs. It is easier for fewer ranchers to make a unanimous decision for their common rangeland while as the number of the utilizers increases decision making could be more difficult.

When a scientific management was followed in all the utilization systems (nomadic and villagers) the

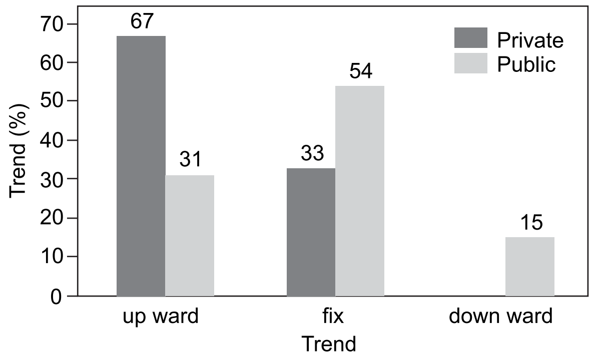

Fig. 1. Comparison of range trend (up ward, down ward and fix) in public and private ownership.

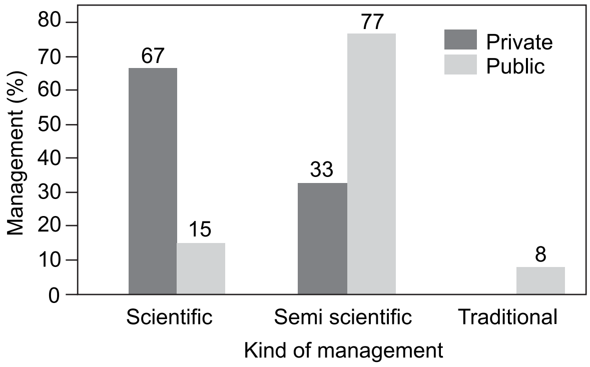

Fig. 2. Comparison of different management in private and public rangelands.

trend in the condition of range was positive and the ranchers made big contribution in range improvement and development programs. The highest score was received by the range sites which were managed and utilized by individual ranchers in any management system. On the other hand public utilization of the rangelands received the lowest points in rangeland management. The results of this survey showed that similar to the developed countries, if the rangeland is allocated to the individuals in a long term system, they will have a sense of ownership on the land which will motivate them to contribute more actively in the rangeland improvement programs. This contribution is not affected by level of education or cultural background of the ranchers.

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A number of ecological propositions and their implications for rangeland management in drylands

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Abstract

Rangeland ecosystems shift across dynamic thresholds between different ecological states in response to natural or human-induced factors. These different ecological states are the result of interactions among climate, soils, grazing history, and management practices. The notion of a single 'pristine' final state is only conceptual in nature, and because of this, dynamic thresholds and the effects of various processes on ecosystem structure and function must be incorporated into decision-making. Rangeland managers should have a working knowledge of the key ecological processes in each state, and the processes that drive a system across a dynamic threshold from one state to another. To do this they need indicators for critical decision-making points. It is essential to identify the thresholds of an ecological transition state and ecological indicators of these states. The criteria of these ecological indicators might be measurable, sensitive to stress on the system, have a known response to disturbance and easy to measure. The state and transition approach may offer an appropriate framework as an aid for decision making and can be used to highlight 'management windows' where opportunities can be seized and hazards avoided. A series of 5 propositions is set out and their implications for management of semi-arid and arid rangelands are discussed.

Introduction

Dynamic thresholds and the effects of nonlinear processes on ecosystem structure and function are rarely considered sufficiently and to date their incorporation in decision-making is inadequate (Eiswerth and Haney, 2001). Natural ecosystems shift between different ecological states through ecological transition zones (Anand and Li, 2001) in response to natural or human-induced factors rather than follow a prescribed successional path (Friedel, 1991). There is now a general recognition that 'pristine' states are only conceptual in nature and that for rangeland ecosystems multiple stable states exist as a result of interactions among climate, soils, grazing history, and management practices (Westoby et al., 1989). But the evolution of rangeland management as a separate discipline was predicated on circumstances (economic, ecological and social) so different from those that apply in most of the world's range/livestock systems. This has led to a re-thinking about what are the important principles that operate in non-commercial range/livestock systems and shifted attention to defining new management goals.

Rangeland ecosystems shift across dynamic thresholds between different ecological states in response to natural or human-induced factors. These different states are stable and each state is a result of interactions among climate, soils, grazing history, and management practices (Westoby et al., 1989). However, dynamic thresholds and the effects of various processes on ecosystem structure and function must be incorporated in decision-making (Eiswerth and Haney, 2001).

On a practical level, rangeland managers need a workable framework. The state and transition approach of Westoby et al. (1989) may offer an appropriate framework as an aid for decision making and can be used to highlight 'management windows' where opportunities can be seized and hazards avoided. Natural resource managers should have a working knowledge of key ecological processes in each state, but they need indicators for critical decision-making points to serve as the basis for developing and interpreting natural ecosystems.

The question of what constitutes an indicator of threshold, and how to measure it, is important for ecosystem management. What attributes are to be measured, how are they to be measured, and how the measurements are to be interpreted, are the subject of continuing debate (Andreasen et al., 2001). Rangeland ecologists need to be able to explore spatial relationships of many species over many environmental features in relation to grazing effect. Whilst the measurement of vegetation composition is important in the assessment of vegetation condition, other attributes are required in order to better understand vegetation dynamics. If only vegetation is monitored, it will not be clear whether any changes in composition are due to interactions between grazing and vegetation alone, or whether the soil, as a habitat for native plants, has been degraded. Tongway and Hindley (2000) have suggested that attributes of the soil-surface condition (soil cover, soil texture, cryptogam cover) may be combined in various ways to provide useful indicators of landscape function such as stability, water infiltration or nutrient cycling.

Rationale

If a system shifts across a dynamic threshold from a stable, productive, undisturbed (defined as "healthy") state to a less healthy state, it would be valuable to have a set of indicators to (i) give an early warning of such change, and to (ii) facilitate the recovery of the system. The U.S. National Research Council (1994) and Andreasen et al. (2001) pointed out the need for an early warning phase between "healthy" and "at risk" states and the need to identify thresholds between "at risk" and "unhealthy" states. Such ecological indicators must be workable and measurable and Dale and Beyeler (2001) proposed the following criteria: easily measured, sensitive to stresses on the system, respond to stress in a predictable manner, be anticipatory, predict changes that can be averted by management actions, be integrative, have a known response to disturbances, anthropogenic stresses, and changes over time, and have low variability in response. However, caution must be exercised with indicators that are highly sensitive to change because they may also be highly sensitive to natural variability and may not be useful (Andreasen et al., 2001).

Understanding the role of plants as indicators has important implications for sustainable rangeland management, and for the rehabilitation of areas that are already degraded (Heshmati et al., 1998). The threshold concept describes unidirectional changes in ecosystem structure and ecosystem functional processes. The state-and-transition model (Westoby et al., 1989) implies that plant community composition makes dramatic changes only during times of unusual environmental influences. Furthermore, the species composition of differing plant communities in particular states, on a particular ecological site, fluctuate within defined limits, which can also be expressed as several domains of attraction (West and Yorks, 2002) or threshold (Friedel, 1991) or ecological transition zones (Anand and Li, 2001) depending on the degree of responses to disturbance. When these thresholds are crossed, recovery to the original ecosystem states is difficult (Friedel, 1991).

Rangeland management implications

The role of rangeland management in either maintaining or restoring rangeland ecosystem needs to be seriously thought about. Even if thresholds could be established and reliable indicator found, it is still not clear whether the rangeland manager can adjust stocking rates, or patterns of grazing in a way that can make any considerable difference. Another important factor is to develop a set of threshold values that will signal the onset of a major change in rangeland ecosystems before it becomes irreversible.

The state and transition approach of Westoby et al. (1989) may offer a more appropriate framework as an aid for decision making and can be used to highlight 'management windows' where opportunities can be seized and hazards avoided. Natural resource managers should have a working knowledge of key ecological processes in each state, but they need indicators for critical decision-making points and to serve as the basis for developing and interpreting monitoring natural ecosystems. Indicators would be useful tools as an early warning between poor and good condition (Andreasen et al., 2001).

From an ecological point of view we might conclude that any form of grazing used by domestic livestock is likely to cause a shift in botanical composition. The longer term benefits (and impacts) of grazing needs to be weighed against the diminution of ecological values, including biodiversity. From the review of the relevant literature we would suggest a number of propositions for consideration for implication in rangeland management. These are set out in Table 1.

Quantifying the link between rangeland condition and livestock performance will be an important step in improving the adoption of more sustainable grazing practices in rangeland environments.

Table 1. Some propositions for rangeland managers to consider.

Proposition 1.	Any form of grazing of rangelands by livestock will inevitably lead to shifts in botanical composition. Some of these will be benign but most will lead to serious compromise of ecosystem stability.
Proposition 2.	Even careful range and livestock management will do some damage to rangelands. Therefore, the long-term impact of pastoralism must be carefully weighed against the biodiversity and other ecological values.
Proposition 3.	Shifts in botanical composition *per se* do not necessarily mean reduced animal productivity but may be early warning of long-term damage.
Proposition 4.	Many methods of range condition assessment do not accurately reflect the changes in animal productivity. Therefore, range monitoring techniques and procedures should be more oriented to the pastoralist's perspective.
Proposition 5:	Plant-based attributes alone cannot serve to characterize range sites and states or trends. Soil factors, including micro topography and cryptogam cover relationships should also be assessed (Tongway, 1995).

Management implications of the five propositions

Proposition 1: Rangelands/grasslands in China are heavily grazed and many areas are thought to be degrading. This assessment comes from range scientists and technicians who note the simple fact that as standing biomass is depleted and livestock populations capture a larger proportion of the plant biomass with more palatable species being eaten more quickly than less attractive forage plants. Problems emerge when we push our interpretation one step further and equate heavy use with irreversible environmental damage. This interpretation is all too often made in practice, and it assumed that rangeland in poor condition is necessarily degraded or degrading. Once made, this equation can be sustained by a logical circularity of breathtaking simplicity. We can see that an area is degrading because of the presence of critical indicator species, and we know that these are critical species because they are associated with degradation.

Proposition 2: The open rangelands of northern and western China and in most countries in central and south west Asia are characterized by extremely infertile soils, erratic rainfall, and annual – as opposed to perennial – pastures. High stocking densities and overcrowding are unacceptable, (because of the association with poverty and accelerated desertification) but are nonetheless the reality. These are thoroughly domesticated, intensively used and ecologically distinctive landscapes in which notions of 'natural' and 'pristine' lack practical significance as a standard for judging the sustainability of current husbandry systems. Current thinking about land degradation falls into two categories – ecological and economic sustainability. The failure of many scientists, technicians and commentators to clearly distinguish between the two has led to much confusion and has tended to overestimate areas at risk and paralyze the decision-making process on what remedial measures to adopt.

Proposition 3: Shifts in botanical composition in range/livestock systems seem to be inevitable but the direct linkage between a loss of productivity as reflected in off take of animals or their useable products (milk, fibre, blood or draught power) is not always so clear. Partly this arises from the fact that as an applied science, range management was developed in the western USA to address the needs of large scale commercial producers who had recently occupied perennial grasslands. For this purpose, degradation could be conveniently identified by comparing current botanical conditions with those that prevailed before the introduction of domestic stock. This does not rule out the use of botanical criteria to identify rangeland degradation. But it does imply that botanical indicators are surrogates for underlying economic trends, and it is the responsibility of the analyst to demonstrate – not merely to assume – that these proxy indicators are reliably associated with genuine economic loss

Proposition 4: Rangeland management has never been a culturally free and wholly objective undertaking. But the standard approach to range assessment has little relevance to most non-commercial pastoral systems in Asia and Africa. For a start, there is often no credible botanical 'before' on which to base a botanically-based assessment. Densely populated and intensively used areas-most of north western China and many other places are degraded, by definition. But what has this 'evaluation' achieved, aside from insulting the competence of the herders and blunting our critical thinking? Wrapped comfortably in a blanket environmental condemnation of the current situation, there is reduced incentive for researchers to do discerning, practical science – science that will address the very real problems of densely stocked range/livestock systems.

Proposition 5: The combined assessment of vegetation and soil features could provide more comprehensive understanding of disturbance effects, such as grazing, and could be a sound basis for management of a particular area. It will help to aim at sustainable utilization of the plant community with regard to full ecological understanding of vegetation condition. The key question is sustainability and this is best reflected in the more durable element – the soil.

Conclusions

There is also an argument for abandoning the notion of carrying capacity. The value of the concept, even for grazing management, is being questioned. Its definition is controversial, its estimation complex, and its appropriateness to non-commercial range livestock systems is called into question on the grounds of variability of rainfall, the spatial mobility of herds, the contribution of crop residues, vis a vis natural pastures for feeding livestock (Behnke et al., 1993).

Conceptual ambiguity, measurement error and the practical difficulties of implementing effective management regimes designed to restore degraded lands have induced some observers to argue that the concept of carrying capacity is all but useless. But our interest in and need for the concept remains undiminished. This encourages us to attempt to clear up some of the logical problems that beset the carrying capacity concept. We do need to identify critical thresholds and be able to specify which management regimes are probably sustainable and for how long. The research agenda for the future must include discerning, practical science – science that will address the very real problems of densely stocked range/livestock systems. Development of scientifically defensible and locally relevant notions of carrying capacity and degradation are an important part of this task.

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Daily transpiration rates of *Festuca ovina* and *Agropyron intermedium* rangeland species

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Abstact

Proper study of the hydrological cycle components is necessary for sound utilization of rangelands which are mostly located in the arid and semiarid regions. Transpiration is one of the major components of the water cycle, but much attention has not been paid to its quantification in range species. The comparison of the different kinds of rangelands species in terms of transpiration rates provides a good information for range management to achieve optimal forage production under a given precipitation regime. The present study presents a comparison in transpiration rate between two important Iranian rangeland species, viz. *Festuca ovina* and *Agropyron intermedium* grown in plastic pots with 50 cm^2 surface areas. The daily evapotranspiration was measured using weighing lysimeter over a period of 36 days under relatively natural conditions. The mean daily transpiration of *Festuca ovina* and *Agropyron intermedium* was, respectively, 5.11 and 5.03 ml. The statistical analysis showed that although the average transpiration per pot did not differ significantly, the differences between the two species in the transpiration per shoot and per unit shoot dry weight was significant.

Introduction

Preservation of soil and water is much important in rangelands as they cover some 40% of terrestrial area of the world, and they are spread mostly in the dry and semi-dry climate (Gamougoun et al., 1984). The soil, water and plant relationships of rangeland species have not been much studied although they are important for effective management of rangelands. Some aspects of hydrologic cycle such as transpiration and interception are particularly neglected owing to difficulties in field measurements. Quantifying the components of water balance for a watershed is crucial towards understanding of the dominant hydrologic processes occurring in a basin (Flerchinger and Cooley, 2000). Many of the key controls on water use by vegetation involve the water uptake by roots, the transfer of liquid water through plants and the control of vapor loss from the leaf surfaces by the opening and closure of the stomata (Roberts, 2000).

The comparison of the transpiration rates of different rangelands species would provides good information for range management under different moisture regimes. Many studies have been undertaken for measurement of transpiration of forest species (Calder, 1978; Kaufmann, 1985; Roberts and Rosier, 1993; Ryan et al., 2000), but the rangeland species have remained neglected. Most of the transpiration estimations have been made through the determination of other hydrologic components in water balance model whose accuracy is controlled by the efficacy of their measurement. Kirnak et al. (2001) in Turkey monitored the transpiration rate from *Solanum melogenea,* planted in small polyethylene pots, by gravimetric method. The present study therefore attempted to get some ideas about the amount as well as the probable difference in water transpired by two important Iranian rangeland species viz. *Festuca ovina* and *Agropyron intermedium.*

Materials and methods

Festuca ovina and *Agropyron intermedium* were planted in small polyethylene pots for gravimetric study of transpiration (Kirnak et al., 2001). The pots, with a surface area of 50.27 cm^2, served as weighing lysimeters. Five replications were used. The weight lost during the day was determined with the help of weighing balance having 0.0001-g accuracy. Un-planted pots were used for measuring evaporation from soil surface. The amount of transpiration was then calculated through subtraction of the evaporation from the evapotranspiration values obtained respectively from the un-planted and the planted pots. The amount of water added to the pot and any drainage loss were precisely considered. The study was done for a period of 36 days, from 29 May to 3 July 2004, under the natural conditions except that pots were protected from natural rainfall. All measurements were made at 1400 hrs when the transpiration was expected to be at its maximum (Kirnak et al., 2001). The transpiration rate was computed for both the species on per pot, per shoot and per unit shoot dry matter basis. The differences between the two species were statistically compared using ANOVA.

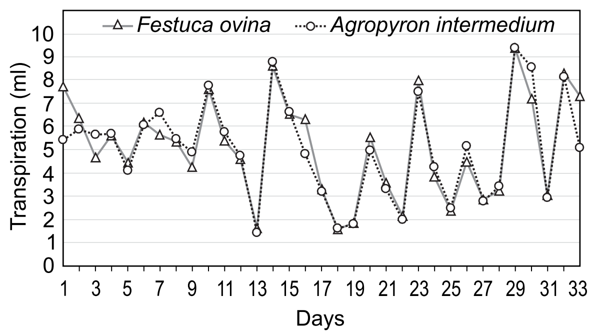

Fig. 1. Daily transpiration rate (ml per pot) of two species during the study period.

Results and discussion

The average daily transpiration of *Festuca ovina* and *Agropyron intermedium* per pot is shown in Fig. 1 The transpiration rate changed greatly over the period of study but the trend in both the species was alike. The daily changes in transpiration rates can be attributed to the change in air humidity and temperature (Roberts, 2000).

Table 1 shows that the average, standard deviation and maximum and minimum values of transpiration of both the species for the whole period of study. Most of the values were almost similar in the two species, although the minimum value in *Festuca ovina* was a little higher than in *Agropyron intermedium*.

The average values obtained during the study are almost similar to those reported by Sadeghi and Rahimzadeh-Halagh (2005) but the minimum and the maximum values are different. The results of the statistical analysis using ANOVA revealed that there was no significant difference (P= 0.05) between the two rangeland species. The values for the amount of transpiration per shoot and per unit dry matter differed in the two species at P= 0.01 level of significance. The rate of transpiration of *Agropyron intermedium* was much higher than of *Festuca ovina* and this difference might be associated with the difference in the shoot structure and coverage (Kaufmann, 1985) and might reflect the probable difference in their physiological behavior (Anderson, 1981; Roberts and Rosier, 1993).

Conclusion

The results of the present study demonstrated that the daily transpiration rate of the studied species on per shoot and per unit dry matter basis were significantly different. *Agropyron intermedium*

Table 1. Differences between the two range species in the average, minimum and maximum transpiration per pot per day and growth parameters per pot.

Variable Species	Average (ml/day)	SD* (ml/day)	Min. (ml/day)	Max. (ml/day)	Ave. No. of shoots	Dry matter (g)
Festuca ovina	5.108	2.174	1.589	9.379	4.2	0.125
Agropyron intermedium	5.029	2.144	1.447	9.353	2.4	0.085

** SD =standard deviation of average daily transpiration* had higher values than *Festuca ovina*. This difference is of great importance for decision makers and ranchers for selection of suitable species for different conditions. More studies on these two species over a longer period of time as well as with other range species should be done to develop large data base for use by the range managers.

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Rangeland degradation related to social and ecological characteristics in the Syrian steppe

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Abstract

In many dry areas in Central and West Asia and North Africa (CWANA), increasing population pressure is causing changes in land use that are degrading the region's natural resource base and threaten the livelihood of the inhabitants. Encroachment of cultivation and overgrazing are rangeland problems that the International Center for Agricultural Research in the Dry Areas (ICARDA) and its partners are addressing in several countries. A survey was conducted in the Syrian steppe (*Badia*) to provide information needed to implement proper grazing management. Fifty communities including 313 households were randomly selected and surveyed in the spring of 2005 and the relationships between rangeland degradation, current management and community characteristics were determined. Rangeland degradation was assessed for each of the communities' rangeland. An index of degradation was determined by evaluating eight indicators. Rangeland utilization was high with over 70% of the forage consumed on 87% of the sites. The amount of forage produced by different range sites varied with over 80% of the sites producing less than 300 kg/ha. Results showed that the rangeland of some communities was more severely degraded than others.

Introduction

More than half of the total area of Syria is *Badia* dry rangeland with mean annual precipitation below 200 mm. Sheep numbers have increased 3.5 fold since 1960 according to livestock statistics issued by the Syrian Ministry of Agriculture and Agrarian Reform (Cummins, 2003). Rangeland is commonly said to be severely degraded, but little research has been conducted to demonstrate the extent. Uprooting shrubs for fuel, overgrazing, recurrent drought, cultivation and mechanization have commonly been blamed for the degradation. We conducted a survey to: 1) characterize the *Badia* Bedouin communities and their rangeland, 2) measure the extent of degradation, 3) determine possible causes of degradation, and 4) investigate possible mechanisms to better manage the land. The survey was implemented in spring 2005 at 4 levels: community, household, range site, and systematic transects to address these issues.

Methods

Data were collected from March to June 2005 from 50 communities where leaders were interviewed to determine general community characteristics and to map the land. The communities were randomly selected from officially censed communities in the Badia. Three-hundred- thirteen households were interviewed to characterize the family, quantify livestock production, and flock management. One hundred-twenty-eight range sites were evaluated in the field with community leaders to characterize the different types of rangeland and conditions. The range sites are defined as sample sites on the community rangeland selected subjectively to represent the majority of the rangeland in the community. Sometimes several sites were sampled if there were big differences in the range. Systematic sampling was also done along transects for a total of 15 samples per community to quantify degradation related to distance from settlements. All the survey points and community boundaries were geo-referenced with global positioning system (GPS) for spatial analysis using geographical information systems (GIS) tools.

Community and household level

Socio-economic data were collected at the community level on demography, governance, property rights, flock mobility, infrastructure, social network and cohesion. A map was developed of the land area with the community leaders and later delineated on the ground using a hand-held GPS. The mapping activity was useful to initiate discussion with the community leaders (Fig. 1).

Range site

Several indicators of range health at the range site level were estimated in the field to assess rangeland degradation and use on a scale from 1 (none-very low) to 5 (very high). Indicators of rangeland soil degradations are: pedestals and terracettes, rills and gullies, flow movement, root exposure, wind erosion, and soil compaction (Pellant et al., 2000). Other indicators are litter movement and invader plants. Ground cover was estimated visually including vegetation, bare ground, rock or gravel and litter. Dominant plant species and indicators of current range use (dung, trampling, and % forage use) were also estimated on all 128 range sites.

Systematic transect

In addition to the range site evaluation with the herders, the same range health indicators, ground cover measurements, and use levels were studied systematically in each community. Three transects were selected from the settlement center to cover most of the communities' grazed rangeland. This included native range and previously cultivated areas. The first transect direction from the settlement was subjectively selected by the village representative who showed the community boundary. The other two transects were mostly at 120 degrees from the first transect. Two sample points were fixed with one at the beginning (50 meters from the settlement) and one at the end of the transect on the community boundary. In a few cases where the land areas were very large, the last point could not be placed at the community boundary. The distance between each of the 3 remaining points were equally spaced between the start point and end point. Seven-hundred-fifty sample points over fifty communities were included in this assessment.

GIS methods

Since the survey data collection was geo-positioned through the use of GPS, GIS analysis was used to either simply assess the data visually or

Fig. 1. Local population involvement in drawing the boundary of their community and defining range sites.

perform certain geo-processing. The spatial display of these data may enable a more precise estimation of the value of properties at locations not sampled than simply averaging between sampled points. The value of a variable between data points was interpolated by fitting a suitable model to account for the expected variation. Several techniques are used to model spatial variation across the landscape. We used the Inverse Distance Weighted Averaging (IDWA) technique. IDWA is a deterministic estimation method whereby values at points not sampled are determined by a linear combination of values at known sampled points. Weighting of nearby points is strictly a function of distance. It weights the points closer to the processing cell greater than those farther away; in other words, nearby observations have a heavier weight (Collins and Bolstad, 1996). Therefore using the range field verification data (range site and systematic transect sampling) several variables were spatially interpolated to create grid maps using the above technique. Certain areas of the *Badia* were not well represented or sampled during the survey. This lack of data is a handicap for generating accurate maps and in this case more ground-truthing is needed.

Results and discussion

Community rangeland characteristics across the Badia

According to the community leaders, 95% of the area was degraded. Only 6 range sites were not degraded. Three of those sites were improved by projects, 2 sites were native and 1 site was previously cultivated. Project improvements were shrub plantation and resting. The two native sites were both dominated by *Poa bulbosa*, *Noaea mucronata* and *Artemisia herba-alba.* The previously cultivated site is now dominated by poor forage *Capparis spinosa.* The typical community had a medium level of soil degradation. The map generated through the interpolation technique of 6 degradation indicators, illustrates that the *Badia* rangeland is more degraded toward the south than the north (Fig 2).

The plant functional groups of the biomass averaged 34% shrub, 20% perennial grass, 19% annual grass, 18% annual forb and 8% perennial forb.

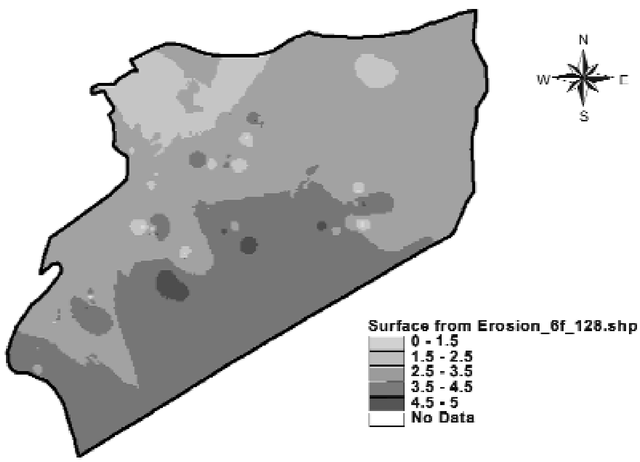

Fig. 2. Badia rangeland degradation map based on a gradient from 0 (no degradation) to 5 (very high), spring 2005.

This is a reasonably healthy balance of plant functional groups. Perennials, which provide year round protection, covered 21% of the ground, annuals providing additional seasonal protection covered 18% of the area. Rock and gravel protect the soil from erosion and covered 14% of the surface. Almost no plant litter was observed at less than 1% and nearly no moss or lichen was present except in a few protected areas. Bare exposed soil was quite high at 46% of the ground surface but cover by vegetation or gravel may be enough to protect the soil from erosion.

Assessment of production potential

Production potential for each community can be approximated based upon several of the measured variables including: estimated biomass for a typical year, current year's biomass composition by life form, perennial or annual plant cover, and bare soil. It is difficult to determine if low site productivity as reflected by these indicators is caused by degradation or inherent capacity of the soil environment. For example, high bare ground could occur because the land has been overgrazed and degraded or simply because the mean annual precipitation is very low. Regardless of the reason for the current level of productivity, it is a useful factor to explain why some communities have higher livestock productivity and better livelihoods than others and to identify communities where improved management could be beneficial. Productivity per hectare is misleading in the pastoral societies as animal productivity is related to the total amount and quality of forage available, not how much is produced per hectare. For these reasons it is possible for communities with low forage productivity per hectare to maintain highly productive flocks because they have access to extensive grazing areas.

Most abundant plant species and use across all range sites

The plant species were rated by abundance from the single most abundant plant that dominated the site with a score of 5, to the least abundant or rare species with a score of 1. The most abundant plants on the range sites were summarized in three ways: 1) percent of land area found most abundant, 2) percentage of the 128 range sites found most abundant and 3) constancy, the percentage of occurrence or presence by site no matter if dominant or rare. Perennial grasses or sedges of high forage value were the most abundant on an area basis though relative productivity was low (Table 1). *Poa bulbosa*, a short lived perennial forage grass that functions like an annual, was dominant on 18% of the total area, on 15 sites and constancy was 56%. *Carex stenophylla*, a perennial sedge, is dominant on 17% of the area but only 1 large site and constancy was 16%. The next most extensive species by area was *Anabasis syrica*, a poor forage but used for fuel and soap (14% area, 17 sites, and 20% constancy), *Artemisia herba-alba*, a good forage shrub (12% area, 8 sites, and 30% constancy), *Peganum harmula*, non forage but a livestock medicinal plant (12% area, 16 sites, and 29% constancy), *Hordeum glaucum*, an annual forage grass (12% area, 15 sites, and 48% frequency), *Plantago ovata*, forage forb (5% area, 1 site, and 10% constancy) followed by *Noaea mucronata* (4% area, 8 sites, and 26% constancy) used for fuel.

Bedouin herders rated the forage value of the plants at each range site. Plants of poor forage

Table 1. Frequency and area of most abundant species in 128 sites in the Syrian steppe, spring 2005.

Species	Total sites Frequency	%	Total area ha	%	Past cultivation ha	%	Never cultivated ha	%	Grazing value
Achillea conferta	3	2.3	4200	0.53	4200	1.44	0	0	good
Achillea fragrantissima	7	5.5	18500	2.33	7000	2.40	11500	2.29	good
Adonis dentata	2	1.6	27200	3.43	27200	9.34	0	0	good
Alhagi maurorum	2	1.6	300	0.04	300	0.10	0	0	good
Ammothamnus gibbosus	1	0.8	1000	0.13	0	0	1000	0.20	None
Anabasis syriaca	17	13.3	110470	13.92	34000	11.68	76470	15.23	poor
Artemisia herba-alba	7	5.5	97665	12.31	40065	13.76	57600	11.47	good
Atriplex halimus	1	0.8	1000	0.13	1000	0.34	0	0	good
Astragalus spinosus	1	0.8	10000	1.26	0	0	10000	1.99	poor
Barley	3	2.3	4250	0.54	4250	1.46		0	good
Bromus tectorum	1	0.8	800	0.10	800	0.27	0	0	good
Capparis spinosa	2	1.6	2200	0.28	2200	0.76	0	0	good
Carex stenophylla	5	3.9	132030	16.65	3000	1.03	129030	25.70	good
Chenolea arabica	1	0.8	3500	0.44	0	0	3500	0.70	good
Cornulaca setifera	1	0.8	1000	0.13	1000	0.34	0	0	None
Gypsophila pilosa	1	0.8	300	0.04	300	0.10	0	0	poor
Haloxylon articulatum	4	3.1	700	0.09	470	0.16	230	0.05	good
Haloxylon salicornicum	2	1.6	4400	0.56	4000	1.37	400	0.08	poor
Hordeum glaucum	15	11.7	61280	7.73	13780	4.73	47500	9.46	good
Micropus longifolius	1	0.8	1000	0.13	0	0	1000	0.20	good
Noaea mucronata	11	8.6	34355	4.33	200	0.07	34155	6.80	poor
Peganum harmala	11	8.6	91450	11.53	87150	29.93	4300	0.86	poor
Pteracanthus triradiata	1	0.8	2000	0.25	0	0	2000	0.40	poor
Plantago ovata	2	1.6	40400	5.09	400	0.14	40000	7.97	good
Poa bulbosa	24	18.8	142620	17.98	59330	20.38	83290	16.59	good
Salsola vermiculata	1	0.8	500	0.06	500	0.17	0	0	good
Tamarix sp.	1	0.8	15	0.01	0	0	15	0.01	None
Total	128	100	793135	100	291145	100	501990	100	
% from total					36.7		63.3		

Table 2. Use of plant species by number of communities that collected and total number of collections per year for 50 communities in the Syrian steppe, spring 2005.

Species	Medicinal (human)		Medicinal (animal)		Food		Fuel	
	com*	collection	com	collection	com	collection	com	collection
Achillea fragrantissima	16	47						
Althaea officinalis	1	1						
Anabasis syriaca							8	59
Artemisia herba-alba	28	64						
Artemisia scoparia							1	10
Capparis spinosa	3	13			1	1		
Citrullus colocynthis	3	23						
Cornulaca setifera							2	12
Gundelia tournefortii					2	11		
Haloxylon articulatum							3	11
Haloxylon salicornicum							11	264
Heliotropium europaeum	2	3						
Kuehneromyces mutabilis				5	27			
Malva aegyptia					5	16		
Matricaria aurea	21	157						
Noaea mucronata							16	475
Peganum harmala			11	83				
Terfezia leonis					12	296		
Teucrium polium	20	100						
Thymus syriacus	5	30						
Ziziphora tenuior	6	18						

**com: number of communities*

value dominated 47% of the sites and 32% the land area. Besides grazing, most of the other uses of the native plants were for fuel and some for medicine. A community household averaged 17 collections for fuel, 7 for food, 9 for human medicine and 2 for animal medicine or a total of 34 collections per year (Table 2). This would be approximately 70 hours per household per year, an indication of the relative importance of native plants to the community for uses other than grazing.

Species dominance

Species dominance is a listing in order of the most dominant to least dominant plant and was used to characterize the range but also to provide evidence of changes in forage species over time. On comparison of the forage value of the most dominant species to less dominants within each site, the most dominant (1) were consistently poorer forage, only 51% good grazing and conversely the least dominant (6) were better forage at 87.5% good grazing value (Table 3). In other words the higher the dominance ranking the poorer the forage. Grazing puts pressure on the most palatable plants, so they tend to disappear over time if stocking rates are high and become replaced by plants of low palatability. Since plants with lower dominance ranking are the ones with the highest forage value, it appears that the forage plants are decreasing from the *Badia*. Evaluators based dominance on the species presence, no matter how much they were grazed since all sites were grazed at the time of sampling. Some species such as cer-

Table 3. Percent of sites by value of use for the 6 most dominant plants at each site in the Syrian steppe, spring 2005.

Dominance	1	2	3	4	5	6
Good grazing	50.8	65	61.5	67.9	76.4	87.5
Poor	43.5	28	25	23.5	18.2	6.3
None	3.2	6	10.4	6.2	3.6	6.3
Fuel	2.4	0.8	1	0	0	0
Human food	0	0	0	1.2	0	0
Human medicine	0	0	1	1.2	1.8	0
Animal medicine	0	0	1	0	0	0

tain annuals are not recognizable after grazing and would tend to be underestimated. These results provide strong evidence that the best forage species have been decreasing over time and the less palatable poor forage plants have been increasing so that they now dominate the vegetation.

Stocking rate and carrying capacity

The amount of forage biomass a particular range site would produce during a typical year of normal precipitation was estimated by trained field scientist. The overall average biomass productivity for a typical year was estimated at 282 kg/ha, which is about enough to feed 5 sheep for 2 months. Only half of the biomass of the *Badia* was from species considered desirable forage even though they occupied 68% of the area (Table 1). The north-eastern area of the *Badia* has the lowest biomass productivity for a typical year (Fig. 3).

Based upon the number of hectares of each range site, we calculated the total biomass of forage available per community. The actual stocking rate (SR) for the year of study was more difficult to determine because flocks are mobile and derive some of their daily nutritional needs off site or from supplemental feeding. Also outsiders sometimes used community range. Data were collected in the socio-economic component of the survey that estimated monthly the number of sheep on community land. A typical community (median values) would have a carrying capacity (CC) of 15,000 sheep unit months of rangeland feed available in a year of normal precipitation. This for example is enough to feed 5,000 sheep for 3 months. The typical (median) stocking rate is 40,500. The stocking rate of the community land was divided by the carrying capacity as determined by biomass estimates to calculate the SR/CC ratio. The median ratio was 3, which means that the median level of overstocking is over 3 fold the theoretically "recommended" proper stocking rate (SRM, 1989). This theoretical rate assumes only half the forage is consumed, which is not practical in Syria where sheep often consume nearly 100% of the forage. Therefore twice the "recommended" proper rate would mean full utilization of the forage. Most of the *Badia* is stocked at full utilization at over double the available forage (Fig. 4).

Trampling by animals and amount of dung on the soil surface is an indication of current use by livestock which was also at a medium level. Forage utilization levels were high at an average of 70% with median value of 80%. Only 50 kg of available (residual) biomass was found remaining at time of sampling for most of the communities and 80% of the biomass was of poor forage species. These four variables (residual biomass, utilization level, dung and trampling) were combined to generate a map of the different levels of use in the *Badia* (Fig. 5). Use was lowest in the northwest corner of the *Badia*. With the exception of a small pocket in the north, rangeland use appears higher in the south where we observed the highest degradation.

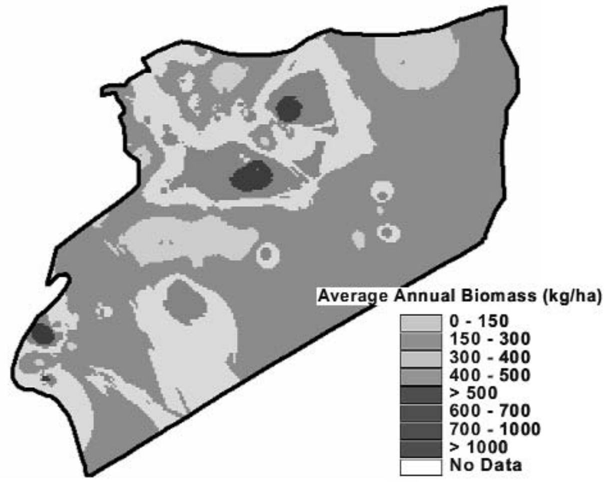

Fig. 3. Estimated biomass production (kg/ha) for a typical year for the Badia rangeland.

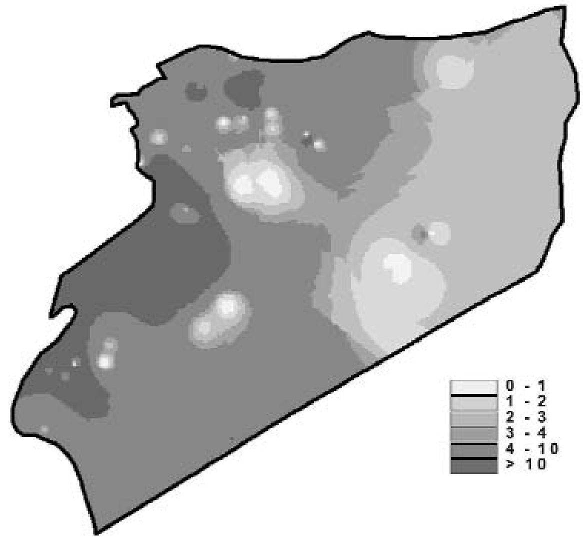

Fig. 4. Ratio of stocking rate by carrying capacity for the Badia rangeland, spring 2005.

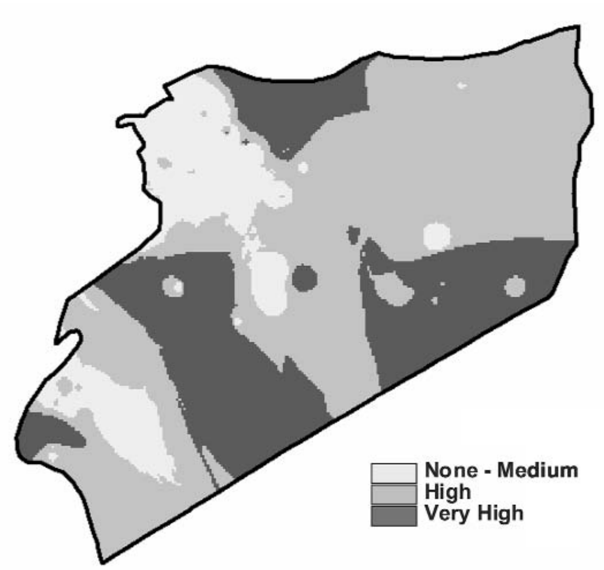

Fig. 5. Range use based on estimated residual biomass, percent utilization, trampling, and dung in the Badia steppe, spring 2005.

It is apparent at these very high stocking rates (3 fold or more) that livestock are consuming nearly 100% of available forage and must be fed substantial amounts of supplemental feed during the grazing season to compensate. The household survey provided further evidence from which we can calculate a rough estimate of total feed demand. Sheep were maintained entirely on barley or other feeds 215 days (7 months) in 2004, which was a year of better than average rainfall. Calculations were based on an average of 1,500 Syrian Lira (28.75 USD) spent on feed per sheep for the year and the cost of 7 Syrian Lira (0.135 USD) required per day to provide a maintenance diet of 1 kg straw and 0.5 kg barley (6.3 mega joules energy). In other words 59% of the feed requirements were provided from purchased feed and only 41% from grazing on range, stubble and crop residues. The household survey found 20% to 36% of the nutritional requirements of the flock were met from rangeland grazing.

Degradation related to past land use and project improvement

The degradation indicators for the 750 sites along transects (Table 4) show that 20% of the sites are high to very highly degraded, 44% medium and 37% none to low. Previous cultivation was the major cause of degradation. Land that was previously cultivated was defined in this study as all land that either farmers said had once been cultivated, or land we found visual field evidence of cultivation. Land below 200 mm precipitation in the *Badia* was banned from cultivation in 1995, 10 years before our survey. On average, 51% of the community rangeland was native range never cultivated. Previously cultivated land was significantly (0.05 paired t-test) more degraded. Degradation was 0.5 points higher on previously cultivated land on a scale of 1-5 for both invader plants and for the erosion indicator of flow patterns. All other degradation indicators were found not different. Most invader plants are of poor forage value. The most abundant plants that are found on land that was once cultivated are *Peganum harmala* (30%), *Poa bulbosa* (20%), *Artemisia herba-alba* (14%), *Anabasis syrica* (12%), and *Adonis dentate* (9%) on an area basis. It appears that these plant species naturally re-vegetated the cultivated areas 10 or more years after cultivation but only *Poa* and *Artemisia* are considered good for grazing. Higher quality forage was found on never cultivated native range where the most abundant plants include *Carex stenophylla* (26%), *Poa bulbosa* (17%), *Anabasis syrica* (15%), *Artemisia herba-alba* (12%), *Hordium glaucum* (9%), *Plantago ovata* (8%), and *Noaea mucronata* (7%). It is unlikely that these previously cultivated lands will ever fully recover to the native vegetative state especially where soil has been eroded. They probably would need to be planted with native or other productive species.

Table 4. Frequency and % of the sites observed at five levels of degradation of the 750 sample sites in the Syrian steppe, spring 2005.

Level of degradation	Frequency	Percentage
None-Very low	30	4.0
Low	245	32.7
Medium	331	44.1
High	136	18.1
Very high	8	1.1
Total	750	100

Range rehabilitation projects reduced bare ground by half, most likely from deferred grazing that would allow annuals to increase. They doubled shrub cover on previously cultivated range but did not increase shrub cover on native range that had never been cultivated.

Conclusion

Previously cultivated land remains degraded 10 years after the ban on cultivation. These areas should receive high priority by restoration projects. Bare ground on the native rangeland was high but most of the range sites surveyed had a sufficient amount of native perennial vegetation to increase in cover if controlled grazing management could be applied. Grazing management at the community level that provides short rests (1-2 months) to at least part of the rangeland each year would allow the existing vegetation to regain vigor and productivity. Restored range would soon revert back to degraded states if grazing is not controlled.

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Investigation of the ecological needs of *Astragalus adscendens* (producer of Gaz) in Lorestan Shoulabad region of Iran

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Abstract

Ecological studies of important range plants are an important for range improvement and development programs. *Astragalus adscendens* is an important range plant that has occupied vast mountainous rangelands in Iran. In this study the ecological requirements of this species were investigated in Shoulabad rangelands in Aligoudarz, Iran. The environmental and edaphic characteristics were recorded by observing 144 plots of 10x10m each in 9 sampling sites representing different range conditions. The results showed that the climatic conditions of rangelands dominated by this species could be classified as semi-arid cold. The highest intensity of *A. adscendens* was found in the elevation range of 2300-2700 m and vegetation cover in the elevation range of 2250-2550 m above mean sea level. The dominant soil type in these elevations was Inceptisol. Slope variation imposed no significant effects on density and vegetation cover of *A. adscendens*.

Introduction

An understanding of the ecological needs of a range species is important for range improvement and development programs. The Iranian flora is very rich and among all the available species, *Astragalus* spp. account for 1/8 of the total flora (Masumi, 1986; Sabety, 1971). *Astragalus adscendens* is an indigenous species in Iranian flora and it is mostly distributed in the rangelands in the mountainous regions (Parsa, 1991). The economic value of this species is high because of its medicinal properties, high protein content, large nectar production for beekeeping , capacity to protect soil because of long growing period and vast vegetation cover, and high biomass production. For this reason, it has attracted major attention of researchers (Ainechi et al., 1976; Lesany, 1975; Niknezhad, 1976; Zargary, 1989; Behda, 1969).

Despite the vast distribution of different ecotypes of *A. adscendens* in mountainous rangelands of the country, there is little information about the ecological characteristics of its habitat (Masumi, 1986; Parsa, 1991). This is in spite of the fact that the economic life of a big proportion of villagers and nomads depends on the use of this plant in the rangelands in their vicinity. The knowledge will help in the improvement and development programs on this species in similar sites in other parts of the country.

Materials and methods

To investigate the ecological requirements of *A. adscendens*, the climatic, edaphic, geologic, and vegetation characteristics of different sites was studied where it was a dominant species. The climatic condition information was obtained from Aligoudarz synoptic weather station and other weather stations in the vicinity. Using a 1/50000 soil map, 13 soil profiles were investigated in the study area and all the major soil characteristics were recorded in the sites with and without *A. adscendens.*

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The vegetation cover as well as topographic characteristics were investigated using 1/50000 map scales. The different vegetation communities were identified within the physiographic borders. The whole range site was divided in to 9 statistical regions where the biological interaction between *A. dscendens* with livestock, humans, fungi, honeybee and other insects was recorded. The sampling plots were 10x10m, located on a transect along the general slope of the sampling site. The sampling procedure was repeated in all four aspects of a mountainous range site.

Results and discussion

According to the climatic condition data, the habitat sites of *A. adscendes* could be classified as semi-arid cold according to Amberjeh categories. These sites receive around 393 mm of annual rainfall and their mean annual temperature is 11.2°C and mean relative humidity 39%.

The dominant soil type in the growing sites of this species was deep Inceptisol. The soil texture was clay loam with high moisture holding capacity. The soil had granular structure. It had high $CaCO_3$, low humus, medium to high nitrogen and medium phosphorus and potassium content. The soil pH was neutral to slightly alkaline. There was no salinity observed in the sites.

The altitude variation significantly affected the vegetation cover and intensity of different *A. adscendens* ecotypes. There was no *A. adscendens* observed at 2200m altitude (Table 1). As the altitude increased beyond this level, the population

Table 1. Percentage cover of *A. adscendens* in relation to elevation and the aspect of plot in sites

Mean of cover average (%)	Cover average (%)	Elevation (m)	Aspect (o)	Code
0.94	0.16	2205	180	A
	0.66	2205	270	
	1.16	2205	90	
	1.8	2205	360	
12.36	1.7	2250	180	B
	10.74	2250	270	
	18.39	2250	90	
	19.61	2250	360	
37.71	4.37	2312	180	C
	35.26	2312	270	
	58.37	2312	90	
	52.48	2312	360	
40.30	2.66	2425	180	D
	41.77	2425	270	
	52.4	2425	90	
	64.39	2425	360	
20.20	1.25	2515	180	E
	20.74	2515	270	
	20.25	2515	90	
	38.52	2515	360	
16.79	1.16	2635	180	F
	17.48	2635	270	
	19.21	2635	90	
	31.33	2635	360	
13.72	0.41	2710	180	G
	-	2710	270	
	-	2710	90	
	-	2710	360	
3.657	0.33	2830	180	H
	4.9	2830	270	
	3.8	2830	90	
	5.6	2830	360	
0	0	2925	180	I
	0	2925	270	
	0	2925	90	
	0	2925	360	

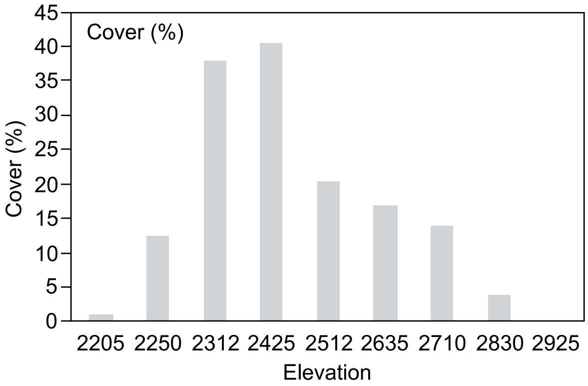

Fig. 1. Relation between of elevation and *A. adsendens* cover.

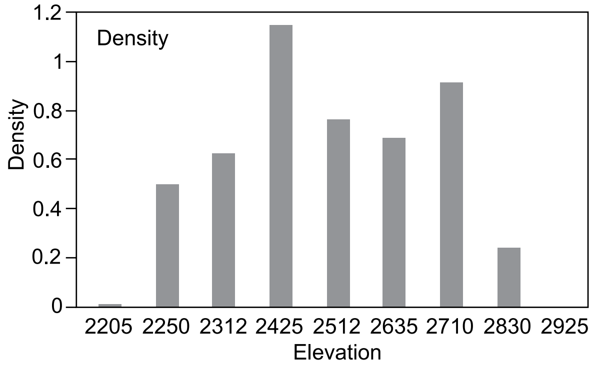

Fig. 2. Relation between of elevation and *A. adsendens* density.

of this species increased. The highest intensity and vegetation cover was seen at 2450m above the mean sea level. Above this elevation, the vegetation cover gradually declined and reached to zero at altitude 2900m (Fig.1). The altitude that had most distribution of this species was between 2250-2550 m (Fig. 2).

The percent vegetation cover and density of *A.* a*dscendens* differed with slope aspect. The population and cover of the species were higher in the northern aspect because of more soil moisture and better soil conditions. However, in the southern aspects the population density significantly decreased due to shallow soils with low organic matter content and less moisture holding capacity. More vegetation cover and plant density was observed in the eastern aspect as compared to the western aspect.

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Adequate number of plots to estimate sedgebrush and wheatgrass forage production in double sampling method

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Abstract

Double sampling method (visual estimation of yield based on actual estimation by clipping forage on a selected number of samples) is an important way to assess forage production of range plants. The accuracy of estimation in this method depends on the number of plots which will be harvested. To assess the forage production of two important range species of sedgebrush (*Artemisia sieberi*) and wheatgrass (*Agropyron trichophorum*), random samples were collected from two range sites dominated by these species. The data were statistically analyzed for precision and expenses. The results showed that in order to have an acceptable estimation of forage production by visual method the regression equation should be developed for sedgebrush by having a sample size of 14% to 35% for actual harvest. For wheatgrass the range of needed sampling was 14% to 30%.

Introduction

One of the main factors in good range management is to have an accurate estimation of available forage (Reich et al., 1993). There are different methods to estimate the available forage in rangelands, each of which has their own limitations. The combination of quantitative and qualitative methods of forage estimation could reduce the limitations and increase the accuracy. Double sampling method is an accurate and less expensive method to estimate the forage production in a rangeland (Arzani, 1989). In this method, besides the visual estimation, some sample plots are clipped and their forage yield determined to develop a simple linear equation (y= a + b x) between the actual yield (y) and the visual estimates (x). The actual range production for the whole area is estimated from the visual estimation values by using this relationship. The key point in this method is to come up with an optimum number of samples to provide needed accuracy along with least expenses. Therefore, it is important to find out the optimum number of samples for each range species to create an equation for the most accurate visual estimation in a given rangeland (Bonham, 1989).

Bonham et al. (1983) believe that at lest 14% sampling should be done to estimate the available forage in short grassland range sites to have the most accurate estimation of available forage. Many of the Iranian rangelands are comprised of bushlands which are over dominated by *Artemisia sieberi*. In rangelands with adequate precipitation grasses create the highest biodiversity in which *Agropyrum trichophorum* has the highest frequency with many genotypes (Moghaddam, 1998). In this study therefore we used both sedgebrush and wheatgrass to determine the magnitude of sampling needed to have a dependable linear equation for accurate estimation of range productivity by visual scores.

Materials and methods

A total of 49 plots of wheatgrass and 34 of sedgebrush were selected for developing the relationship between the visual score and actual forage determined by clipping. Using a linear transect, one square meter quadrates were randomly marked for sampling the vegetation productivity. Time used in sampling served as an indicator of the expenses in this study and the available forage biomass for both species was evaluated both visually and by clipping method. The time consumption for both methods and species was recorded. Data were statistically analyzed and regression analysis done using SPSS statistical package.

Based on the minimum plot number needed to create a linear regression equation, the optimum plot number was determined by using the accuracy-expenses graph. The expense estimation for sampling for each species was achieved by the following equation: $C=c_n+c'_{n'}$; were C = total expenses; c_n= expenses in direct method; and $c'_{n'}$ = expenses in indirect method (visual method).

The accuracy of sampling was tested by using the standard method described elsewhere (Clason and Southward, 1992; Atchpole and Catchpole, 1991). The accuracy and expenses were plotted against the number of samples used for determining the prediction equation. The best choice would be where the distance between accuracy curve and the expense curve would be highest as that would give a combination of the highest accuracy and least expenses.

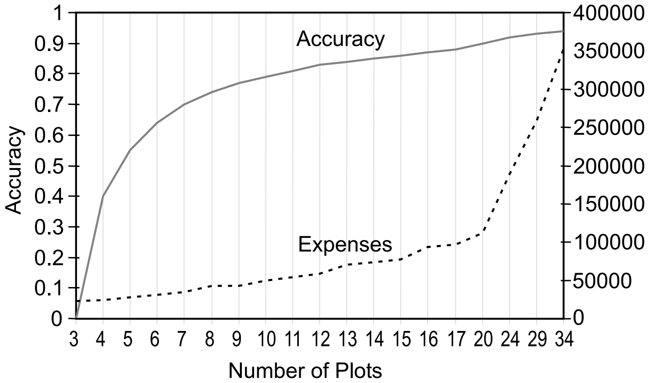

Fig. 1. Expenses and accuracy in estimation of productivity of sedge brush as related to the number of plots used for double sampling.

Results

The minimum number of double plot samples needed to get reliable regression estimation for forage production for sedgebrush was five. The accuracy of sampling increased with increase in the number of plots sampled for direct yield estimate (Fig. 1.).

The accuracy curve showed a sharp rise when the number of clipped plots increased from 3 to 5 out of a total of 34 plots (Fig. 1, Table 1). The rate of increase became moderate when the number increased further to 9. Thereafter, the increase in the accuracy became slow as the number of plots sampled increased from 9 to 24. On the other hand, the curve for expenses of sampling showed a moderate rise when the number of clipped plots increased from 3 to 12. When the number of clipped plots increased from 12 to 20 the slope of expense curve showed a moderate rise and it increased sharply when the clipped plots increased from 20 to 34 (Fig. 1, Table 1).

The range of optimum proportion of sampling could be identified by relating the accuracy and cost curves. As stated before, the number of plots that gives highest distance between the accuracy and cost curves corresponds to the optimum number. In the sedgebrush community, out of a total of 34 plots, the minimum and maximum number of double plots needed to create an acceptable equation for best estimation of forage production was 5 and 12, respectively (Fig. 1). This amounted to harvesting 14% to 35% of the total area. Testing the significance of difference in the regression coefficients in the regression equation for 14 % sampling (5 out of 34 plots) and that for

Table 1. The number of plots considered optimum for harvesting in the paired sampling of range productivity, based on cost and accuracy considerations, out of a total of 34 plots for sedgebrush and 49 plots of wheatgrass.

Particulars	Sedge brush	Wheat grass
Total number of plots	34	49
Plots needed to be sampled for optimum results	5 to12	7 to15
Slope of the accuracy vs. plot number curve:		
Sharply increasing when plots increased from	3 to 5	3 to 6
Moderately increasing when plots increased from	5 to 9	6 to12
Slowly increasing when plots increased from	9 to 34	12 to 49
Slope of cost vs. plot number curve:		
Slowly increasing when plots increased from	3 to 12	3 to 16
Moderately increasing when plots increased from	12 to 20	16 to 30
Sharply increasing when plots increased from	20 to 34	30 to 49

35% sampling (12 out of 34 plots) revealed that there were no significant differences between them. Hence, on the basis of the expenses, it is clear that 14% sampling would be optimum for accurate measurement of productivity of sedge bush by visual method.

Similar results (curves not shown but described in Table 1) were obtained for wheatgrass in which case the number of samples required to be clipped varied from 7 to 15 out of a total of 49 plots, or harvesting 14 % to 30% of the total area (Table 1).

Discussion

The expenses and accuracy are the two main factors to be considered when one uses a double sampling method. The accuracy is dependent on many different factors such as plant species, clipping instrument, proportion of the total area sampled, and so on. Double sampling method has to make a compromise between accuracy and expenses. Although the accuracy will be highest if estimation would be done by harvesting all the area but the cost would be prohibitive. On the other hand, in the system entirely depending on visual score the costs would be less but so will be the accuracy.

A positive relation between accuracy and the proportion of area sampled has permitted the determination of the least number of samples that could be considered acceptable for each plant species in this experiment. This is in agreement with the results of Arzani (1994). The accuracy of estimation will significantly increase as the number of sampling plots increase; however, after the number of sampling plots would pass an optimum level, the accuracy will not follow the same rate of increase with further increase in the plots sampled (Arzani and King, 1994). Gholineghad (1997) showed that the optimum amount of clipped area in shrublands site was 20% to 25% and for grassland site was 11% to 18%. The relation between harvest and visual estimation could differ for different sites, years and people (Bonham et al., 1983 and Reich et al., 1993). Most of the researchers believe that sampling of 20% area will provide with an acceptable accuracy in double sampling method (Bigdeli, 1997; Mesdaghi, 1993; Arzani and King, 1995). In our experiment, the optimum sample size to be clipped for wheatgrass ranged from14% to 30% while for sedgebrush it ranged from 14% to 35% of total area. Since there is no significant difference between the slopes of regression line of the upper and lower limits of suggested levels of sampling, it is concluded that considering the sampling expenses the lower percentage of the suggested sampling range could be used to get an accurate estimation with least expenses for each plant species investigated in this research.

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Theme: Forage and Livestock Production

Productivity of vetches under alpine grassland conditions in China

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Abstract

Improved lines each of common vetch (*Vicia sativa)*, woolly-pod vetch (*V. villosa* ssp. *dasycarpa*) and narbon vetch (*V. narbonensis*) obtained from the International Center for Agricultural Research in the Dry Areas (ICARDA) were evaluated for seed and forage production at Xaihe in the alpine grassland of China. Annual mean rainfall and temperature were 444 mm and 2.6°C, respectively. Differences in productivity were found among the 3 vetch species and among the lines within each species. Nine common vetch and 4 narbon vetch lines produced seeds. Common vetch lines nos. 2505, 2556, 2560 and 2566 and narbon vetch line no. 2561 were identified as having the necessary potential for seed and forage production in China's alpine grasslands.

Introduction

Alpine grasslands account for more than 30% of the total grassland area in China and are the major source of feed for yak and Tibetan sheep kept by millions of poor farmers in the region. They mainly occur on the Qinghai-Tibet Plateau at more than 2500 m above sea level, where annual temperature averages less than 5°C. The productivity of the alpine grasslands has declined recently due to over-grazing (Ren et al., 2000). Nan (2005) recommended integrating grassland grazing with the use of sown pastures and forage legumes to provide hay for winter and early-spring feeding as one way of reducing the grazing pressure and improving livestock productivity in the region. However, due to low temperatures and short growing periods in the alpine grassland areas, perennial forage legumes cannot survive, and annual legumes cannot produce sufficient seeds when planted there. Therefore, studies have been conducted in an attempt to introduce or develop perennial forage legume cultivars that are adapted to alpine conditions. These included studies on germplasm evaluation (Yan, 1990), the breeding of cold tolerant cultivars through hybridization of existing genetic resources (Cao et al., 1991), and studies on the development of cultural practices which would protect sown forage legume pastures from winter and spring damage (Cui et al., 1997; Sun and Gui, 2001). However, these efforts have met with little or no success.

Common vetch (*Vicia sativa*) is an important annual forage legume which is grown in China (Wang and Ren, 1989) and other parts of the world (Abd El-Moneim and Ryan, 2004). In China, smallholder crop-livestock farmers on the Loess Plateau sow common vetch for livestock feed and soil conservation purposes (Li, 1984; Wu, 1993), while herders in the alpine grassland areas grow vetch in association with oats (*Avena sativa*) for hay (Ma and Han, 2001). Most of the locally available vetch cultivars cannot produce seed under these conditions. However, the *Vicia* species found elsewhere in the world exhibit considerable diversity, and this could be explored to find seed-producing material suitable for China. The West Asia and North Africa (WANA) region, for example, is the center of origin and primary diversity for *Vicia* species (Robertson et al., 1996) and many species can be found in the world's largest collection of forage legumes held by the International Centre for Agricultural Research in the Dry Areas (ICARDA). ICARDA also runs an active *Vicia* improvement program (Abd El-Moneim, 1993; Abd El-Moneim and Ryan, 2004). Promising lines of common vetch, narbon vetch (*V. narbonensis*) and woolly-pod vetch (*V. villosa* ssp. *dasycarpa*), selected for cold and drought tolerance, were therefore sent to China from ICARDA's collection and for evaluation under the alpine grassland conditions found in the country. This paper reports the results of a study that assessed the seed and forage yields of these lines in China.

Materials and methods

Study site

The experiment was conducted at Xaihe (35°12’N, 102°31’E; 3000 m above sea level) in the alpine grassland area of Gansu Province, China during the period 1998-1999. The average rainfall is about 444 mm and the mean daily temperature is 2.6°C. The soil type is a Chernozem with organic carbon 42 g/kg, total nitrogen 23.4 g/kg and available phosphorus 17.5 mg/kg.

Treatments and design

Nine lines of common vetch (accession nos. 2486, 2505, 2556, 2558, 2560, 2566, 2604, 2616 and 2628) and ten each of narbon vetch nos. 2378, 2381, 2386, 2388, 2391, 2461, 2465, 2469, 2470 and 2561) and woolly-pod vetch nos. 2432, 2438, 2439, 2442, 2445, 2450, 2451, 2452, 2457 and 2562) were evaluated in 1998 and 1999 in Xiahe, Tibetan Autonomous County, using a randomized complete block design with 4 replicates; Plots were 2x2 m, and 1-m wide path was left between replicates, plots within a replicate were separated by 0.5 m wide path. Seeds were sown by hand in rows 0.25 m apart at 75 kg/ha for common vetch and 60 kg/ha for woolly-pod vetch and narbon vetch. Sowing dates varied between 22 April and 15 May each year, when the air temperature was constantly higher than 5°C at each site. Plots were hand-weeded and no fertilizer was applied. Whole plots were harvested between 15 and 26 September each year. At harvest, all the mature pods were hand-picked, air-dried, threshed, and the weight of seeds was subsequently recorded. The remaining herbage including the immature pods was cut to ground level with a sickle and weighed to estimate forage yield. Sub-samples (500 g) were oven-dried at 90°C for 24 hours to allow an estimation of dry matter (DM) to be made.

Statistical analysis

Data were analyzed using the General Linear Models (GLM) procedures (SAS, 1987). Seed and forage yield data for common vetch were pooled over both years because there was no significant year x line interaction.

Results

Common vetch

Forage and seed yield varied significantly ($P<0.05$) among lines, with nos. 2556, 2560, 2566 and no. 2604 yielding more than 6t/ha DM (Fig. 1). Line no. 2505 and no. 2628 produced more than 1 t/ha of seed over the 2-year study period.

Narbon vetch

Forage DM yield of the narbon vetch lines varied significantly ($P<0.05$), from 2.89 t/ha in line no. 2386 to 5.15 t/ha in line 2561 (Fig. 2). Only 4 of the 10 lines produced seeds, and their seed yield ranged from 0.32 t/ha in line no. 2465 to 0.82 t/ha in line no. 2561.

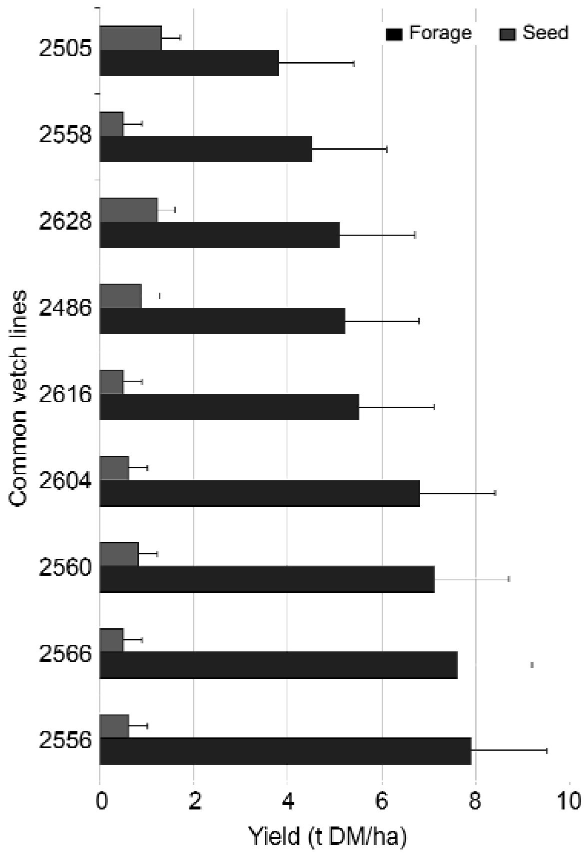

Fig. 1. Forage and seed yields of common vetch (*Vicia sativa*) lines at Xiahe County, Gansu Province, China.

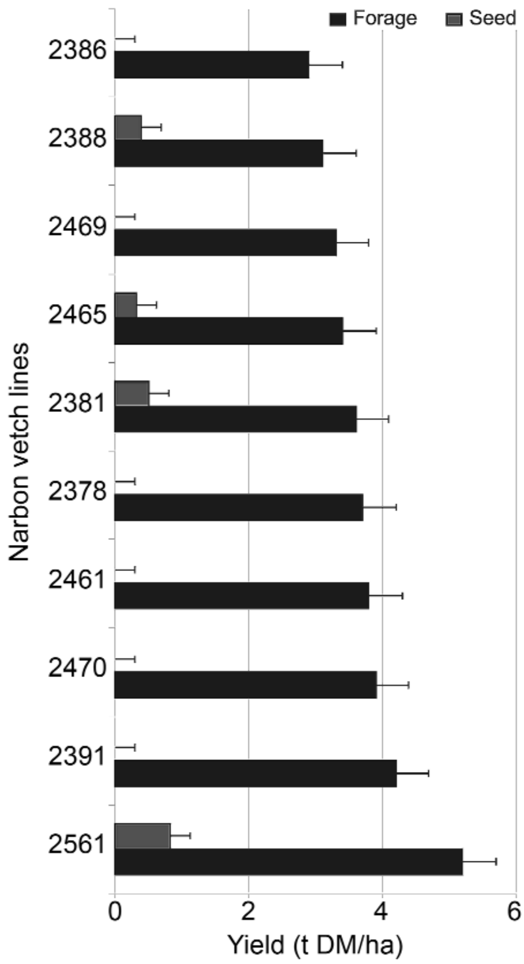

Fig. 2. Forage and seed yields of narbon vetch (*Vicia narbonensis*) lines at Xiahe County, Gansu Province, China (1998 and 1999).

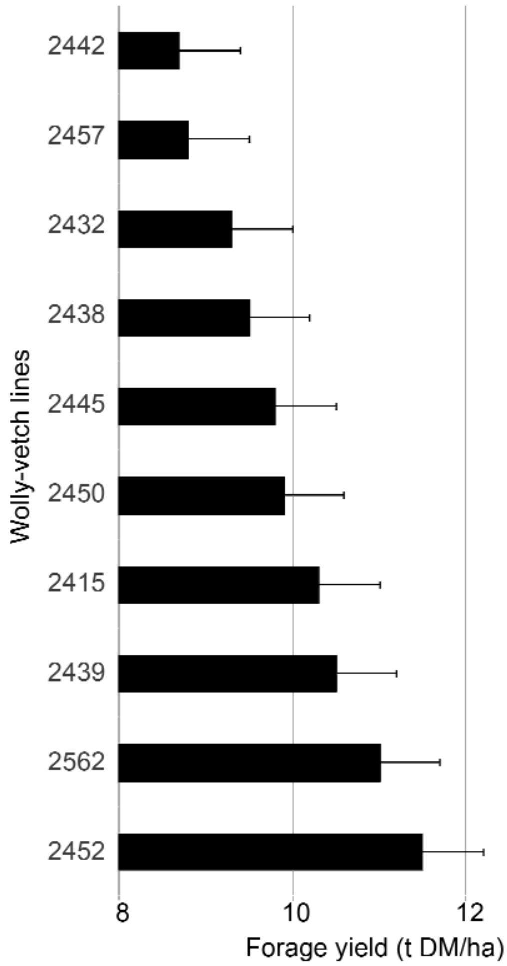

Fig. 3. Forage and seed yields of woolly-pod vetch (*Vicia villosa* ssp. *dasycarpa*) lines at Xiahe County, Gansu Province, China (1998).

Woolly-pod vetch

All lines produced more than 8 t/ha DM in 1998 with nos. 2439, 2451, 2452 and 2562 producing more than 10 t/ha DM (Fig. 3). None of the lines produced seed in 1998, and because seed production was a major selection criterion, the trial on woolly-pod vetch was terminated after the first year.

Discussion

This is the first report of a systematic evaluation of *Vicia* species lines grown under alpine grassland conditions in China. In agreement with other studies (Abd El-Moneim et al., 1990; ICARDA, 2000), forage and seed yield varied significantly between the lines of narbon vetch and woolly-pod vetch. Of the 3 species evaluated, woolly-pod vetch produced more amount of forage than common vetch and narbon vetch. Similar results have been reported for comparative trials of woolly-pod vetch and common vetch under rain-fed conditions on the Loess Plateau (Wu, 1993) and under irrigation on the Northern Plain (Zhang et al., 1992) in China, and also for the 3 species in WANA (Abd El-Moneim, 1992). Previous research in Xiahe and in other regions with similar environmental conditions concluded that common vetch was not well adapted to alpine grasslands (Yan, 1990). By contrast, this study showed common vetch to be the most promising species because all of the nine lines tested produced seeds and a substantial amount of forage.

The overall objective of ICARDA’s vetch breeding program is to develop and disseminate genotypes adapted to areas with annual rainfall ranging from 233 - 504 mm and absolute minimum temperature from 5.8 to 9.9°C (Abd El-Moneim and Ryan, 2004). The mean annual rainfall at the experimental sites used in the current study (444 mm) was similar to that in ICARDA's target regions in which the lines were developed. However, the mean temperature at the sites (2.6°C) was far colder than the target range. The seed and forage yields of the various vetch lines in our study show that some lines selected by ICARDA are obviously adapted to regions with relatively lower temperatures than those found in WANA.

With high seedling vigor, rapid winter growth and high yields of seed and straw (Abd El-Moneim and Cocks, 1988; ICARDA, 2000), narbon vetch is probably one of the most attractive annual forage legumes for the dry areas. To our knowledge, this is the first report from China on the evaluation of narbon vetch as a forage legume. Four (accession nos. 2388, 2465, 2381 and 2561) of the 10 lines studied flowered, suggesting that it would be possible to select genotypes adapted to alpine grassland conditions. Among the lines studied, line 2561 appeared to have great potential in the crop-livestock production system in China.

The failure of woolly-pod vetch lines to produce seeds supports the conclusion of Abd El-Moneim (1992) that woolly-pod vetch is poorly adapted to alpine grassland conditions. However, it may fit into Chinese farming systems in areas in which the growth period is longer and the mean temperature is higher than in Xiahe.

This study has identified lines of common vetch (nos. 2505, 2556, 2560 and 2566) and narbon vetch (no. 2561) that have potential for seed and forage production in the alpine grassland of China. Further studies are warranted in order to integrate the promising lines into the smallholder crop-livestock farming systems found there.

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Forage potential of non-leguminous and leguminous fodder shrubs in the dry areas of Central and West Asia and North Africa

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Abstract

Integration of fodder shrubs into the production systems in the dry areas of Central and West Asia and North Africa (CWANA) could reduce rangeland degradation and mitigate desertification, but information is limited on the yield and quality of native and introduced fodder shrubs in the region. The objective of this study was to quantify the variations in yield (fodder, wood, and seed) and fodder quality – crude protein (CP), acid detergent lignin (ADL) and fiber (ADF), neutral detergent fiber (NDF), *in vitro* organic matter digestibility (IVOMD) and 24-hour *in vitro* gas production (GAS-24h) of 26 non-leguminous and eight leguminous fodder shrubs in order to identify promising species for agroforestry in dry areas. Fodder, wood and seed yields and fodder quality varied (P < 0.05) among the non-legume and legume fodder shrubs. For the non-legume shrubs, multi-variate analysis based on both agronomic and fodder quality attributes showed *Artemisia halimus-halimus* and *A. herba-alba* from Spain, *A. canescens, A. ploycarpa* and *A. lentiformis* from USA, *A. halimus* and *A. herba-alba* from Syria and *A. nummularia* from Australia and South Africa to have greater potential than *Haloxylon subaphyllus, Kochea prostrate, Ceratoides ewersmanniana, Eurhotia ewersmanniana, Haloxylon aphyllum* and *Salsola orientalis* from Uzbekistan, *Atriplex canescens* and *Salsola vermiculata* from Jordan, *Atriplex glauca* and *A. undulate* from Australia, *Atriplex cordobensis* from Bolivia, and *Salsola rigida* from Kazakhstan. *Colutea istria* from Jordan and Syria and *Medicago arborea* from Spain were the most promising leguminous shrubs. The promising fodder shrubs could be integrated into the smallholder crop/rangeland-livestock farming systems in the dry areas of CWANA and similar environs in other regions as feeding/browsing reserves, living fences and hedges, wind-breaks, fodder banks and improved fallows to provide fodder, fuel-wood, shade, and medicine. They could also be used to stabilize moving sand-dunes and to conserve the soil in order to reduce rangeland degradation and mitigate desertification.

Introduction

Rangelands in the dry areas of Central and West Asia and North Africa (CWANA) contribute to livelihoods of the poor population by providing feed, fuel-wood and herbal plants (Gintzburger et al., 2000). The contribution of rangelands to improved livelihoods is declining drastically due to a combination of various factors, including degradation resulting from overgrazing and desertification due to drought and climate change. The integration of native and introduced fodder shrubs into the smallholder crop/rangeland-livestock production systems could reduce pressure on the rangelands and mitigate desertification (Le Houérou, 2000). However, information is scanty on environmental adaptation, biomass production and fodder yield and quality of fodder shrubs in the region (Le Houérou, 2000; Ammar and Gonzalez, 2005, Mukimov et al., 2005). Also, intra and inter-specific variations in fodder yield and quality (Larbi et al., 1996;1997; 1998 a, b), essential for matching provenances to agroforestry technologies, tree improvement and selection programs, and prioritization of research on fodder yield and quality have not been widely reported (Le Houérou, 1994; 2000).

In 1996, participants of an international workshop on 'Fodder shrub development in arid and semi-arid zones' recommended that the International

Center for Agricultural Research in the Dry Areas (ICARDA) should lead research-for-development on fodder shrubs in the dry areas of CWANA (Gintzburger et al., 2000). Accordingly, ICARDA and national, regional and international partners are evaluating several native and introduced fodder shrubs in different agro-ecological zones to identify promising species for integration into the production systems in the dry areas to improve land productivity and ecosystems health. This paper reports preliminary studies on variations in fodder, wood and seed yields, and fodder quality of 26 non-leguminous and eight leguminous fodder shrubs grown in north-west Syria.

Materials and methods

Study site

The experiment was conducted at ICARDA's research station at Tel Hadya (35° 55´ N, 36° 55´ E, altitude 362 m), south of Aleppo in north-west Syria. Average annual rainfall is about 342 mm, and the growing period is 5 – 6 months long. The climate is Mediterranean with rainfall from October till May. The soil at the experimental site is a reddish-brown clay (Vertic Luvislols) with a pH (H_20) of 8.3.

Sampling for fodder, wood and seed yields

Twenty-six non-legume (Table 1) and six legume (Table 2) fodder shrubs were used. They were planted in 2000 from 8-week-old seedlings at a density of 1000 seedlings per hectare. A unit plot consisted of two rows of each species, 25 m long, and spaced 2 m between rows and 1 m within rows. Ten representative plants of each species were tagged in mid-March 2004. Five of the tagged plants were cut back at the end of March 2004, and the coppice regrowths were harvested at the end of December 2004 and April 2005 to estimate fodder and wood yields. At each harvest, the plants were pruned to 50 cm above ground, weighed fresh, and separated into fodder (leaves plus stems less than 10 mm in diameter) and wood fractions. Sub-samples of the fodder and wood were oven-dried at 60oC for 48 h to determine dry matter (DM) content.

Seed yield was estimated from the five plants that were not cut-back. Matured seeds were hand-harvested periodically, air-dried, and weighed. Seed yield from each harvest was bulked at the end of the study period to estimate total seed yield.

Chemical analysis

Oven-dried fodder samples from the 2005 harvest were ground through a 1-mm screen for determination of total nitrogen (N) by the Kjeldahl method (AOAC, 1990). Crude protein (CP) was calculated as N x 6.25. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were analyzed according to Van Soest et al. (1991).

In vitro organic matter digestibility (IVOMD) was determined by a modified two-stage procedure (Moore and Mott, 1974). Procedures described by

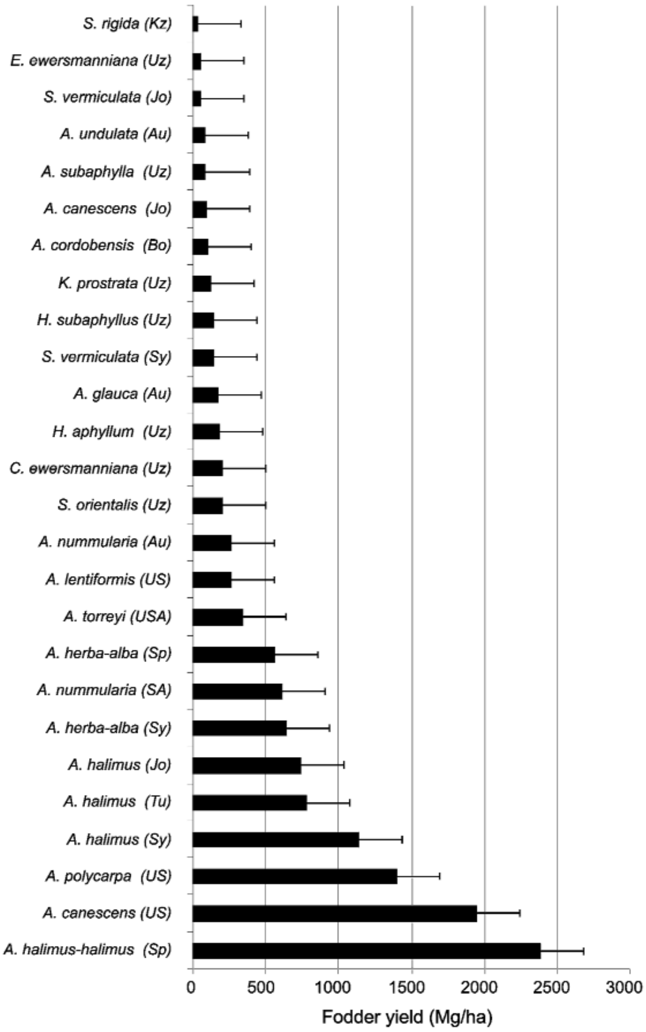

Fig. 1a. Variations in fodder yield among 26 dryland non-leguminous fodder shrubs, Tel Hadya, north-west Syria. Letters in brackets indicate country of origin.

Nsahlai et al. (1994) were used to estimate *in vitro* gas production after incubation of samples for 24-hours (GAS-24h) with rumen liquor from rumen-fistulated Awassi rams.

Statistical analysis

Fodder and wood yield data were analyzed as a split-plot experiment with harvests as main-plots and shrub species as sub-plots, whilst seed yield data were analyzed in a randomized block design using plants as replications (SAS 1990).

Univariate correlation and regression analyses were used to establish relationships between the determinants of quality. Average values for fodder, wood and seed yields, and concentrations of CP, ADL, ADF, NDF, IVOMD and GAS-24h for each species were subjected to cluster analysis, using the average linkage method for the purpose of grouping the species into clusters with potential for development of integrated crop/rangeland-livestock agroforestry technologies. When significance is not given in the text, it implies to minimum *P < 0.05*.

Results

Fodder, wood and seed yields

Non-leguminous fodder shrubs:
Fodder, wood and seed yields varied significantly among the non-leguminous shrubs. Fodder yield was lowest in *Salsola rigida (*Syria) and highest in *Artemisia halimus-halimus* (Spain), with 80% of

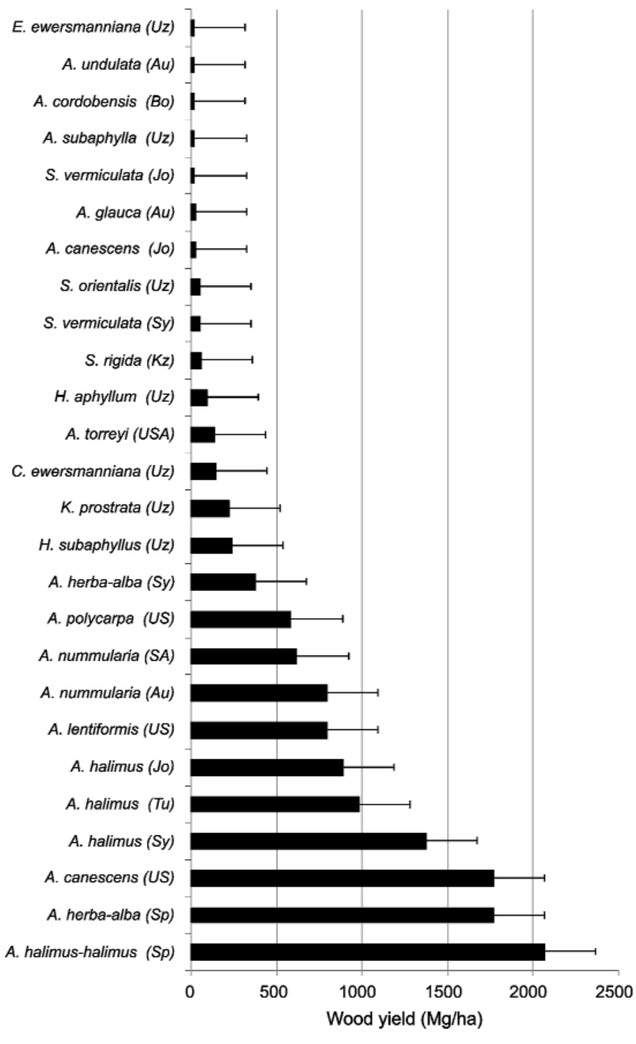

Fig. 1b. Variations in wood yield among 26 dryland non-leguminous fodder shrubs, Tel Hadya, north-west Syria. Letters in brackets indicate country of origin.

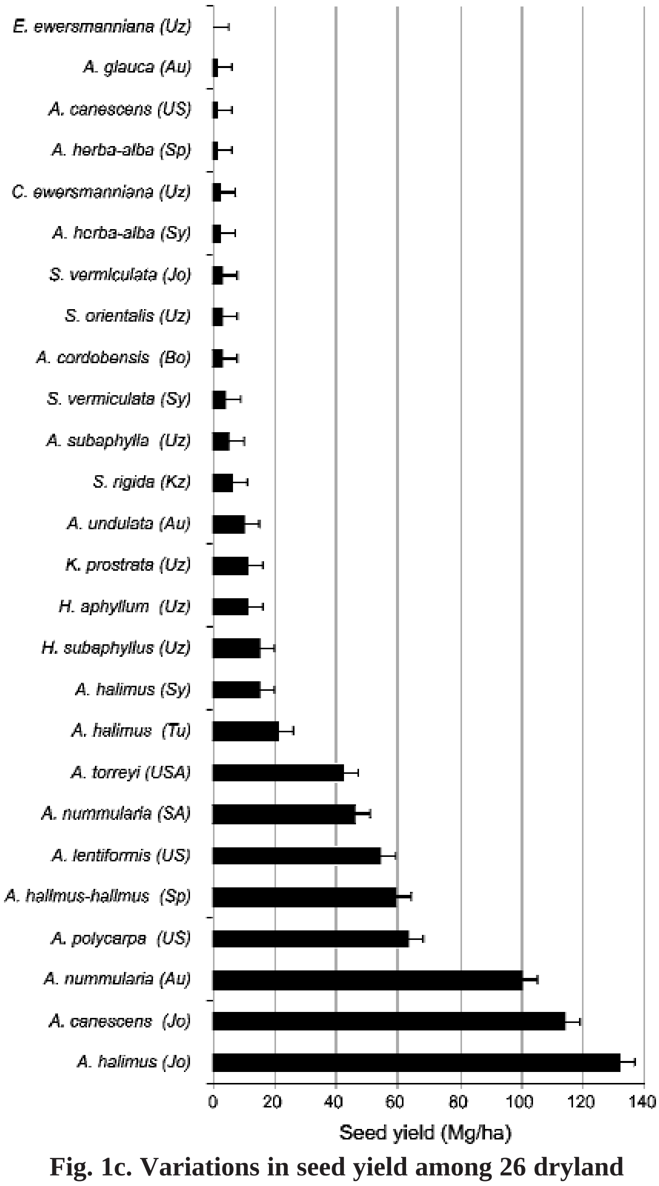

Fig. 1c. Variations in seed yield among 26 dryland non-leguminous fodder shrubs, Tel Hadya, north-west Syria. Letters in brackets indicate country of origin.

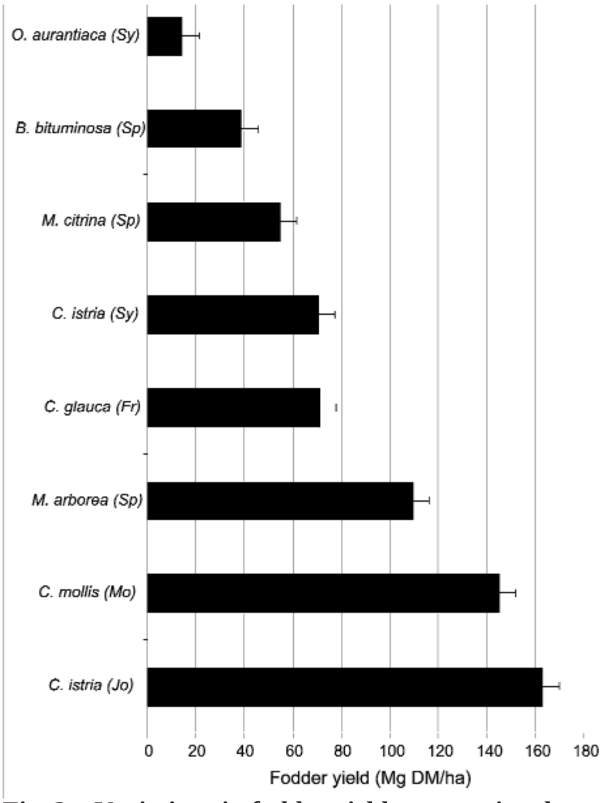

Fig. 2a. Variations in fodder yield among nine dryland leguminous fodder shrubs, Tel Hadya, north-west Syria. Letters in brackets indicate country of origin.

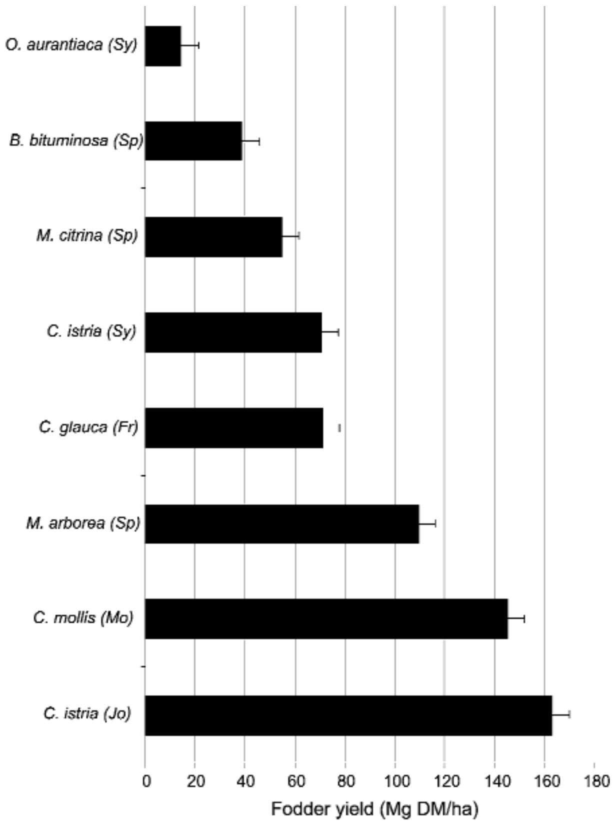

Fig. 2b. Variations in wood yield among nine dryland leguminous fodder shrubs, Tel Hadya, north-west Syria. Letters in brackets indicate country of origin.

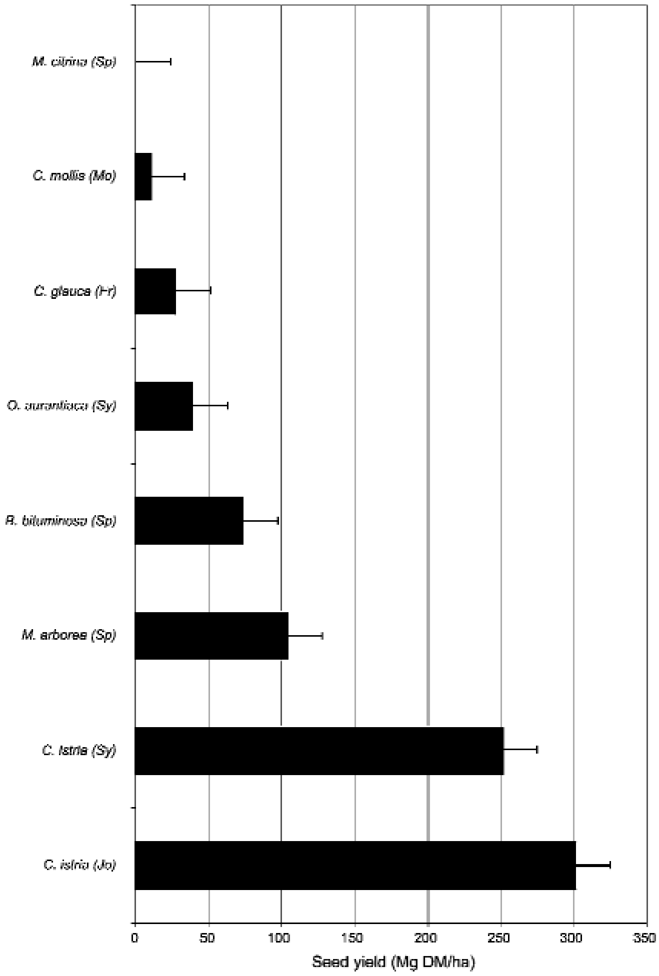

Fig. 2c. Variations in seed yield among nine dryland leguminous fodder shrubs, Tel Hadya, north-west Syria. Letters in brackets indicate country of origin.

the species producing less than 1000 Mg/ha fodder (Fig. 1a). Wood yield was generally below 1000 Mg/ha with the exception of four species – *A. halimus-halimus* and *A. herba-alba* (Spain), *A. canescens* (Jordan) and *A. halimus* (Syria) (Fig. 1 b). Seed yield was generally less than 60 Mg/ha, with the exception of A. *halimus* and *A. canescens* from Jordan, and *A. nummularia* from Australia (Fig. 1 c).

Leguminous fodder shrubs
Yields of fodder, wood and seed varied significantly among the leguminous shrubs. Fodder yield of *Colueta istria* (Jordan), *Chamaecytisus mollis* (Morocco) and *Medicago arborea* (Spain) was significantly higher than the other shrubs (Fig. 2 a). Wood (Fig. 2 b) and seed (Fig. 2 c) yields of *C. istria* from Syria and Jordan were significantly higher than the rest of the species.

Determinants of fodder quality

Non-leguminous shrubs:

The concentrations of CP, ADL, ADF, NDF, IVOMD and GAS-24h varied significantly among the non-legume fodder shrubs (Table 1). The CP concentration was lowest in *Kochia prostrata* and highest in *Atriplex glauca*, with six species recording concentrations lower than 100 g kg^{-1}. *Haloxylon aphyllum* had the lowest ADL concentration, and *Atriplex undulata* had the highest. The lowest ADF and NDF concentrations were recorded in *S. rigida*. The highest concentrations of ADF and NDF were recorded in *Artemisia herba-alba* and *C. ewersmanniana*, respectively. Six browses recorded ADF concentrations greater than 200 g kg^{-1}, whilst NDF concentrations greater than 300 g kg^{-1} were recorded in nine shrubs.

The IVOMD was highest in *K. prostrata* and lowest in *Aellenia subaphylla*. Eleven shrubs had IVOMD concentrations greater than 500 g kg^{-1}. The GAS-24h was lowest in *Halothamnus subaphyllus* and highest in *Atriplex lentiformis*.

Leguminous shrubs:

Chemical composition, IVOMD and GAS-24h varied significantly among the leguminous shrubs. The CP concentration was lowest in *Coronilla glauca* and highest in *Chamaecytisus mollis* (Table 2). The lowest ADL, ADF and NDF concentrations were recorded in *Colutea istria* (Jordan), and the highest in *Chamaecytisus mollis*, *Medicago arborea* and *Bituminaria bituminonosa* respectively. *Coronilla glauca* had the lowest IVOMD, and *Colutea istria* (Jordan) the highest. The GAS-24h was lowest in *Colutea istria* (Syria) and highest in *Medicago citrina*.

Table 1. Variations in concentrations (g kg^{-1} DM) of crude protein (CP), acid detergent lignin (ADL), acid detergent fiber (ADF), neutral detergent fiber (NDF), *in vitro* digestible organic matter (IVOMD) and *in vitro* gas volume (ml 200 mg^{-1} DM) after 24-hours (GAS-24h) of incubation with rumen liquor in fodder of 26 non-leguminous dryland fodder shrubs

Species/ecotypes	Origin	CP	ADL	ADF	NDF	IVOMD	GAS-24h
Aellenia subaphylla	Uzbekistan	122	25	197	329	391	29.17
Artemisia herba-alba	Syria	111	81	267	317	479	30.17
Artemisia herba-alba	Spain	94	74	215	269	518	34.83
Atriplex canescens	USA	100	48	135	235	491	31.67
Atriplex canescens	Jordan	133	41	122	261	524	36.17
Atriplex cordobensis	Bolivia	73	79	158	286	417	32.67
Atriplex glauca	Australia	195	51	149	238	486	34.50
Atriplex halimus-halimus	Spain	158	79	157	263	514	37.83
Atriplex halimus	Syria	151	66	137	245	512	36.67
Atriplex halimus	Jordan	121	74	150	254	509	34.50
Atriplex halimus	Tunisia	151	79	162	247	430	31.00
Atriplex lentiformis	USA	106	49	120	270	512	38.67
Atriplex nummularia	Australia	181	53	134	296	506	37.17
Atriplex nummularia	South Africa	117	67	140	236	469	34.67
Atriplex polycarpa	USA	105	36	123	223	450	30.67
Atriplex torreyi	USA	109	92	144	281	524	37.00
Atriplex undulate	Australia	123	109	204	321	463	34.17
Ceratoides ewersmanniana	Uzbekistan	143	45	245	468	438	34.67
Eurhotia ewersmanniana	Uzbekistan	154	29	232	424	463	33.17
Halothamnus subaphyllus	Uzbekistan	128	29	185	300	457	25.00
Haloxylon aphyllum	Uzbekistan	81	24	132	250	435	29.50
Kochia prostrate	Uzbekistan	69	37	224	371	526	39.33
Salsola orientalis	Uzbekistan	70	33	146	268	445	30.17
Salsola rigida	Kazakhstan	130	24	102	214	507	33.83
Salsola vermiculata	Syria	84	45	187	349	517	35.83
Salsola vermiculata	Jordan	115	42	176	328	415	29.50
Mean		**116**	**58**	**172**	**295**	**474**	33.62
S.E.		5.5	5.1	7.4	8.1	6.6	1.9
Maximum		195	109	267	468	526	38.67
Minimum		69	24	102	214	391	25.00

Relationships between determinants of fodder quality:

Positive and significant correlations were recorded between ADF and NDF (r = 0.81) and IVOMD and GAS-24h (r = 0.73) for the non-leguminous shrubs. Regression equations for predicting the concentrations of NDF from ADF and of IVOMD from GAS-24h were: $YNDF = 118.27 + 1.02ADF$, $r^2 = 0.65$, *and* $YIVOMD = 170.31 + 9.02GAS\text{-}24h$, $r^2 = 0.53$ respectively.

Similarly, positive and significant correlations existed between the concentrations of ADL and ADF (r = 0.77), ADL and NDF (r = 0. 80), ADF and NDF (r = 0.98); and IVOMD and GAS-24h (r = 0.75) for the leguminous shrubs. Regression equations for predicting the concentrations of ADF and NDF from ADL were: $YADF = 50.07 + 2.64ADL$, $r^2 = 0.59$, $YNDF = 60.49 + 3.59ADL$, $r^2 = 0.64$. Similarly, IVOMD concentration in the fodder could be predicted from the gas volume using the regression equation: $YIVOMD = 273.88 + 8.11\ GAS\text{-}24h$, $r^2 = 0.57$.

Classification of shrubs:

Table 3 shows clustering of the non-legume shrubs into high, medium, and low potential groups based on agronomic and fodder quality attributes. The high potential group was characterized by relatively high fodder and wood yields, high IVOMD and low ADF and NDF concentrations, and intermediate seed yield and CP concentration. The medium group had high seed and intermediate fodder and wood yields; and intermediate concentrations of ADL, NDF and IVOMD. The low potential group, dominated by browses from Uzbekistan, was characterized by relatively low yields (fodder, wood and seed), high ADF and NDF, and low IVOMD concentrations.

Discussion

Significant variations in fodder, wood, and seed yields, and concentrations in CP, ADL, ADF, NDF, IVOMD and GAS-24h of 26 non-leguminous and eight leguminous fodder shrubs in the dry areas of north-west Syria. The non-leguminous fodder shrubs could be grouped into high, medium and low potential groups based on agronomic and fodder quality attributes. *Atriplex halimus-halimus* and *A. herba-alba* from Spain, *A. canescens, A. ploycarpa* and *A. lentiformis* from USA, *A. halimus* and *A. herba-alba* from Syria and *A. nummularia* from Australia and South Africa were found to have high to medium potential than *H. subaphyllus, K. prostrate, C. ewersmanniana, E. ewersmanniana, H. aphyllum* and *S. orientalis* from Uzbekistan, *A. canescens* and *S. vermiculata* from Jordan, *A. glauca* and *A. undulate* from Australia, *A. cordobensis* from Bolivia, and *S. rigida* from Kazakhstan. For the leguminous fodder shrubs, *C. istria* from Jordan and Syria and *M. arborea* from Spain were the most promising. The promising non-legume and legume fodder shrubs could be integrated into the small-holder crop/rangeland-livestock farming systems in the dry areas of CWANA and similar environs as feeding/browsing reserves, living fences and

Table 2. Variations in concentrations (g kg^{-1} DM) of crude protein (CP), acid detergent lignin (ADL), acid detergent fiber (ADF), neutral detergent fiber (NDF), *in vitro* digestible organic matter (IVOMD) and *in vitro* gas volume (ml 200 mg^{-1} DM) after 24-hours (GAS-24h) of incubation with rumen liquor in fodder of eight leguminous dry-land fodder shrubs

Species/ecotypes	Origin	CP	ADL	ADF	NDF	IVOMD	GAS-24h
Bituminaria bituminosa	Spain	128	33	162	217	689	36.00
Chamaecytisus mollis	Morocco	146	42	151	207	646	34.67
Colutea istria	Syria	130	21	107	131	716	27.33
Colutea istria	Jordan	127	14	94	122	722	29.66
Coronilla glauca	France	85	33	109	149	540	28.66
Medicago citrina	Spain	98	34	159	206	666	41.16
Medicogo arborea	Spain	93	39	170	207	633	35.83
Onobrychis aurantiaca	Syria	100	31	112	140	688	37.83
Mean		**115**	**30**	**130**	**169**	**667**	**34.27**
S.E		4.6	3.1	5.5	6.9	7.6	2.311
Maximum		146	42	170	217	722	41.83
Minimum		85	14	94	122	540	27.33

Table 3. Classification of 26 non-leguminous fodder shrubs into high, medium and low potential groups for development of crop/range-livestock agroforestry technologies based on fodder, wood and seed yields and concentrations of crude protein (CP), acid detergent lignin (ADL), acid detergent fiber (ADF), neutral detergent fiber (NDF), *in vitro* digestible organic matter (IVOMD)

	Group					
Item	**High**		**Medium**		**Low**	
	A. halimus-halimus	Spain	*A. halimus*	Tunisia	*A. torreyi*	USA
	A. canescens	USA	*A. halimus*	Jordan	*H. subaphyllus*	Uzbekistan
	A. halimus	Syria	*A. nummularia*	South Africa	*K. prostrata*	Uzbekistan
	A. herba-alba	Spain	*A. nummularia*	Australia	*C. ewersmanniana*	Uzbekistan
	A. polycarpa	USA	*A. lentiformis*	USA	*H. aphyllum*	Uzbekistan
			A. herba-alba	Syria	*S. orientalis*	Uzbekistan
					A. canescens	Jordan
					A. glauca	Australia
					S. vermiculata	Syria
					A. cordobensis	Bolivia
					A. subaphylla	Uzbekistan
					A. undulata	Australia
					S. rigida	Kazakhstan
					S. vermiculata	Jordan
					E. ewersmanniana	Uzbekistan
Yield (Mg DM/ha)						
Fodder		1483±709.3		547±230.7		130±79.1
Wood		1509±573.2		741±215.8		75±75.4
Seed		27±30.8		59±48.7		15±29.1
Nutritive value (g/kg)						
CP		123±5.2		131±5.1		115±5.8
ADL		61±4.1		67±3.5		47±5.1
ADF		153±5.7		162±6.9		173±6.8
NDF		247±4.1		270±5.3		313±6.2
IVOMD		497±5.0		484±5.4		467±6.6

hedges, wind-breaks, fodder banks and improved fallows to provide fodder, fuel-wood, shade, medicine. They could be used to stabilize moving sand dunes and to conserve soil in order to reduce rangeland degradation and mitigate desertification (Lailhacar, 2000; Papanastasis, 2000).

Fodder, wood and seed yields varied among the fodder shrubs in agreement with other reports (Le Houérou, 1994; Lailhacar, 2000; Guevara et al., 2005; Larbi et al., 2006) partly due to variations in anatomical, physiological and morphological characteristics associated with the acquisition of moisture, light and nutrients for biomass production ((Le Houérou, 2000; Amato et al., 2004). The significant variations in fodder CP, cell-wall content (ADL, ADF, NDF), IVOMD concentrations and GAS-24h confirmed previous reports (Warren et al., 1990; Lailhacar, 2000; Papanastatis, 2000; Kaitho et al., 1998; Ammar and Gonzalez, 2005; Larbi et al., 1998a; 2006), and could be due to differences among the species in leaf: twig ratio and cell wall thickening (Wilson, 1994). Cell-wall concentration in fodder shrubs is negatively related to preference, voluntary DM intake, and potential DM degradability (Larbi et al., 1998; Kaitho et al., 1998). Therefore, observed differences in ADL, ADF and NDF could have implications for the use of the shrubs as feed. Also, the variations in CP and IVOMD concentration, and GAS-24h among the shrubs could be partly attributed to the observed differences in concentrations of cell-wall contents (Warren et al., 1990; Haddi et al., 2003; Ventura et al., 2004).

For tropical forages, digestibility is depressed and forage intake drops when CP concentration is lower than 80 g kg^{-1} (Minson, 1990), partly because nitrogen is insufficient to meet the needs of rumen bacteria. In the current study, all but three species (*A. cordobensis*, *K. prostrate* and *S. orientalis*) had CP concentration greater than the above minimum, suggesting that the browse species could effectively provide supplemental nitrogen for ruminants fed basal diets of low nitrogen cereal crop residues. However, the availability of nitrogen in browse species depends on the concentration of secondary compounds such as condensed tannins which influence adhesion, colonization and enzymatic activity of the rumen microbial ecosystem and consequently the degradation of the different dietary fractions (Guimarãaes-Beenlen et al., 2006). Thus, studies on secondary compounds in the browse species may be warranted to improve their use in ruminant feeding systems.

The positive and significant correlations between ADF and NDF, ADL and ADF, ADL and NDF, and IVOMD and GAS-24h confirmed earlier reports (Nsahlai et al., 1994; Larbi et al., 1998 a, b). The significant correlations between IVOMD and GAS-24h suggest that IVOMD concentration in the fodder could be predicted from the GAS-24h under situations were facilities for determining IVOMD are not available. Development of such simple predictive equations could enhance evaluation of browse germplasm as feed and warrants further studies.

The groupings in Table 3 suggest that yield (fodder, wood, and seed) and fodder quality attributes could be used to identify promising fodder shrubs for the development of agro-forestry technologies. The classification of the browses in the current study should, however, be interpreted with caution because although some of the species recorded a high fodder yield, there is very little documentation on their potential as livestock feed. Secondly, the species could differ in critical determinants of fodder quality, such as palatability, voluntary intake, *in viv*o digestibility, and other anti-nutritional factors that were not measured in the current study.

This study focused on inter-specific variations in fodder, wood and seed yield and fodder quality, although we appreciate that differences exist among provenances of the same species in yield and fodder quality (Larbi et al., 1996; 1998). Provenance evaluation of the species in the current study may therefore be needed to select those with highest potential for feed and wood production.

Shrubs in the high and medium potential groups have relatively higher fodder yields and concentrations of IVOMD and CP, and lower cell-wall contents than those in the low potential group (Table 3). This observation suggests that feed value of the shrubs in the high and medium groups could be relatively higher than those in low potential group, because cell-wall contents in fodder shrubs are negatively correlated with preference, voluntary DM intake, and potential DM degradation in the rumen (Larbi et al., 1998; Kaitho et al., 1998). Further studies are needed to determine whether the grouping of the shrubs could be translated into animal output, which is a better measure of forage quality (More et al., 1990).

Conclusion

Fodder, wood, and seed yields, and concentrations in CP, ADL, ADF, NDF, IVOMD and GAS-24h varied significantly among of 26 non-leguminous and eight leguminous fodder shrubs grown in the dry areas of north-west Syria. For the non-leguminous shrubs, multi-variate analysis based on agronomic and fodder quality attributes showed that *A. halimus-halimus* and *A. herba-alba* from Spain, *A. canescens, A. ploycarpa* and *A. lentiformis* from USA, *A. halimus* and *A. herba-alba* from Syria and *A. nummularia* from Australia and South Africa have greater potential than *H. subaphyllus, K. prostrate, C. ewersmanniana, E. ewersmanniana, H. aphyllum* and *S. orientalis* from Uzbekistan, *A. canescens* and *S. vermiculata* from Jordan, *A. glauca* and *A. undulate* from Australia, *A. cordobensis* from Bolivia, and *S. rigida* from Kazakhstan. *Colutea istria* from Jordan and Syria and *Medicago arborea* from Spain were the most promising legume fodder shrubs. The promising non-legume and legume fodder shrubs could be integrated into the smallholder crop/rangeland-livestock farming systems in the dry areas in CWANA and similar environs in other regions as feeding/browsing reserves, living fences and hedges, wind-breaks, fodder banks and improved fallows to provide fodder, fuel-wood, shade, and medicine. They could also be used to stabilize moving sand-dunes and to conserve soil in order to reduce rangeland degradation and mitigate desertification.

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Investigation on effects of phenological stages and species on forage quality of rangelands

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Abstract

The variation in the forage quality of the plants of five range species at two different phenological stages was investigated. Samples were collected from Taleghan area of Iran. Crude protein, ADF, dry matter digestibility and metabolizable energy were assessed. Results showed that forage quality of the tested species significantly differed at the two phenological stages. It was higher at the vegetative stage and lower at the maturity stage. Forage quality of species also differed significantly and the highest forage quality was found in *Lotus goeblia* and lowest in *Cynodon dactylon*. There was significant difference in the change in various quality parameters due to the stage of growth in different species.

Introduction

Forage plants in the range lands are the main source of nutrition for livestock. Therefore, their quality is an important consideration in raising livestock. The forage quality is defined as an expression of the characteristics that affect consumption, nutritive value, and the resulting animal performance. Many factors influence forage quality. The most important are forage species and the stage of growth of the plants the livestock feed on them. Secondary factors influencing the quality are the fertility status of the soil, amount of fertilizers applied, temperature conditions during the growth, and the variety used.

The phenological stage of the plants is the most important factor determining forage quality (Arzani et al., 2004). Forage quality generally declines with an advance in crop growth towards maturity. The stage of maturity also influences the forage consumption by animals. As plants mature and become more fibrous, forage intake drops dramatically. More mature forage is less nutritious because the older plants generally have a lower proportion of the dry matter in the leaves and a higher proportion in the stem material, which is rich in indigestible fiber. Young, tender stems, leaves, and flowers provide the highest quality forage.

Forage quality also differs greatly between grasses and legumes. The protein content of legumes is generally much higher than that of grasses, and legume fiber tends to be digested faster than the fiber in grass, allowing the ruminants to eat more of legume. The decline in the nutritive value in legumes with age is primarily due to changes in stem rather than leaf dry matter digestibility and cell wall content and due to an increase in the proportion of stem to leaf tissue in the plant (Albrecht et al., 1987).

A meaningful assessment of forage quality requires an evaluation of its chemical make up. Laboratory analyses are used to determine the nutritive value of forages. A typical forage analysis includes measurement of the content of dry matter, crude protein, and fiber. Many other parameters are calculated from the data of analyses. Determination of crude protein, digestible dry matter, and metabolizable energy is considered appropriate for evaluation of the range forage quality (Minson, 1987; Rhodes and Sharrow, 1990; Garza and Fulbright, 1998). Successful grazing management must consider the type of livestock and their nutritive needs in relation to the seasonal quality of the forages (Valentine, 2001). Arzani (1994) reported that the nutritional value of range forage was dependent on plant composition, since different species have different nutritive values. Chemical composition of plants in influenced by soil conditions, general climatic conditions and stage of maturity. Pinkerton (1996) reported a close relationship between digestibility and cell wall characteristics in the forage material.

This study was conducted to quantify the difference in the quality parameters of different forage species as affected by the stage of their plant growth.

Material and methods

The study was carried out in the Taleghan region of Iran, located between 50°34′30″ to 50°44′18″ east longitudes and 36°10′4″ to 36°16′58″ north latitudes and covering an area of 1325 km^2. It is a mountainous region with an average elevation of 2500m (maximum elevation 4400m; minimum 1630 m). The average annual rainfall is 500mm. The vegetation cover has developed based on the climate, topography and soil conditions; but human activity had an important role in effecting changes in the vegetation in the region. There are some desirable species in vegetation including perennial grasses such as *Dactylis glomerata*, *Bromus tomentellus*, *Agropyron tauri*, *Agropyron trichophorum*, *Hordeum bulbosum* and *Stipa barbata*. In the higher elevation areas other valuable species like *Prangos uloptera*, *Diplotaenia cachrydifolia* and *Ferula ovina* are dominant. Species of genera *Astragalus*, *Lotus*, *Thymus*, *Medicago*, *Salvia*, *Stachys*, *Achillea* and *Euphorbia* were also observed in the region.

Investigation on forage quality

Information about vegetation communities was obtained and samples of the species were collected at two stages of phenology (vegetative stage and maturity) for determination of forage quality. Five samples (replications) for each species at each phenological stage were gathered. Each sample comprised ten individual plants selected randomly and clipped from 1 cm above the ground level. Samples were dried at 60°C for 24 hours, then ground and used for analysis. Forage quality determinations included crude protein percentage (CP), acid detergent fiber percentage (ADF), dry matter digestibility (DMD), and metabolizable energy (ME).

Crude protein content (CP) was calculated by multiplying the total N content by 6.25. It includes both true protein and non-protein N and does not make a distinction between available or unavailable protein. Nitrogen content was determined by the micro-kjeldehal technique using a ‘kjeltec’ system.

Acid detergent fiber (ADF) is a measure of the least digestible plant carbohydrate (cellulose and lignin). It is negatively correlated with digestibility, and consequently is often used to estimate energy content of forage. Lower ADF value indicates higher digestibility. It was determined using the method described by van Soest (1982) with a ‘fibertec’ system.

Dry matter digestibility was estimated using the formula DMD%=83.58-0.82ADF% +2.262 N% as suggested by Oddy et al. (1983). Metabolizable energy was estimated using the equation ME/DM=0.17 DMD%-2.0 as described by CSIRO (1990) where ME/DM is the metabolizable energy in mega joules (MJ) per kg of feed DM.
Data were analyzed based on a factorial design using SPSS software. The factors included five species and two phenological stages and there were five replications. Treatment combinations were compared using Duncon’s Multiple Range test.

Table 1. The forage quality parameters of the five range species at vegetative (v) and maturity (m) stage.

Species	Stage	CP%	ADF%	DMD%	ME (MJ/kg DM)
Agropyron tauri	v	12.48±0.6C*	37.46±0.54A	57.95±0.60C	7.85±0.1C
	m	6.17±0.12G	44.44±0.37F	49.55±0.34H	6.42±0.05H
Bromus tomentellus	v	16.68±0.8B	33.41±0.2C	63.05±0.40B	8.71±0.07B
	m	3.96±0.12J	39.96±0.3G	52.31±0.27G	6.89±0.04G
Cynodon dactylon	v	10.59±0.89D	36.01±0.88B	58.35±0.68C	7.92±0.12C
	m	4.31±0.18I	44.83±0.63F	48.44±0.59I	6.23±0.1I
Lotus goeblia	v	17.61±0.37A	21.73±0.32D	73.06±0.40A	10.42±0.07A
	m	12.44±0.15F	31.10±1.4H	64±1.2F	8.88±0.20F
Stipa barbata	v	16.04±0.61B	33.01±0.55C	63.11±0.60B	8.72±0.1B
	m	5.34±0.15H	44.78±0.53F	48.92±0.50HI	6.31±0.08HI

** Values followed by different letters within a column differ significantly based on Duncon’s Multiple Range Test.*

Results

Result of various forage quality parameters for the five species at two stages of growth are presented in Table 1. Advancement in plant growth caused statistically significant ($P<0.05$) reduction in CP, DMD and ME content of forage of all the species while the ADF percentage significantly increased. Species differed greatly in their quality parameters and the differences were statistically significant.

Stage by species interaction was also significant showing that the degree of change in the various parameters due to the stage of development differed in different species. The highest CP percent was obtained in *Lotus goeblia* at the vegetative stage and the lowest was in *Bromus tomentellus* at maturity stage. ADF percentage was the highest in *Cynodon dactylon* at the maturity stage and lowest in *Lotus goeblia* at the vegetative stage. *Lotus goeblia* had highest metabolizable energy level at the vegetative stage and *Cynodon dactylon* the lowest at the maturity stage.

Discussion

The management and conservation of rangeland resources is one of the most important issues for animal production and soil conservation. The first consideration in range management is to ensure that the basic plant and soil resources are used in such way that they continue to be productive. Good management of rangeland in the arid and semi-arid areas aims at keeping the most desirable plants growing vigorously on the long term basis. This aim cannot be achieved without the consideration of available forage. Estimating carrying capacity is a basic technique for range management and its determination is a major problem for the range managers.

Gain in live weight of animals grazing in summer rangeland is significant from the beginning to the end of the grazing period because of the availability of good quality forage to livestock (Arzani, 1994). Therefore, range is an important resource for herders and it is essential that the basic plant and soil resources are used there in such a way that they continue to be productive. As Stoddart et al. (1975) stated the efficiency of livestock production is closely correlated with the nutrient value of forage available. The nutrient value of range forage is dependent on vegetation composition (Arzani, 1994; Norton and Waterfall, 2000) and the stage of growth of the range species (Arzani et al, 2004).

In our study, the forage quality between species and phenological stages differed significantly ($P<0.05$). Among the species *Lotus geblia* and *Cynodon dactylon* showed the highest and the lowest forage quality respectively. Therefore, efforts should be made to promote species like *Lotus geblia* in the range. High percentage of CP, DMD, ME and low percentage of ADF were obtained from all species in vegetative stage of growth. In contrast, at the maturity stage CP, DMD and ME decreased and ADF increased. Similar finding had been reported by Arzani et al. (2004).

Most species in this study had acceptable forage quality at both stages of growth. This is good for livestock herders grazing their animals on these rangelands. However, in view of the difference in the quality of the grazed vegetation at various stages of growth, supplemental feeding regime will have to change for the livestock during the feeding cycle to optimize livestock productivity.

Conclusions

Knowledge of the forage quality of range species available to grazing animals assists in achieving their most timely utilization, predicting nutrient deficiencies, and determining the need for nutrient supplementation. The stage of growth greatly affects forage quality and at the maturity stage the quality sharply decreases. Animals solely grazing under such conditions could suffer dietary deficiencies. Hence, optimum supplementation program will have to be devised under such conditions.

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Theme: Biodiversity Conservation and Utilization and Ethnobotany

Importance of agrobiodiversity and options for promoting its on-farm conservation and sustainable use: Case of West Asia dryland agrobiodiversity project

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Abstract

West Asia encompasses the mega-center of diversity of species of global importance (wheat, barley, lentil, and many forage legume and fruit tree species) whose conservation will contribute to sustaining agriculture and food security worldwide. The landraces and wild relatives of these species form the basis of the traditional farming systems and contribute significantly to the livelihoods of local communities in the drylands and mountainous ecosystems in the countries in North Africa and West Asia. The GEF-funded project on conservation and sustainable use of dryland agrobiodiversity has developed a holistic approach to promote the conservation of the landraces and wild relatives of the species originating from Jordan, Lebanon, the Palestinian Authority and Syria. The socio-economic and farming systems surveys showed that agriculture contributes to approximately 50% of the household income and that the landraces of barley, wheat, lentil, chickpea, olive, fig, are still widely used and contribute along with livestock to the livelihoods of local communities in the target areas. The technological, institutional and policy options are developed and tested within the project, which can contribute to the improvement of the livelihoods of local communities while conserving and sustaining the natural resource base and local agrobiodiversity. This contribution presents the relationship between local agrobiodiversity and the livelihoods of local communities and the examples of technologies, add-value and alternative sources of income to improve and diversify the incomes of the main custodians of agrobiodiversity.

Introduction

Agrobiodiversity occupies a unique place within the biological diversity as it relates directly to food security and agricultural development. According to the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) of the Convention on Biological Diversity (CBD, 2000 a), agricultural biodiversity encompasses a variety of animals, plants and micro-organisms, at genetic, species and ecosystem levels, necessary to sustain key functions of the agro-system, its structure, and processes for, and in support of, food production and security. Agrobiodiversity is actively managed by farmers and therefore the inherited indigenous local knowledge is an integral part of the agrobiodiversity conservation.

The importance of dryland agrobiodiversity has been emphasized in particular by the CBD (2000) as it relates to livelihoods of poor rural communities and to the crops and livestock of global significance. It holds genes for adaptation to harsh conditions and to climate change and provides important ecological services including obligatory rest habitats for migrating birds and animals. Over one billion people, or one-sixth of the world population, live in the drylands and their livelihoods are supported and maintained mainly by agricultural activities relying mostly on local agrobiodiversity. Therefore, drylands-agrobiodiversity deserves special attention at national, regional and international levels. The SBSTTA of the CBD recommended to the Conference of Parties to establish a program on dryland biodiversity including grassland, savannah, and Mediterranean lands.

West Asia region encompasses one of the three mega-centers of diversity and combines the centers of origin and domestication of crops of global significance such as wheat, barley, lentil, forage legumes, and several fruit trees (Hawkes, 1983; Harlan, 1992). Landraces and wild relative species of these crops are still found in the traditional farming systems and remaining natural habitats mainly prevailing in drylands and mountainous regions. But, because of acute demographic pressure, inappropriate policies and limited research efforts, this local agrobiodiversity is increasingly threatened by recurrent droughts and climate change and by anthropogenic factors resulting in over-exploitation and miss-management mainly through over-grazing, deforestation and destruction of natural habitats for urbanization and agricultural expansion purposes. The use of improved varieties and the introduction of new crops have decreased the area under landraces even in non-optimal environments.

The livelihoods of local communities and the food security and agricultural development worldwide will depend on the conservation and availability of these valuable genetic resources. The CBD (1992, 2000b) and the Global Plan of Action (FAO, 1996) have stressed the need for applying complementary *ex situ* and *in situ* /on-farm conservation methodologies (Maxted et al., 1997). Over the past three decades, there is a greatly increased recognition of the importance of embedding conservation in a wider social and economic framework with a strong need for policy reforms to empower the custodians of local agrobiodiversity. *In situ* /on-farm conservation approach is becoming increasingly important in the conservation of plant genetic resources and the Global Environment Facility (GEF) has funded some projects aiming at promoting the *in situ*/on-farm conservation of agrobiodiversity. Two projects have contributed significantly to strengthening the scientific basis of agrobiodiversity in the North Africa and West Asia region (Jarvis et al., 2000), the date palm on-farm conservation (Noureddine, 2005) and the West Asia Dryland Agrobiodiversity (Mazid et al., 2007). The West Asia Dryland Agrobiodiversity project has worked to develop a holistic approach to promote community-driven actions for conservation and sustainable use of local agrobiodiversity. All these projects recommend the full involvement and empowerment of local communities for the success of conservation of agrobiodiversity.

This contribution provides information on the status and threats to on-farm agrobiodiversity in the dry areas of West Asia and the needed technological, institutional and policy options for empowering local communities to conserve and sustain the use of local agrobiodiversity.

Methodology

During the period of 1999-2005, the International Center for Agricultural Research in the Dry Areas (ICARDA) coordinated a GEF-funded regional project, "Conservation and sustainable use of dryland agrobiodiversity in Jordan, Lebanon, the Palestinian Authority and Syria," to promote community-based *in situ* conservation of landraces and wild relatives of species of global importance originating from the Fertile Crescent (barley, wheat, lentil, alliums, vetch, medics, grasspea, trifolium, figs, olives, almonds, pistachio, pears, prunes, apricots, etc.). The project field activities were conducted in 26 villages and 73 monitoring areas selected within the target region (Ajloun and Muwaqar in Jordan, Aarsal and Baalbeck in Lebanon, Jenin and Hebron in Palestine, and Al-Haffeh and Sweida in Syria) covering diverse ecosystems from semi-arid to high elevation and high rainfall areas and representing different farming systems in the West Asia and North Africa (WANA) region. The activities were implemented at the national level by the national research institutions (the National Center for Agricultural Research and Technology Transfer, NCARTT in Jordan; the Lebanese Agricultural Research Institute, LARI in Lebanon; the General Council for Scientific Agricultural Research, GCSAR in Syria) and by the Ministry of Agriculture and UNDP- Programme of Assistance to Palestinian People in Palestine. Technical backstopping was provided by ICARDA, IPGRI and ACSAD and several international experts contracted by the project. Specific thematic groups were established to ensure the standardization of the methodologies and approaches and the harmonization of the implementation of the activities. A socio-economic and policy thematic group was also included. The major pillars of the approach and the main outputs sought in the project were:

- Better knowledge of the status and the trends of local agrobiodiversity and major threats to it;

- Development and transfer of appropriate technologies and alternative uses of land covered in the project;
- Investigation and demonstration of add-value technologies and alternative sources of income for the people using local biodiversity;
- Development of enabling policy and legislation reforms;
- Capacity building and awareness increase about sustainable use and conservation of dryland agrobiodiversity among major stakeholders;
- Enhancing regional networking, integration and collaboration; and
- Monitoring of the progress and assessment of impacts.

Farming systems surveys were conducted in 2000 as baseline study and in 2004 for assessing the trends in landraces use and appreciation and in assessing the preliminary impacts of the projects on the livelihoods of the custodians of agrobiodiversity. Around seventy households were individually surveyed per target area during each period and their assets were assessed using the livelihood-analysis approach along with the household structure and income source, cropping systems and cultural practices, changes in land use, landrace used, seed and seedling use and exchange, and gender role in conserving agrobiodiversity. In the 2004 survey, farmers who collaborated with the project and those who did not participate in any project activities were surveyed to assess the impacts of the project interventions.

The status of agrobiodiversity was analyzed through the diversity of farming systems (type of enterprises), the average number of crops and the average crops per field, the number of varieties including landraces used for each crop, and the seed and seedling sources. Farmers were also asked about the differences in productivity and attributes between improved varieties and landraces and about the future of various crops in their farm. The sources of household income were also determined through the questionnaire. Participatory rural appraisals were conducted with groups of farmers in each target area (32-45 farmers) to assess the total number of landraces known for each crop and the major threats facing local agrobiodiversity.

The project launched several activities for improving the income of local farmers and provided the needed training and technical backstopping.

Results and discussion

Assessment of status and threats of local agrobiodiversity

The predominant farming system depends mostly on the environmental conditions, mainly the topography and the climatic conditions (Table 1). In the rangeland-dominated area, such as Muwaqqar, Jordan, and Aarsal in Lebanon, livestock is the only activity for 77% and 53% of local communities, respectively. In these two sites, the remaining farmers plant barley mainly and olive tree under irrigation in Muwaqqar and vetch and cherries in Aarsal. In the mountains of Ajloun in Jordan and Al-Haffeh in Syria, 66% and 80% of farmers, respectively, are growing mainly fruit trees and 20% are practicing both crop production and livestock raising. In Al-Haffeh, none of the farmers has small ruminants and in Ajloun farmers are mainly raising goats in semi-intensified system. In the remaining target areas, the farmers are split between crop producers and crop-livestock producers and 1-8% are exclusive herders. These results show the great diversity of the farming systems with the importance of livestock in drier and flatter areas and of the fruit trees in the mountainous areas. In Palestine the number of herders is lower, which might be due to the restricted access to rangelands because of the conflict there. The crop-livestock system is an important attribute of farming systems in arid and semi-arid areas and it contributes to the buffering of the effects of drought with livestock playing an important role in the providing cash to farmers.

Table 1. Types of predominant farming systems in the target areas in the four countries (2004 survey)

Type of enterprise	Jordan		Lebanon		Palestine		Syria	
	Muwaqqar	Ajloun	Aarsal	Baalbak	Hebron	Jenin	Sweida	Al-Haffeh
Crops only	10	66	24	58	44	42	54	80
Livestock only	77	14	53	8	2	1	2	0
Crops and livestock	13	20	18	32	54	57	44	20

The second indicator of local agrobiodiversity is shown by the number of crops used at the farm level. As shown in Table 2, the average number of crops grown in the farm ranged from 2.3 to 4.9 showing that farmers in all agro-climatic zones tend to grow more than two crops, but the highest number is in mountainous and high rainfall areas. In the latter systems, several crop species are grown in the same field as indicated by the crop diversity index.

In Ajloun and Al-Haffeh, some farmers plant up to fifteen crops in their fields with mainly fruit trees in top layer and field crops in the lower layer. Some farmers are even planting medicinal and vegetables under the fruit trees. Among the predominant fruit trees are olive, apple, grapes, cherries and figs in Ajloun, Sweida, and Al-Haffeh and among the field crops are barely, wheat, lentil, chickpea and vetch. This diversity of crops contributes to the diversification of the diet of local communities, the feed calendar for their animals, and the sources of their income. It also allows for the spread of labor needs over the whole year.

The third indicator of agrobiodiversity investigated is the number of landraces known or still in use by farmers. For fruit trees, large numbers of landraces were cited by the farmers: more than 10 landraces of olive, 20 of grapes, 15 of figs, 5 of cherries, 2 of almonds, 3 of apples, 3 of apricots and four of plums. The improved varieties are mainly used in case of apple, cherry and apricot. Barley, lentil and chickpea varieties planted are exclusively landraces, commonly designated as *baladi* (local), which might have several populations.

Table 3 shows the number of landraces known to the farmers and those actually used by them. The relatively lower number of landraces used by farmers as against the numbers known to them shows that some landraces have decreased in importance or disappeared in the target areas.

Farmers are now using mainly improved varieties in case of apple, cherries and apricot. In case of wheat in Palestine, although large number of landraces are used, farmers are importing seed of improved varieties. In other countries, the spread and adoption of improved varieties is limited because the farmers recognize the good adaptation of their landraces to the predominant harsh conditions and their crop-quality traits that meet their requirements (Table 4). In case of olive, the improved varieties in Jordan and Syria are ecotypes selected from landraces. Some farmers have even grafted landraces on the improved varieties after realizing the weakness of latter.

The farmers appreciate landraces of most crops for their adaptation to low-input conditions and to major biotic and abiotic stresses. In addition, these landraces have good quality attributes which allow the products to fetch a price premium in the market.

The fourth indicator of agrobiodiversity is related to the genetic diversity within the landraces, which can be revealed by genetic studies using morphological and DNA markers techniques. Landraces of field crops are formed of multilines giving them population buffering against the change in environments and seasonal conditions. This type of diversity is important for breeding programs along with the number of landraces. Farmers in the mountain-

Table 2. Average number of fields and crops per farm and crop diversity index in target areas in the four countries (2004 survey)

Item	Jordan		Lebanon		Palestine		Syria	
	Muw-aqqar	Ajloun	Aarsal	Baalbak	Hebron	Jenin	Sweida	Al-Haffeh
Number of fields/farm	2.25	2.45	3.59	4.23	5.00	4.72	4.91	2.58
Number of crops/farm	2.25	3.86	4.43	4.18	4.84	4.47	4.69	2.89
Crop diversity index	1.00	1.58	1.23	0.99	0.97	0.95	0.96	1.12

Table 3. Number of wheat landraces cited by farmers and the number of landraces and improved varieties used by them

Item	Jordan		Lebanon		Palestine		Syria	
	Muw-aqqar	Ajloun	Aarsal	Baalbak	Hebron	Jenin	Sweida	Al-Haffeh
Landraces cited	2	6	2	2	7	7	11	5
Landraces used	2	4	1	1	5	5	8	3
Improved varieties	1	2	1	1	2	2	3	1

ous areas tend to leave wild relatives of crops on the edges of their field for protection or for use as rootstocks when needed. In case of wheat and barley, some natural introgression between cultivated and wild species are observed.

Table 4. Percent of total area grown to landraces of various crops in the targets areas (2000 survey)

Crops	Jordan	Lebanon	Syria	Palestine
Barley	100	100	100	100
Wheat	95	100	95	30
Lentil	100	100	100	100
Olive	90	90	95	100
Almond	50	90	50	100
Fig	95	100	100	100
Apple	5	1	1	0
Pear	50	-	50	0
Grape	80	100	100	80
Cherries	10	30	10	-

As seen in Table 4 and confirmed by the participatory rural appraisal results, landraces of barley, lentil, fig and grape are not threatened by replacement with improved varieties in all the target areas, although these landraces are replaced by improved varieties when the growing conditions are improved and when intensification is possible. For wheat, landraces are still used in the target areas of Jordan, Syria and Lebanon, but in Palestine, the imported improved varieties are predominating due to non availability of good seeds of the landraces. For pears, apricots and almonds, the area is equally split between improved varieties and landraces. For cherries, farmers are mainly using improved varieties in the new plantations. In case of apples, area of landraces such as Sukkari and Khashabi is reduced significantly and does not represent more than 5%.

Most of the target areas have witnessed an expansion of the plantation of fruit trees, olives in Jordan, Syria and Palestine, cherries in Lebanon and Syria, and apples in Syria. This expansion is occurring at the expense of the area under the landraces of such field crops as barley, wheat and chickpea or it is occurring in lands newly reclaimed from forest and rangeland natural habitats. Farmers have also acknowledged the disappearance of some landraces of all crops and have attributed this to limited efforts to multiply their seeds within the existing informal seed production system and fruit tree nurseries. Marketing problems and storability could also have contributed to the decrease in importance of landraces.

Another major threat to local agrobiodiversity is related to loss of local knowledge due to limited interest of young generations to invest and work in agriculture.

Contribution of alternative sources to total household income

Farming households in the target areas had many activities to meet their livelihood needs. They had diverse sources of income, and there were also variations in the amount and percentage of income from different sources among the four countries (Table 5). Income from on-farm activities, including return from crops and fruit trees, livestock products, and live animals, represented less than half of the total household income in the four countries. Government employment income was important in Jordan (48%) and Syria (20%), while off-farm income (from non-agricultural activities) was important in Lebanon (34%) and Palestine (26%). Livestock is the main source of on-farm

Table 5. Contribution of alternative sources to total household income (%)

Income source	Jordan	Lebanon	Palestine	Syria
Crops & fruit trees	16	28	27	34
Livestock products	15	6	6	5
Live animals	11	7	16	4
Total on-farm income	42	41	49	43
Off-farm (Agriculture)	3	3	3	1
Off-farm (Non-agriculture)	4	34	26	6
Government employment	48	10	15	20
Remittances (Outside country)	3	1	0	4
Other sources	0	12	10	26
Total off-farm income	58	59	51	57
Average household income (US$)	6896	7120	8905	2919

income in Jordan, whereas plant production (crops and fruit trees) is the major source of on-farm income in Lebanon, Palestine, and Syria.

Contribution of alternative income sources to the total household income was diverse according to the target areas in each country. In Jordan, income from government employment was significant at Muwaqqar followed by income from livestock, while at Ajloun income from crops and fruit trees was important. In Lebanon, household income from off-farm activities outside agriculture was the main source at Aarsal (mainly from quarries) and income from crops and fruit trees was the major source at Nabha. However, there were many factors that influenced the contribution of alternative sources to total household income such as farm resource availability, farmers' education, skills and experiences, and opportunities for off-farm activities.

These results showed the importance of local agrobiodiversity in the livelihoods of local communities in the remaining biodiversity rich areas. However, agriculture covered only partially the needs of local communities and most farmers had to rely on off-farm resources for securing their livelihoods. These included remittances from government employment as in case of Jordan, quarries and other non-agricultural jobs in case of Aarsal in Lebanon and Hebron in Palestine. It appears that the on-farm conservation and sustainable use of local agrobiodiversity can not be effective without improvement and diversification of incomes of the custodians of the agrobiodiversity. This diversification of income is ensured by off-farm activities. But, options for further improvement and diversification of incomes need to be investigated within any strategy for promoting the on-farm conservation of local agrobiodiversity.

Investigation of new opportunities for alternative sources of income

The future role of agricultural activities in the livelihoods of rural communities will depend on developing new technological packages to enhance agricultural productivity while sustaining the natural resource base, adding value to the products. In addition, there will be need to identify alternative sources of income in addition to the implementation of development projects to ensure rural development and better livelihoods of rural communities. The Dryland Agrobiodiversity Project initiated many business-oriented activities targeting mainly women. These activities included food processing using the products of local agrobiodiversity such as the production of jams, compotes, syrups using produce of fruit trees, and making high quality burghul and freikeh from durum wheat. The project introduced to the local market for the first time the jams and compotes made by the participating farm households from the wild relatives of fruit trees (wild plum) and of many neglected species (*Zizyphus* spp., *Arbutus* spp., *etc.*). These products are actually marketed by women cooperatives in Jordan, Lebanon and Syria. The women were also trained in home gardening to produce vegetables, herbs and medicinal plants, and to specialize in nursery management and multiplication of landraces of fruit trees. Training and technical backstopping were provided to women in the local communities on several activities allowing the diversification of incomes. Among these activities were bee keeping for honey production, making dairy products, mushroom production, soap production, etc. These initiatives allowed groups or individual farmers to improve their income and livelihoods. In Lebanon, eco-tourism was introduced in remote villages of Ham and Maaraboun, which was sustained by private eco-tour companies.

Conclusion

Agriculture and agrobiodiversity in arid and mountainous regions continue to play a key role in the livelihoods of poor communities there. The conservation and sustainable use of this agrobiodiversity will require a holistic approach allowing the empowerment of the custodians of agrobiodiversity, the investigation of add-value and alternative sources of income and the implementation of rural development projects.

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Ethnobotanical studies on medicinal plants of Ziarat region in northern Iran

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Abstract

Medicinal plants are an important group among the economical plants. More than 7500 plant species of this group are found in Iran. Golestan province in Iran is one of the main regions in plant diversity. In this research, medicine plant distribution in Ziarat region has been investigated. Ziarat covers an area of 3662m² having an altitude ranging from 650m to 2250m above the sea level and an average annual rainfall of 574.5 mm. There is a need to study the distribution of medicinal plants in different regions of this area and also for introducing the existing medicinal species to other areas. Our study showed that some 107 medicinal species belonging to 93 genra and 42 families were present in this area. After determination of species we interviewed the local people to find out the traditional medicinal uses. Asteraceae with 21 species, Lamiaceae with 12 species and Fabaceae with 10 species constituted the bulk of the collected species. In this research customary usage of traditional medicinal species of this region was studied, which could be a basis for phytochemical, pharmacological and economic researches for this region.

Introduction

The people of Iran have inherited two precious things as a result of millions of years of evolution in the natural environment in the country. One is the valuable biodiversity and the other is a treasure of traditional knowledge about the medicinal value of a part of this biodiversity as a support to human life. This valuable intellectual heritage about native traditional medicines and medicinal plants is passed on from generation to generation and it has evolved because of the closeness of local people with the nature. It has therefore got to be preserved and protected for future generations as well. For recording this traditional knowledge about the medicinal plants in the Ziarat region of Iran, which is particularly rich in the plant biodiversity a study was conducted over a period of two years in which the plant species were identified and the local tribal people of Ziarat were interviewed about the traditional medicinal uses of the commonly used plants.

Material and method

The study was carried out in the Ziarat region, in Golestan province, some 16 km away from Gorgan city. It covers an area of 3662 ha and has a population of 2000 people. With several mountain ranges varying in altitude from 700 to 2500m, the area enjoys varied environmental conditions. The average annual rainfall is about 574.5mm and the mean temperature is 12.6°C.

A field survey was done of the plant species growing in the region and a total of 107 species were collected over a period of two years (2001 – 2003). The major species of interest to the local people in traditional medicine are listed in Table 1. They were botanically identified using the national herbarium of the Institute of Forest and Rangeland of Tehran. The local traditional practitioners and herbal pharmacists were interviewed at their places of work to get information on the use of these plants for curing different ailments. The information so obtained was also checked with the information provided by various researchers working on ethnobotany (Agelet and Valles, 2001; 2003a; 2003b; Alexiades and Sheeldon, 1996; Amico and Sorge, 1997; Atran, 1999; Barbini et al., 1999; Berlin, 1992; Berlin et al., 1966; Bonet et al., 1992; Bonet and Valles, 2003; Capasso et al., 1982; De Feo and Senatore, 1993; De Feo et al., 1992; Karaman and Kocabas, 2001).

Table 1. Plant used in folk medicine in Ziarat region of Golestan province, Iran

Specimen	Parts used	Claimed medicinal uses
Heracleum persicum	Fruit	Carminative, antiseptic, appetite
Hypericum perforatiun	Yellow latex	Cold sore, chicken pox, back pain
Stachys lavandulifolia	Aerial parts	Headache, facial pain, nose bleeding, tonic
Teucrium polium	Aerial parts	Infusion for gout, rheumatism, stomachache , heal wounds
Mentha aquatica	Aerial parts	Headache, purgative, carminative, antiseptic, antibacterial, stomachache
Mentha longifolia	Aerial parts	Carminative, antifungal, stomachache
Berberis vulgaris	Fruit and root bark	Blood pressure, cardiac tonic, cholesterol and diabetes
Juniperus communis	Fleshy female cone	Urinary tract infection (UTI), antiseptic, headache
Achillea milefolium	Inflorescence	Stomachache, dysmenorrhea, expel intestinal worms
Descuraina sophia	Fruit	Increase milk production, cooling effect
Rumex acetosa	Leaves	Anticancer, anti-inflammation
Plantago lanceolata	Fruit, leaves	Anti-inflammation, relaxant, bronchitis
Peganum harmala	Seed	Expel intestinal worms, antiseptic, promote menstrual flow
Artemisia annua	Aerial parts	Stomachache, feverfew, antibiotic, antifungal
Marrubium vulgare	Leaves	Bronchitis-asthma, cough, whooping
Malva neglecta	Aerial parts	Cold, flue, bronchitis
Cichoriom intaybus	Root	Tonic for liver, headache, UTI, rheumatic pain, gout
Origanun vulgfe	Aerial parts	Cold, sedative, diarrhea
Taraxacum offincialis	Root, leaves	Diuretic, detoxifying, gall stone, constipation
Capparis spinosa	Flower buds	Sedative, stomach pain, sweat reduce, herpes
Viola odorata	Flowers	Indigestion, sedative, nervousness
Urtica dioica	Root, aerial parts	Diabetic, reduce cholesterol, tonic, blood cleaning
Fumaria officinalis	Aerial parts	Anti-toxic, liver disorders
Anthemis altissima	Flower	Sedative, antiseptic, expel intestinal worms
Portulaca oleracea	Aerial parts	Tonic digestion , expel worm , diabetic, arthritic, anticancer
Echium amoenum	Flower	Laxative, sedative, antiseptic, expel intestinal worms
Rosa canniaa	Fruit	Astringent, diuretic, expectorant, tonic
Silybum marianum	Inflorescence seed	Jaundice, hepatitis, liver tonic, promote milk production
Adiantum capillus-veners	Aerial parts	Cold, flu, fever, cough, bronchitis, expectorant
Equisetum arvenasis	Stem	Jaundice, hepatitis, liver tonic, promote milk production
Fragaria vesca	Aerial parts	Diarrhea , kidney stone, sedative, diuretic
Galanthus sp.	Bulb	Antiseptic, tonic, reduce blood pressure, cleansing
Tanacetum partheniuam	Leaves, fruits	Anti-migraine, headache, fever
Glycrrhizia glabra	Root	Antiseptic, tonic, reduce blood pressure, cleansing
Nasturtium officinalis	Aerial parts	Anti-migraine, headache, tonic for hair
Rubus froticosus	Leaves, fruit, flower	Diarrhea, tonic, antiseptic, anti-diabetic, anemia
Sambucus ebulus	Fruit , flowers	Anti-scorbutic, cold, flu, fever , tonic
Ruta graveoleance	Aerial parts	Anti-oxidant, tonic , promote immune system
Oenthera lamakiana	Seed oil	Eczema, anti-inflammation of skin

Results and discussion

The variation in the climatic conditions in the different parts of the Golestan province has resulted in the development of a very rich flora. An abundance of medicinal plant diversity in the Ziarat region of this province makes it an excellent site for studying ethnomedicine. Data were therefore gathered on 107 medicinal herbs from 93 genra belonging to 42 families. Families Asteraceae with 21 species, Lamiaceae with 12 species, and Fabaceae with 10 species were the most dominant in the Ziarat region. The survey of the local people revealed that this extraordinarily rich flora is used by the local people in making indigenous medicine on which 90% of population depends. Aerial parts (leaves and flowers) as well as roots of several specie have been used for human and animal food and medicine (Table 1). Both internal and external use of herbs is common. For internal use decoction and infusion in water were the main preparations used. Most reported medicinal uses were related to the treatment of digestive disorders, cardiovascular problems, broncho-pulmonary ailments, and dermatological infections. The herbs were also used for their analgesic, carminative, sedative, diuretic, and anti-inflammatory properties. The local tribes have given these plants popular names, which are used in their daily handling of the herbs. Finally, the survey revealed that beside the pharmacological use, a large number of plants were used in magical or religious practices, which were essentially linked to their medicinal uses.

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Investigation on important medicinal trees in Golestan province, Iran

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Abstract

Some trees and shrubs have been used in traditional medicine and food for centuries in Iran and there is information available in the local communities about their phytochemical and medicinal properties. This paper introduces some important plants useful for their medicinal characteristics and common in the Charbagh region of Gorgan. Charbagh village is located 70 km southeast of Gorgan city, at an elevation ranging from 1800 to 3500 meter above sea level. The average annual rainfall in this area is 305mm.There is a large variety of vegetation in the Golestan province. Some 36 species of trees or shrubs of medicinal use grow in this region and are used by people in traditional manner in the villages. Root, stem, leaf, fruit and secondary products have been used for making potions and infusions for internal use and tincture and lotions for external treatment for various ailments by traditional physicians as the only source of remedy for diseases in this region. The most important species are *Juniperus communis, Berberis vulgaris, Alnus glotinosa, Carpinus betulus, Colutea arborescens, Cornus australis, Corylus vrelana, Crataegus oxycantha, Rhamnus palassi, Ilex aquifolium, Lonicera caprifolia, Mespilus germaniac, Tillia begonifolia, Paliurus spina christi, Prunus spinosa, Quercus castaneafolia, Rosa canina, Rubus fruticosus, Salix alba, Smilax excelsa, Taxus baccata, Viscum album, Cerasus* spp, *Mespilus* sp., and *Pyrus spinosa.*

Introduction

For centuries people have used plant products with varying success to cure and prevent diseases throughout the history. Trees and shrubs are very important considering their medicinal properties in addition to their role in wood production. The large variation in the climatic conditions in different parts of Golestan province makes it an excellent site to study ethnomedicine here as the use of trees and shrub medicines is wide spread in this region. Traditional healers and pharmacists assign arbitrary shelf-life to all their dried plant material and sell them to local populations for medicinal purposes.

Material and method

Golestan province covers an area of 430,000 ha, with several agro-climatic regions, mountain ranges, forests and grasslands, as the elevation in the province ranges from 70 to3500m above see level. The forest vegetation contains many tree and shrub species that are used in local medicine by native villagers. This study was based on a detailed review of literature on the flora of the province, based on which a list of important trees and shrubs was prepared, and then, using photographs and field observations, their distribution was determined. A total of 36 species of trees and shrubs were collected over a period of two years (2001-2003). They are listed in Table 1. A survey was undertaken of the local people to determine the nature of use of the species in the village medicine based on the indigenous knowledge.

Result and discussion

The 36 species of medicinal trees and shrubs collected belonged to 26 families. Rosaceae, Betulaceae, Cupresaceae, Ulmaceae, Salicaceae, Caprifoliaceae were the dominant families. The survey revealed that these species were being used for making medicines for treating human and animal ailments. Infusion or decoction of aerial parts, bark, and root were the main preparations used in the local traditional medicine. Preparations for external use were also made. The traditional therapeutical uses are given in Table 1.

Although these species are being widely used by the local communities in traditional medicine based on indigenous knowledge, their use can be further expanded through proper planning of introducing the right species in different areas and proper procedures for making medicinal products from them. This will also lead to better conservation of agrobiodiversity.

Table1. Traditional phyto-therupeatical uses of different tree and shrub species commonly found in Charbagh region of Golestan province.

Specimen	Parts used	Claimed medicinal uses
Punica granatum	Fruit	Tapeworm infestation, laxative, purgative, astringent, diarrhea
Quercus castanceafolia	Bark, galls	Hemorrhoid, diarrhea, dysentery, rectal bleeding, nasal polyps, eczema, astringent
Rosa canina	Hips	Diarrhea, diuretic, gastric inflammation
Rubus fruticosus	Leaves, berries	Sore throats, wounds, astringent, diarrhea, hemorrhoids
Ruscus aculeatus	Aerial parts, rhizome	Menstrual bleeding, bladder stone, jaundice, headache, diuretic, laxative
Taxus baccata	Leaves	Rheumatic pain, urinary infection, anti-cancer
Tillia begonifolia	Flowers	Anti spasmodic, sedative, tension relief, sinus, headache, stress, cold, flu, fever, high blood pressure, arteriosclerosis, itchy skin
Viscum album	Leaves	Lower blood pressure and heart rate, anxiety, headache, epilepsy, hyperactivity in children, anticancer
Sorbus torminalis	Fruit	Coughs, diarrhea, fever, diuretic, kidney stone, bronchitis
Betula pendula	Leaves, bark, sap	Bladder and kidney problems, kidney stone, diuretic, eczema, psoriasis, chronic skin problems, rheumatism, dysentery, hemorrhages.
Castanea sativa	Leaves, bark	Whooping cough, bronchitis, catarrh, diarrhea, sore throats, rheumatic stiff joint of muscles
Celtis australis	Leaves, fruit	Astringent, heavy menstrual and inter-menstrual uterine bleeding, peptic ulcers, diarrhea, dysentery
Cornus sp	Fruit	Heavy menstrual bleeding, tonic, detoxification
Ficus carica	Fruit, latex	Laxative, constipation, pain, inflammation, tumors, expectorant, dry cough, bronchitis, warts, insect bites
Ilex aquifolium	Leaves, berries	Fever, diuretic, laxative, jaundice, rheumatism, vomiting
Juniperus communis	Fruit, essential oil,	Tonic, diuretic, antiseptic, gout, stimulates menstruation
Morus alba	Leaves, twigs, fruit	Expectorant, cough, catarrh, fever, sore throats, headache, dizziness, tonic, toothache, laxative, diabetic, insomnia
Phytolacca americana	Root, fruit	Sore, ulcer, tumors, vomiting, pain, rheumatic arthritics, respiratory infection
Crataegus monogyna	Aerial parts and fruit	Cardio-tonic, dilate blood vessel, relaxant, antioxidant, heart remedy, blood pressure
Ephedra sp	Stem	Increase sweating, dilate bronchioles, diuretic, stimulant
Humulus lupulus	Strobiles	Sedative, soporific, antispasmodic, anxiety, tension, headache, period pain, aid to digestion
Salix alba	Dried bark	Anti-inflammatory,fever, anti-rheumatic, astringent, joint remedy, reduce sweating, back pain, night sweats
Sambucus nigra	Aerial parts	Increase sweating, diuretic, anti-inflammatory, hay fever, earache, catarrh, flu
*Ulmus rubra*Inner	Bark	Demulcent, emollient, nutritive, laxative, acidity, indigestion, acne, boils, constipation in children, hemorrhoids
Ailanthus altissima	Bark, root bark	Diarrhea, dysentery, worms, asthma, cardiac depressant
Berberis rulyaris	Stem root bark, berries	Antibacterial, amoebicidal, stimulate bile secretion, cancer inhibiting, anti-diabetic, peptic ulcers, gallstones, jaundice, antiseptic, gastro-intestinal infection.

Lonicara caprifolia	Flowers, leaves, bark	Asthma, chest condition, heart, diuretic, gout, kidney stone, liver problem, ulcer, sore throat, coughs, anti-spasmodic
Ricinus commucs	Seed oil, seed	Strongly laxative, promoting bowel movement, anti-constipation
Prunus spinosa	Fruit	Diuretic, cystitis, nephritis, arthritis, gout, diarrhea, stop bleeding, expel worms
Smilax excelsa	Root	Skin problems, anti-inflammatory, arthritis, gouts, menopausal problems, pre-menstrual problems, tonic
Vitis vinifera	Leaves, fruit	Astringent, anti-inflammatory, diarrhea, heavy menstrual bleeding, uterine hemorrhage, vaginal discharge, varicose veins, gastro-intestinal tract, expectorant
Ziziphus jujube	Fruit	Tonic, sedative, anti-allergic, promote immune-system
Alnus glotinosa	Leaves	Fever, cooling effect, antiseptic
Carpinus betulus	Leaves	Astringents, sore throat, tonic, fever
Mespilus sp	Fruit	Cardio-tonic, reduce blood pressure
Diospyros lotus	Fruit	Antiseptic, fever, flu, cold, diarrhea

Theme: Stress Physiology

Photosynthesis and water relations in two tree species from the Chinese Loess Plateau under moisture stress

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Abstract

Reforestation with *Robinia pseudoacacia* has been widely performed in the Chinese Loess Plateau for the purpose of soil and water conservation. However, much evidence suggests that this species does not grow well in many parts of the region. By contrast, natural forests of *Quercus liaotungensis* show signs of having high adaptability and making stable ecosystems. Measurements of photosynthesis using current year seedlings revealed that *R. pseudoacacia* exhibited higher assimilation and transpiration rates and lower water use efficiency than *Q. liaotungensis*. Severe water stress induced by withholding water resulted in permanent wilting of most of the pot-cultured seedlings within 14 and 24 days for *R. pseudoacacia* and *Q. liaotungensis*, respectively. The predawn and midday leaf water potentials in both species did not show marked changes until the soil volumetric water content decreased to about 0.05. Then the leaf water potentials exhibited a steady decline for a short period, before they vastly decreased to the stage of permanent wilting. The soil water content at which this steep decline appeared was lower for *Q. liaotungensis* than for *R. pseudoacacia*. The decreases of transpiration and carbon assimilation rates were more gradual in *Q. liaotungensis* than in *R. pseudoacacia*. Regressions of leaf water potentials to assimilation rates showed that both predawn and midday water potentials at an assimilation rate of zero were lower in *Q. liaotungensis* than in *R. pseudoacacia*. The results suggest that *Q. liaotungensis* might be more suitable for the Loess Plateau where the soil water is limited. *R. pseudoacacia* should be planted in relatively water-adequate places to fit its high assimilation rate and water consumption, albeit drought tolerant to some extent.

Introduction

Desertification has long been recognized as a global economic, social and environmental problem and is of special concern to nations in arid and semiarid regions (UNCOD, 1977; UNEP, 1991; UNCED, 1992; UNCCD, 1994). China is implementing a Grain-for-Green project to prevent desertification and reestablish vegetation in the ecologically fragile western regions, yielding millions of hectares of reforested land each year (People's Daily, 2000; Li, 2004). In the Loess Plateau region, where soil erosion is severe, reforestation has been considered to be of great importance for the conservation of soil and water (Cheng and Wan, 2002; Tian et al., 2003). On the other hand, as some trees have a large consumptive use of water, all species can not be encouraged for plantation in this region.

Ecophysiological properties of trees are commonly taken into account when their capacity for growth and stress tolerance is evaluated (Kozlowski and Pallardy, 1997; Larcher, 2003). Species growing in the Loess Plateau region have to be able to respond to ecological conditions of this region that are characterized by soil water deficit and spasmodical distribution of rainfall. In the central Loess Plateau of northern Shaanxi province, apart from a few natural forests dominated by *Q. liaotungensis*, there are many planted

R. pseudoacacia stands of various ages. The latter has been recognized to be the main species for plantation in this region by local governments. Examination of the species in this region has been conducted regarding propagation, plantation techniques and the physiological behavior in relation to nutrient and water conditions (Li et al., 1996; Li et al., 2002; Liu et al., 2003; Shan et al., 2003; Wang et al., 2003; Li and Ma, 2003).

Both *R. pseudoacacia* and *Q. liaotungensis* are reported to be drought tolerant and can therefore survive under the dry soil conditions of this region, and *R. pseudoacacia* is particularly considered suitable because of its rapid growth, nitrogen fixation, and easy method of culture (Zheng, 1985; Shan et al., 2003). However, there has been some evidence that *R. pseudoacacia* is not as resistant to drought as other species indigenous to this region (Wang et al., 1996; Chai and Li ,1996; Chai and Li,1997; Yamamoto et al., 2005). Dieback phenomenon occurs frequently in the mature plantation of *R. pseudoacacia* and many stands show early decline in growth. In contrast, natural forests of *Q. liaotungensis* show high adaptability and ability to make stable ecosystems in this region (Yamanaka et al., 2005). Therefore, it is necessary to reexamine whether the presently used species are appropriate for the prevailing environmental conditions.

In view of these considerations, we investigated the comparative physiological responses of the two above-mentioned species to water stress, so that the local government could be advised on a the right reforestation strategy.

Materials and methods

Plant material and experimental design

A glasshouse experiment was carried out at the Arid Land Research Center, Tottori University, Japan. Seeds of *Robinia pseudoacacia* L. and *Quercus liaotungensis* Koidz. were collected from the northern Shaanxi province of China in late autumn of 2003. They were sown in germination tanks filled with vermiculite in early March 2004, and maintained in a glasshouse at 20-30°C. The germinated plants were transplanted in to 7×7×19.5 cm paper pots containing sand and peat (2/1, v/v). The seedlings were cultured under normal conditions for the subsequent three months, during which they were watered everyday and fertilized once a week using a diluted nutrient solution (Hyponex®, Hyponex, Japan).

Polyvinyl pots of ø15.8 × 19.5 cm were prepared for the stress treatment. Each pot was filled with 5 kg dry sand (3.5 dm^3) with a net-covered drain hole near the bottom for the outflow of excessive water. One week before the start of the treatment, 20 seedlings of each species were selected for their uniformity in size and development. The average stem height and root collar diameter were 40.6 cm and 3.2 mm for *R. pseudoacacia*, and 17.1 cm and 3.0 mm for *Q. liaotungensis*, respectively. Each seedling was carefully washed with clean water to remove all the soil from the roots, and was weighed on an electronic balance. The seedlings were then transplanted in the pots and watered to let the soil reach field capacity. The soil water content for each seedling could thus be monitored by weighing the pots, assuming that the change in seedling weight during the 3- to 4-week consecutive measurements was negligible compared to the change of soil water content. Watering was carried out every evening to replenish the amount lost over the previous 24-h period.

Drought stress treatment was induced by withholding water from 5 July, by which time the seedlings were growing normally. The seedlings of *R. pseudoacacia* and *Q. liaotungensis* were totally dehydrated on days 10-14 and days 17-24 of water withholding, respectively. Therefore, measurements were continued only until day 14 for *R. pseudoacacia* and day 24 for *Q. liaotungensis*.

Measurements of physiological parameters

Leaf water potential, gas exchange, and soil water content were measured at 1- to 3-day intervals after the drought treatment started, with the values measured on 5 July (day 0) as control. Measurements were made on five to six seedlings each time except at the last stage of the treatment when only four or three seedlings were used as many seedlings had dehydrated by that time. All measurements were made on well-expanded leaves. Predawn (Ψpd) and midday (Ψmd) leaf water potentials were measured at about 4:00 and

12:00 h local time, respectively, using a pressure chamber (DIK-7001, Daiki Rika Kogyo Co. Ltd., Tokyo, Japan). For each *Q. liaotungensis* seedling, a single leaf was cut at its base with a sharp blade and placed in the chamber with the petiole end protruding through the opening of the chamber. In the case of *R. pseudoacacia*, a lamina containing five leaflets was used for each measurement. The water potential was recorded as 5 MPa when it was beyond the measuring limit of 5 MPa, i.e. at the final stage of the treatment. Each pot of sampled seedlings was weighed on an electronic balance just after the measurements of predawn water potentials and the soil volumetric water content (θ) was calculated.

Net assimilation (A) and transpiration (E) rates were measured with a portable photosynthesis system (LI-6400, Li-Cor Inc., Lincoln, NE, USA). Measurements were performed at 8:00 – 9:00 h under approximately optimal conditions, with leaves at 27-34°C, leaf-air vapor pressure deficit at 1-4 KPa, and ambient CO_2 concentration at 370-380 µmol mol^{-1}. Light intensity inside the leaf chamber was controlled at photosynthetic active radiation (PAR) of 1800 µmol m^{-2} s^{-1}. Light-response curves for each species were also measured on five to six non-treated (paper-potted) seedlings, with 10 light intensities ranging from 0 to 1800 µmol m^{-2} s^{-1} PAR. Instantaneous water use efficiency (WUE) was calculated by dividing assimilation rate by transpiration (A/E).

Data analysis

As the pace of total water loss varied with the individual seedlings during the drought treatment, we did not take the average for the data of replicated seedlings in each measuring day. Therefore, the effects of water stress on the parameters of water potential and photosynthesis were expressed by dotted graphs with the variable of soil volumetric water content. In the case of light-response curves, the data of replicates were averaged and expressed with standard errors.

Results

Soil water loss and leaf water potential

After the drought treatment was initiated, the soil volumetric water content for *R. pseudoacacia* rapidly decreased and approached 0 at days 10-14. The soil water reduction for *Q. liaotungensis* was rather gradual, with the water content approaching 0 at days 15-24.

The predawn and midday leaf water potentials of the water stressed seedlings in both species did not show marked changes until the soil water content decreased to about 0.05 (Fig. 1). With the progressing water stress, the leaf water potentials decreased. However, the steady decline lasted only for a short period before the drastic decrease to the extent of permanent wilting. The soil water contents at which these steep declines appeared were lower for *Q. liaotungensis* than for *R. pseudoacacia*. This was also illustrated by the logistic curves that were fitted to the water potential changes.

Photosynthesis and transpiration

The rate of photosynthesis and transpiration in both species reduced with the reduction in the soil water content (Fig. 2). These changes showed appearance of a logarithmic function. However, the decreases in both photosynthesis and transpiration were lower in *Q. liaotungensis* than in *R. pseudoacacia*. The

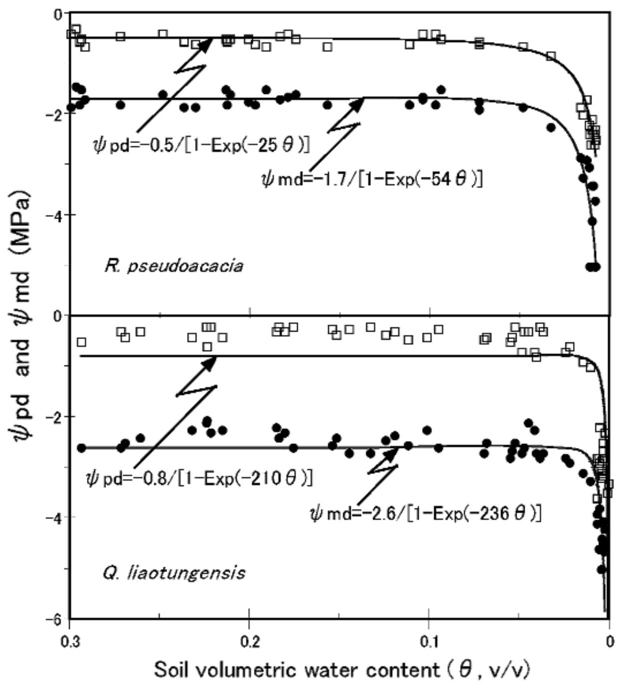

Fig. 1. Predawn (Ψpd) and midday (Ψmd) leaf water potentials of the two species in relation to soil volumetric water content during the soil drying period. Logistic curves were plotted on the parameters.

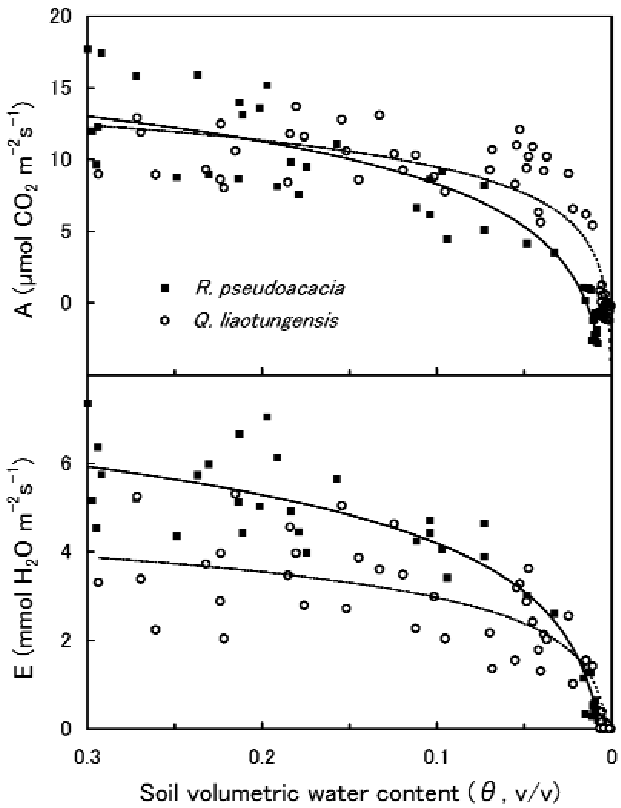

Fig. 2. Photosynthesis (top) and transpiration (bottom) of the two species in relation to soil volumetric water content during the soil drying period. Logarithmic curves were plotted on the parameters.

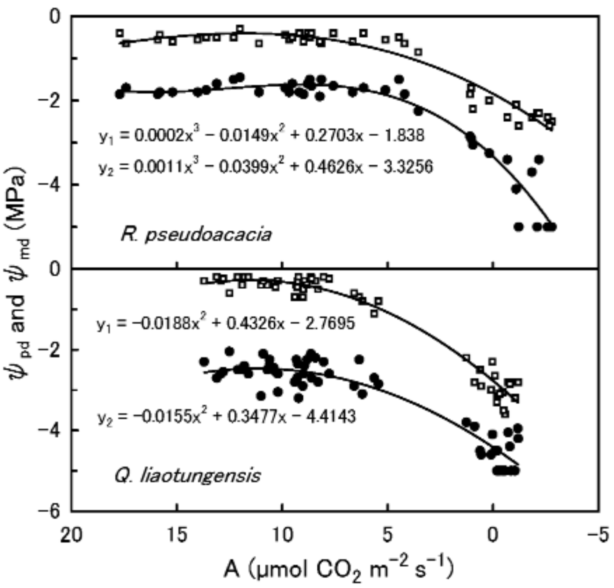

Fig. 3. Predawn and midday leaf water potentials in relation to the photosynthetic rates in each measured day for the two species during the soil drying period.

regression analysis showed that predawn and midday leaf water potentials for *R. pseudoacacia* seedlings at a morning assimilation rate of zero were about -1.84 and -3.33 MPa; respectively, whereas for *Q. liaotungensis* they were as low as about -2.77 and -4.41 MPa, respectively (Fig. 3).

The response of photosynthesis, transpiration and water use efficiency to various intensities of photosynthetic active radiation, PAR (0, 10, 50, 100, 200, 300, 500, 800, 1500 and 1800 μmol m^{-2} s^{-1}) is shown in Fig. 4. Both CO_2 assimilation and transpiration were positively affected as the PAR increased. High intensities of PAR (800-1800 μmol

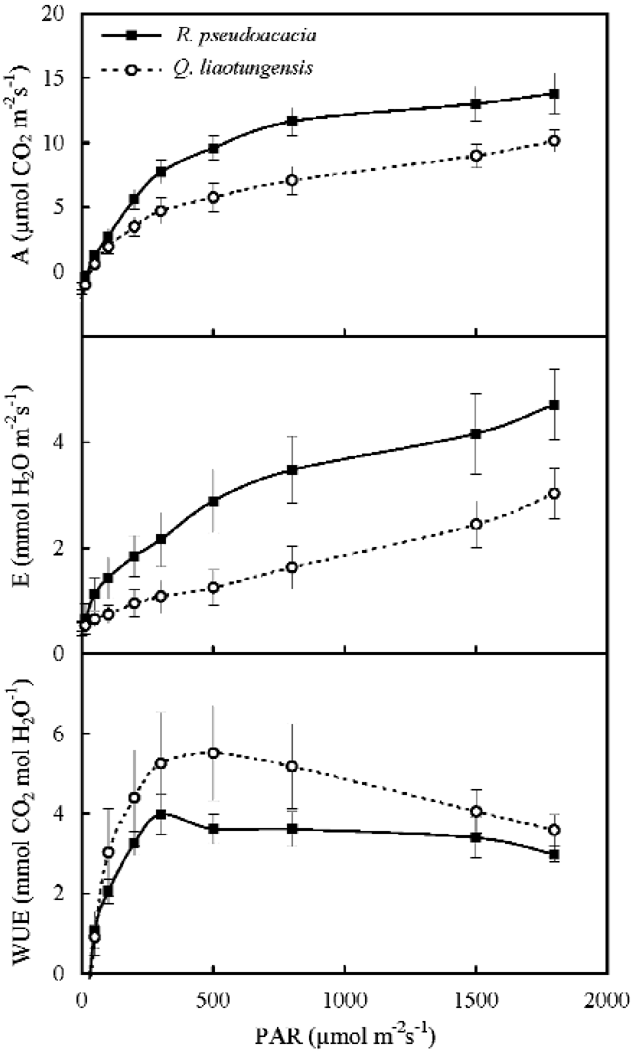

Fig. 4. Leaf photosynthesis (top), transpiration (middle) and instantaneous water use efficiency (bottom) for non-stressed seedlings of the two species at various intensities of photosynthetic active radiation (light-response curves). The data are expressed as mean and standard errors (n=5).

m^{-2} s^{-1}) yielded high assimilation rate. However, the increase in transpiration rate was higher than in the CO_2 assimilation rate. High instantaneous water use efficiency was obtained at 300-1500 µmol m^{-2} s^{-1} PAR for both species. *R. pseudoacacia* seedling exhibited higher assimilation and transpiration rates and lower water use efficiency than *Q. liaotungensis* at all levels of PAR.

Discussion

Generally, water consumption of a plant varies with species and size. The more rapid water loss by *R. pseudoacacia* in the present experiment can be attributed to more number of leaves and higher rate of transpiration in this species than *Q. liaotungensis* seedlings. With the properties of rapid growth, relatively thin leaflets and high rate of photosynthesis, *R. pseudoacacia* tended to tolerate drought conditions with active transpiration or abscission of leaves at the later stage of withholding watering. In contrast, *Q. liaotungensis* seemed to have more economical use of water. It maintained a low rate of photosynthesis at exceedingly low leaf water potentials (Fig. 3).

During the soil drying cycle, the response of the seedlings of both species can be roughly divided into 3 phases (Figs. 1, 2). In the first phase, the physiological parameters, such as photosynthesis and transpiration rates and leaf water potentials, were approximately constant and equal to that of well watered seedlings. This stage covered a wide range of soil water contents. The second stage began when the rate of soil water supply to the seedlings might be less than potential consumption. Stomata were thus sensitive to other environmental conditions and the rates of photosynthesis and transpiration reduced even in the morning. Predawn and midday leaf water potentials were consequently not able to reach their normal levels. Further decline in the soil water content resulted in the start of the third stage which was characterized by a rapid decline in all the parameters. This stage soon finished as a result of permanent wilting. This response pattern has also been observed by similar investigations for other crop species (Sinclair and Ludlow, 1986; Sadras and Milroy, 1996).

Substantial differences between the two species were found in water potentials and gas exchange during the third stage. By plotting either logistic or logarithmic curve on Figs. 1 and 2, it was revealed that the occurrence of the third stage was later in *Q. liaotungensis* than in *R. pseudoacacia*. This difference can be interpreted as a substantial variance in dehydration tolerance between the two species. From these results in combination with the light-response curve, which indicated a lower WUE for *R. pseudoacacia*, it is suggested that *R. pseudoacacia* has lower drought tolerance than *Q. liaotungensis*.

The tree planting in China has always been performed to meet a definite objective. Local governments tried to stop soil erosion in the Loess Plateau region as soon as possible by introducing *R. pseudoacacia*, which would meet the objective in a few years. So far, this species has been planted on a large scale in the Loess Plateau region and its use is still encouraged by the government. Yet few plantations of *R. pseudoacacia* show characteristics of a typical forest ecosystem in this region. The stands show very poor microenvironments and poor diversity, and succession may not take place in them (Otsuki et al., 2005).

For proper reforestation and the development of sustainable agriculture in semiarid regions, water resources must be properly managed. Both reforestation and agriculture can deplete water resources as a result of transpiration by plants (White, 1978; Thomas, 1991). The result of our investigation that *R. pseudoacacia* has a higher photosynthetic rate is consistent with its feature of rapid growth. But the high transpiration rate will inevitably result in large amounts of water consumption. Consequently, a dry soil layer often develops under *R. pseudoacacia* stands, making the forest floor extremely harsh (Hou et al., 1999; Wang et al., 2001).

It is obvious that more scientific support is needed for the application of China's Grain-for-Green policy. The most urgent is to understand what species are appropriate for reforestation in a definite site to form a stable ecosystem with large biodiversity. In the central Loess Plateau region of northern Shaanxi province, *Q. liaotungensis* forests could be established at shady and half-shady slopes, whereas more drought-resistant indigenous species, for example conifers or shrubs, should be planted on sunny slopes to minimize water loss.

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Two distinct low-affinity Na^+ uptake pathways in the halophyte *Sueda maritime* (L.) Dum.

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Abstract

Na^+ uptake by plant roots has largely been explored using species that accumulate little Na^+ into their leaves. Here we report that cAMP and Ca^{2+} (blockers of non-selective cation channels, NSCCs) and Li^+ (a competitive inhibitor of Na^+ uptake) did not have any significant effect on the uptake of Na^+ by the halophyte *Suaeda maritima* when plants were in 25 or 150 mM NaCl (near-optimal for growth). However, TEA^+, Cs^+ and Ba^{2+} (inhibitors of K^+ channels) significantly reduced the net uptake of Na^+ from 150 mM NaCl over 48 h, by 54%, 24% and 29%, respectively. In contrast to the situation in 150 mM NaCl, neither TEA^+ nor Cs^+ significantly reduced net Na^+ uptake in 25 mM NaCl. Ba^{2+} did significantly decrease net Na^+ uptake (by 47%) in 25 mM NaCl. Ba^{2+} significantly reduced $^{22}Na^+$ influx (measured over 2 minutes in 25 mM NaCl) by 41%, but TEA^+ had no effect. The data suggest that neither NSCCs nor LCT (low-affinity cation transporter) are major pathways for Na^+ entry into root cells. We propose that two distinct low-affinity Na^+ uptake pathways exist in *S. maritima*: Pathway 1 is insensitive to TEA^+ or Cs^+, but sensitive to Ba^{2+} and mediates Na^+ uptake under low salinities (25 mM NaCl); Pathway 2 is sensitive to TEA^+, Cs^+ and Ba^{2+} and mediates Na^+ uptake under higher external salt concentrations (150 mM NaCl). Pathway 1 might be mediated by an HKT-type transporter and Pathway 2 by an AKT1-type channel.

Introduction

Common salt, sodium chloride, is an important part of our environment because of its presence in seawater, which has lead to the natural occurrence of tracts of salt-affected land near seashores and in dry regions of the world. However, not all of the land that is salt-affected is of natural occurrence. Because of poor management of agriculture, salt is now also affecting farmland in many parts of the world. The salt reduces yields and, at worst, can make fields useless for cultivation. The total area of salt-affected land is not precisely known, but it is likely to be about a billion hectares (Flowers and Yeo, 1995).

Various mechanisms have evolved in plants to allow them to cope with growing in saline soils; all are based on limiting the concentration of sodium and chloride ions accumulating in the cytosol - since cytosolic enzymes are sensitive to these ions in both glycophytes and halophytes (Flowers et al., 1977; Flowers et al., 1986). The cytosolic concentrations of sodium and chloride are determined by the net fluxes across the plasma membrane and the tonoplast. Unfortunately, it is not yet clear which proteins are involved in the transmembrane movement of Na^+, although a number have been proposed as mediating this process.

Electrophysiological studies suggest that Na+ influx occurs via voltage-independent channels (VICs) or non-selective cation channels (NSCCs), but their precise molecular identities are not known (Tyerman and Skerrett, 1999; Demidchik et al., 2002). A further candidate for mediating sodium transport is a 'Low-affinity Cation Transporter' (LCT) from wheat, although its physiological role remains to be established *in planta* (Schachtman et al., 1997; Amtmann et al., 2001). Another wheat protein, the 'High affinity K Transporter' (HKT1) has been shown to function as a K^+-Na^+ symporter (Schachtman and Schroeder, 1994; Rubio et al., 1995; Gassmann et al., 1996). HKT1 homologs have been cloned from many species of plants and divided into two distinct types according to their properties of Na+ and K+ transport in heterologous expression systems: the arabidopsis AtHKT1 transported only Na+ (Uozumi et al., 2000); rice OsHKT1 showed an AtHKT1-like Na^+-specific transport activity, whereas OsHKT2 showed a wheat HKT1-like K^+-Na+ transport activity (Horie et al., 2001); both eucalyptus EcHKT1 and EcHKT2 mediated Na+ and K^+ uptake (Fairbairn et al., 2000).

Based on the capacity of *Arabidopsis thaliana hkt1* mutations to suppress Na^+ accumulation and hypersensitivity of the *sos3–1* mutant, Rus et al. (2001) proposed that AtHKT1 is a determinant of Na+ entry into plant roots. The evidence from wheat also supports this viewpoint: transgenic wheat plants in which native *HKT1* expression is significantly reduced through the introduction of antisense showed decreased Na+ uptake into roots (Laurie et al., 2002). However, Mäser et al. (2002) and Berthomieu et al. (2003) showed that loss-of-function mutations in the *AtHKT1* gene lead to Na^+ over-accumulation in shoots and rendered plant leaves Na^+ hypersensitive. Taken together with the expression of *AtHKT1* in arabidopsis being restricted to the phloem tissues, a model was proposed in which AtHKT1 would mediate Na^+ loading into the phloem in leaves and unloading in roots, this recirculation removing large amounts of Na^+ from the shoot and playing a crucial role in plant tolerance to salt (Berthomieu et al., 2003; Horie and Schroeder, 2004). However, the model of Na^+ recirculation in the phloem might not be necessary to explain the phenomenon that *hkt1* mutation suppresses Na^+ sensitivity of *sos* mutants and that *AtHKT1* transgene expression increases NaCl sensitivity of arabidopsis. It appears that AtHKT1 controls Na^+ homeostasis *in planta* and thereby determines K^+ nutrient status (Rus et al., 2004). Furthermore, it has yet to be explained how removal of Na^+ from shoots to roots aids a plant. An alternative explanation might be that salt sensitivity is associated with an inability to prevent phloem loading of Na^+.

Compartmentalization of Na^+ and Cl^- in vacuoles is a particularly important aspect of the way plant cells deal with external salt, because the vacuolar ions contribute to osmotic adjustment. Consequently, the properties of the vacuolar membrane, properties determined by the constituent lipids (Leach et al., 1990) and proteins, are a significant aspect of salt tolerance. Of the tonoplast proteins, those involved in transport of Na^+ and Cl- are a Na^+/H^+ antiporter (Hamada et al., 2001; Ma et al., 2004), which is energized by the proton gradient generated by the vacuolar H^+-ATPase and the H^+-PP_iase (Apse et al., 1999; Fukuda et al., 1999; Gaxiola et al., 1999; Gaxiola et al., 2002) and a tonoplast anion channel (White and Broadly, 2001).

The extrusion of cytoplasmic Na^+ out of the cell is another putative route to avoid Na^+ accumulation in the cytosol (Blumwald et al., 2000), although it is not clear how the export of ions to the apoplast aids a plant, since these ions are presumably still available at the plasma membrane. Reducing Na^+ influx must be the key step for controlling Na^+ accumulation, although, as we have noted, the mechanism of plant Na^+ uptake remains largely unknown.

At present, Na^+ uptake by plant roots has been explored using glycophytes (e.g. arabidopsis, rice or wheat) and halophytes (e.g. *Suaeda maritima*, *Thellungiella halophila*, *Puccinellia tenuiflora* and *Mesembryanthemum crystallinum*). Most glycophytes and some halophytes, such as *T. halophila* (Inan et al., 2004; Taji et al., 2004) and *P. tenuiflora* (Wang et al., 2002; Wang et al., 2004), have a strong selectivity for K^+ over Na^+ and absorb limited Na^+ (Wang et al., 2002). *M. crystallinum* possesses epidermal bladder cells in its aerial parts, which store Na^+ (Adams et al., 1998; Su et al., 2002); ion transport in such plants may be confounded with the complex processes of salt secretion and the development of salt bladders. Species in the genus of *Suaeda* are salt-accumulating plants, and have a strong capacity for Na^+ accumulation (Yeo and Flowers, 1980; Wang et al., 2002).

In this study, we used the typical Na^+-accumulating succulent halophyte *Suaeda maritima* to examine its Na^+ influx pathways and found two distinct low-affinity Na^+ uptake pathways. We also present physiological evidence that NSCCs and LCT are not the major pathways for Na^+ entry into root cells of *S. maritima*.

Material and methods

Plant materials and treatments

Seeds of *Suaeda maritima* (L.) Dum. originating from Cuckmere Haven in East Sussex, UK, were germinated at 25°C on filter paper wetted with sterile water. After about 6 days, seedlings were transplanted to sand irrigated with modified Hoagland nutrient solution containing 6 mM KNO_3, 1 mM $NH_4H_2PO_4$, 0.5 mM $MgSO_4$, 0.5 mM $Ca(NO_3)_2$, 60 mM Fe-citrate, 92 mM H_3BO_3, 18 mM $MnCl_2$, 1.6 mM $ZnSO_4$, 0.6 mM $CuSO_4$ and 0.7 mM $(NH_4)6Mo_7O_{24}$. Solution was changed every 3 days. After 18 days in sand culture, the plants were transferred to beakers containing 70 mL of the same modified Hoagland solution and left for 3 days to acclimatise before being used in experiments; each beaker contained 3 plants. The plants were grown in a room, where the temperature ranged from 23-28°C and the relative humidity averaged 65%/75% (day/night); the daily photoperiod was 16/8 h (light/dark and the light flux density during the light period was between 220 and 240 mmol m^{-2} s^{-1}).

Seedlings, which were 21 to 23 days old (with shoots that were about 6 cm in height with young lateral branches), were used to evaluate the effect of inhibitors of ion transport on growth and ion accumulation. Each treatment, which lasted between 48 h and 144 h (see figure and table legends or the text for details) under the conditions described above, had 8 replicates with three plants per beaker. Where tetraethylammonium-Cl (TEA-Cl), CsCl or $BaCl_2$ was included in the treatment, the relative humidity of the growth chamber (Sanyo cabinet; PAR of 200 mmol m^{-2} s^{-1}) was maintained at 100% to minimise the effect of transpiration on Na^+ accumulation, since these three inhibitors caused plants to wilt. For treatments with $BaCl_2$, $MgCl_2$ (0.5 mM) replaced $MgSO_4$ (0.5 mM) in the Hoagland nutrient solution.

Growth measurements and Na^+ and K^+ concentration determination

At the end of the treatment, plant roots were washed twice for 8 min in ice-cold 20 mM $CaCl_2$ to exchange cell-wall-bound Na^+ and the shoots rinsed in deionised water to remove surface salts. Root, stem and leaf were separated and blotted; fresh weights were determined immediately and samples oven-dried at 70°C for 3 d to obtain dry weights. Tissue water content was calculated from the difference between fresh and dry weights. Na^+ and K^+ were extracted from dried plant tissue in 100 mM acetic acid at 90°C for 2 h, and ion analysis was performed using an atomic absorption spectrophotometer (Unicam SP919, Cambridge, UK).

$^{22}Na^+$ influx experiments

Three-week-old *S. maritima* seedlings were used to evaluate $^{22}Na^+$ influx according to the method described by Essah et al. (2003). Briefly, roots with 4 cm of attached main stem were excised and pre-treated for 10 minutes in nutrient solution (15 mL) containing 25 mM unlabled NaCl, with a change of solution after five minutes, and then transferred to a Hoagland uptake solution (5 mL) containing 25 mM NaCl plus 37 to 185 kBq L^{-1} of $^{22}Na^+$. After two minutes, roots were removed from the uptake solution, blotted and transferred to 200 mL of ice-cold NaCl (25 mM plus 10 mM $CaCl_2$), for two successive rinses of 2 minutes in fresh solution and then a further rinse of 3 minutes. Finally, the roots were blotted gently, weighed and transferred to plastic vials containing 2.5 mL of Optiphase Hisafe (Fisher Chemicals, Loughborough) and the uptake of Na determined using a scintillation counter (Wallac Rackbeta).

Results of growth, ion concentration, water status and $^{22}Na^+$ influx rate of plants are presented as averages with standard deviations.

Statistical analysis

Statistical analyses, one-way ANOVA and Duncan’s multiple range test, were performed using software (SPSS).

Results

Suaeda maritima grows optimally in salt concentrations of about 150 mM sodium chloride (Yeo and Flowers, 1980) and accumulates sodium ions in its leaves to concentrations of around 5 mmoles per g dry weight. Little is known, however, of the proteins that might mediate sodium transport in this or any other halophytes. In order to throw light on the way in which sodium ions enter the root of *S. maritima*, we have examined the effects of a range of inhibitors on growth and ion uptake.

Effects of cAMP, Ca^{2+} and Li^+ on growth and ion accumulation of Suaeda maritima growing at near-optimal salinity (150 mM NaCl)

We evaluated the effects of cAMP and Ca^{2+}, which inhibit Na^+ influx through non-selective cation channels (NSCCs) (Maathuis and Sanders, 2001; Demidchik and Tester, 2002), and Li^+, which is considered an analogue of Na^+ and is a competitive inhibitor for Na^+ uptake and transport (Serrano, 1996; Rubio et al., 2004). Compared to control (plus NaCl, but no inhibitor), cAMP (500 mM), Li^+(10 mM) and Ca^{2+}(10 mM) did not have any significant effect on fresh or dry weight or tissue water content of leaf, stem or root (Fig. 1); neither did they have any significant effect on Na^+ or K^+ concentrations in different plant parts (Fig. 2). Prolonging the treatment time from 48 h to 144 h did not induce any significant effect of cAMP, Li^+ or Ca^{2+} on fresh or dry weight, tissue water content or K^+ concentrations of *S. maritima* (data not presented). Na^+ concentrations were only significantly decreased in the stem by Ca^{2+} - by 18% compared to control but Ca^{2+} did not significantly reduce whole plant Na^+ content, because 81% of Na^+ was accumulated in the leaf and only 14% in the stem.

Effects of various K^+ channel blockers on growth and ion accumulation of Suaeda maritima growing at near-optimal salinity (150 mM NaCl)

TEA^+ and Cs^+ inhibit K^+ uptake through most K^+ channels and some other transporters (Hedrich and Schroeder, 1989; Tester, 1990). In preliminary experiments (data not presented), we found that plants whose roots were treated with TEA^+ and Cs^+ wilted, an effect not seen with other inhibitors we used. So, in the experiments involving TEA^+ and Cs^+ treatments, we reduced transpiration by keeping the plants in a chamber with 100% RH. Under these conditions, TEA^+ and Cs^+ significantly decreased leaf fresh weight (by 46% and 42% compared with the control, respectively; Fig. 1). TEA^+ also decreased leaf dry weight (by 29%; Fig 1); the effect of Cs^+ was not statistically significant. Leaf tissue water content was significantly reduced by both TEA^+ (by 48%) and Cs^+ (by 45%) treatments compared with the control (Fig. 1). TEA^+ also significantly decreased stem fresh weight (27%) and stem tissue water content (28%) and decreased root fresh weight (by 29%) and dry weight (30%); Cs^+ did not have a significant effect on fresh and dry weight or tissue water content of stem and root (Fig. 1).

The exposure of plants to external Na^+ invariably leads to an increase in the concentration of that ion in the plant. TEA^+, however, significantly decreased Na^+ concentrations in leaf, stem and root by 48%, 45% and 21%, respectively, compared with corresponding organs of control plants, which were treated with NaCl, but not the

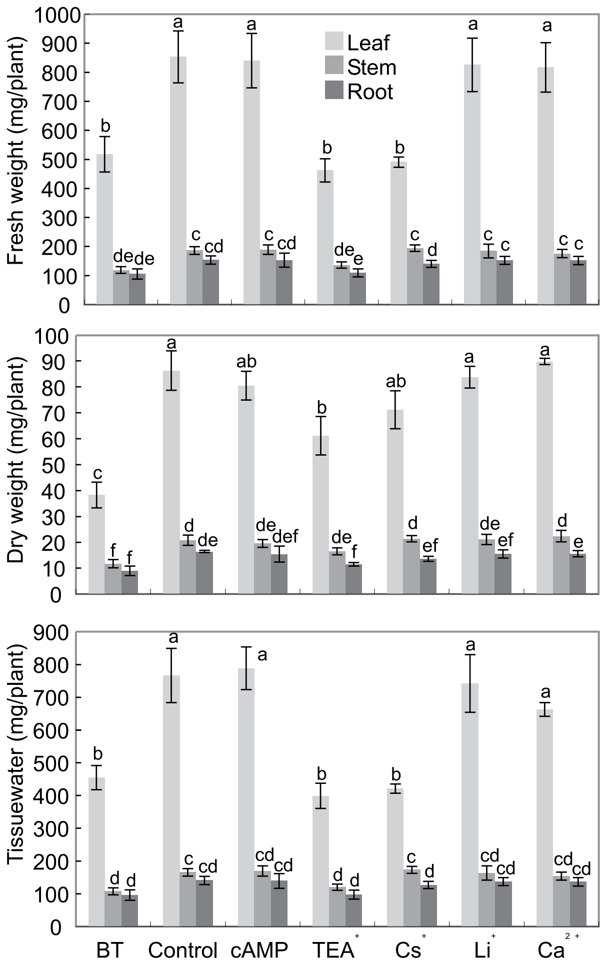

Fig. 1. Growth and tissue water content of *S. maritima* seedlings in response to treatment with NaCl (150 mM), cAMP(500 M), TEA+ (10 mM), Cs+ (3 mM), Li+ (10 mM), or Ca^{2+} (10 mM). BT represents 'Before Treatments'. Values are averages ± SD (n=24). Columns with different letters indicate significant difference at P<0.05 (Duncan test).

inhibitor (Fig. 2A). Although Cs^+ treatment also reduced Na^+ concentrations in leaves, the concentrations in stems and roots increased (Fig.2A). Further analysis of the data showed that while TEA^+ altered the quantity of Na^+ in different plant parts, it had little effect on its distribution within the plant (Table 1). However, Cs^+ reduced the quantity of Na^+ in leaf tissue and increased the proportion in the stem (Table 1).

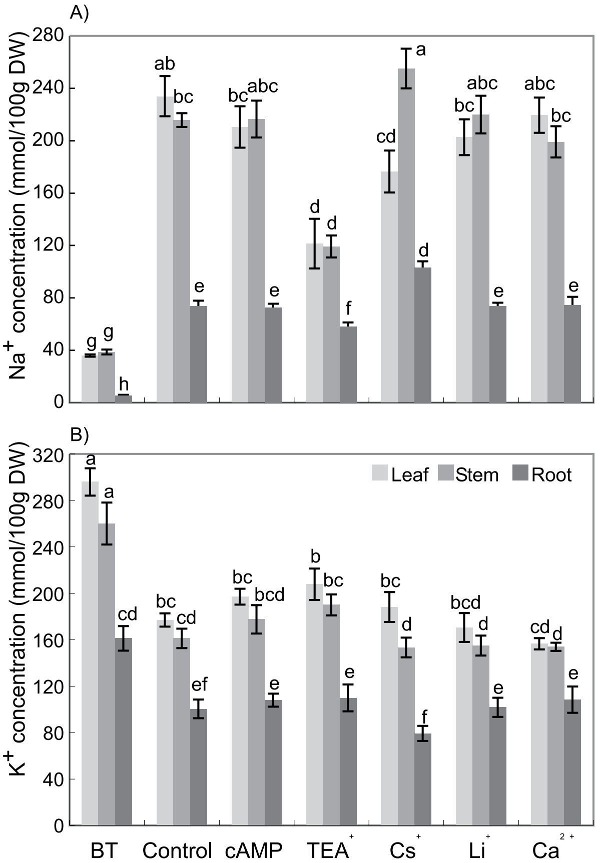

Fig. 2. Na^+ and K^+ concentrations in *S. maritima* seedlings treated with NaCl (150 mM), cAMP(500 M), TEA^+ (10 mM), Cs^+ (3 mM), Li^+ (10 mM), or Ca^{2+} (10 mM). BT represents 'Before Treatments'. Values are averages ± SD (n=8). Columns with different letters indicate significant difference at P<0.05 (Duncan test).

K^+ concentrations in salinised plants fell when compared with the situation before salinisation (Fig. 2B). However, neither TEA^+ nor Cs^+ (nor any of the other inhibitors used) had any effect on the K^+ concentration in leaf, stem or root (Fig. 2B). After a NaCl treatment of 48 h, TEA^+ and Cs^+ slightly reduced K^+ content of the whole plant compared with Na^+ content (data not presented). These plants had been grown in 6 mM K^+ external solution and we did not add Na^+ to the solution until the treatment, so the K^+ content was high (159.10±21.20 μmol/plant) and Na^+ content was low (18.85±2.51 μmol/plant). This suggests that the high K^+ background is the reason why TEA^+ and Cs^+ - the inhibitors of K^+ channels and transporters - did not significantly affect K^+ content in our experiments.

Effects of inhibitors on growth, tissue water and ion concentrations of *S. maritima* growing in 25 mM NaCl

Although the optimal salinity for the growth of *S. maritima* is around 150 mM NaCl, about 85% of growth measured as organic dry weight is achieved in 25 mM NaCl (Yeo and Flowers, 1980), allowing separate assessment of the response that stimulates growth from that which requires osmotic adjustment for survival. Treating plants growing in 25 mM NaCl for 144 h with Li^+ or cAMP did not have any significant effect on fresh and dry weight or tissue water content when compared to control plants (data not presented). Ca^{2+}, on the other hand, significantly increased root fresh weight and tissue water content by 39% and 43%, respectively; however, Ca^{2+} had no significant effect on root, stem and leaf dry weight. Although Ca^{2+} had no effect on shoot growth, it did reduce the Na^+ concentration in the stem (by 23%) and raise that of K^+ in the root (by 40% - where the root water content was increased). cAMP also increased the root K^+ concentrations (by 28%, data not presented) compared to control

Table 1. Effect of TEA^+ and Cs^+ on Na^+ relative distribution in different plant parts. The quantity of sodium in each plant part was calculated from the data in figures 1 and 2 and used to calculate the proportions of the total quantity in each part.

Treatments	Total quantity (μmol / plant)	Na^+ proportion (%)		
		Leaf	Stem	Root
Control	259.22±22.61	78	17	5
TEA^+	100.71±11.02	74	20	6
Cs^+	194.30±16.97	65	28	7

plants. Even though Ca^{2+} improved water status and Na^+ or K^+ concentrations in some parts of *S. maritima* at low external NaCl concentrations, none of these substances (Li^+, cAMP, Ca^{2+}) significantly affected whole plant Na^+ and K^+ contents (data not presented).

We also examined the effects of TEA^+ (10 mM) and Cs^+ (3 mM) at the lower concentration of 25 mM NaCl on *S. maritima* in a chamber with 100% RH. TEA^+ severely reduced fresh weight and tissue water in leaf and stem of *S. maritima* (Fig. 3); Cs^+ significantly decreased leaf fresh weight and tissue water by 26% and 30% compared with the control, respectively. Neither TEA^+ nor Cs^+ had any effect on the dry weight of leaves or roots; TEA^+ reduced the dry weight of stem by 32%; Cs^+ did not significantly affect stem dry weight (data not presented). Although TEA^+ significantly decreased stem Na^+ concentrations by 16% (Fig. 4), its effects were generally much smaller than at the higher external concentration of NaCl (150 mM; Fig. 2). TEA^+, as at the higher salt concentration, again increased stem K^+ concentration, and significantly in this case, by 42% (cf Figs 2 and 4). Cs^+ significantly increased root Na^+ concentrations by 51% and decreased root K^+ concentrations by 34% compared to control (Fig. 4). However, TEA^+ and Cs^+ did not significantly affect whole plant Na^+ and K^+ contents (data not presented).

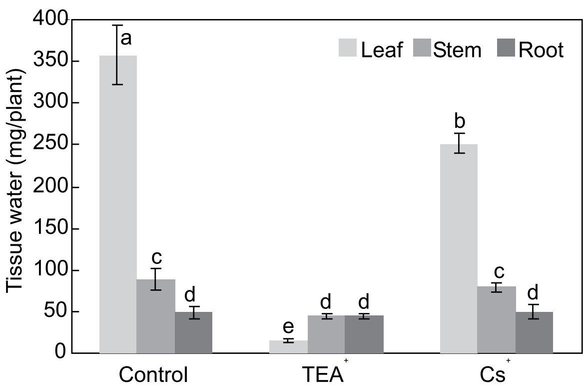

Fig. 3. Tissue water content of *S. maritima* seedlings in response to treatment with NaCl (25 mM), TEA+ (10 mM) or Cs+ (3 mM). Values are averages±SD (n=24). Columns with different letters indicate significant difference at P<0.05 (Duncan test).

Effect of TEA^+ and Cs^+ on net uptake of Na^+

TEA^+ significantly reduced the net uptake of Na^+ from 0.56±0.04 mmol g^{-1} fresh weight min^{-1} in the untreated plants growing in 150 mM NaCl to 0.26±0.03 mmol g^{-1} fresh weight min^{-1} (Table 2).

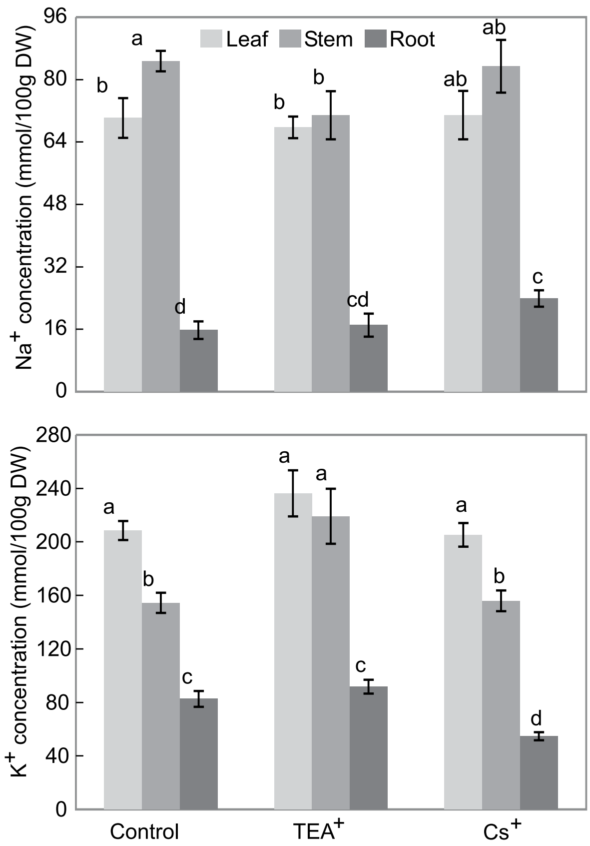

Fig. 4. Na^+ and K^+ concentrations in *S. maritima* seedlings treated with NaCl (25 mM), TEA^+ (10 mM) or Cs^+ (3 mM). Values are averages±SD (n=8). Columns with different letters indicate significant difference at P<0.05 (Duncan test).

Table 2. Effect of TEA^+ and Cs^+ on net Na^+ flux (μmol g^{-1} fresh weight root min^{-1}) of *S. maritima* growing in different salt concentrations for 48 h. Different letters within the same row indicate significant differences at P<0.05 (Duncan test).

NaCl concentration (mM)	Inhibitor		
	None (control)	TEA^+	Cs^+
150	0.56±0.04 a	0.26±0.03 c	0.43± 0.03 b
25	0.20±0.02 a	0.15±0.01 a	0.18±0.03 a

Net uptake of Na^+ in the presence of Cs^+ (0.43±0.03 mmol g^{-1} fresh weight min^{-1}) was significantly different from that of the control plants (plus 150 mM NaCl, but without inhibitor; Table 2). These results suggest that TEA^+ strongly inhibits Na^+ absorption by the root, but did not affect Na^+ transport within the plant; Cs^+ not only inhibited Na^+ uptake, but also blocked Na^+ transport to the leaves, causing a greater portion of Na^+ to be retained in the stem and root in comparison with control (Table 1). In contrast to the situation in 150 mM NaCl, 10 mM TEA^+ or 3 mM Cs^+ did not significantly reduce net Na^+ flux (the net quantity of Na^+ absorbed by the plant per unit of root and per unit of time) of *S. maritima* growing in 25 mM NaCl (Table 2).

Ba^{2+} inhibits Na^+ uptake of *S. maritima* both in 25 mM and 150 mM external NaCl

Ba^{2+} is known to be another K^+ channel blocker in plants (Tester, 1988; Kelly et al., 1995) dramatically reducing K^+ uptake mediated by K^+ transporters - AtKUP1, EcHKT1 or EcHKT1 (Fu and Luan, 1998; Fairbairn et al., 2000). Ba^{2+} also inhibited Na^+ uptake mediated by OsHKT1 or OsHKT4 and completely inhibited Na^+ uptake in rice roots (Garciadeblas et al., 2003). Thus, we tested the effects of Ba^{2+} on Na^+ and K^+ uptake in *S. maritima* under different external NaCl concentrations.

Plant dry weight was not affected significantly over the period of treatment (48 h) by the different concentrations of NaCl with or without 5 mM Ba^{2+} (data not presented). However, Ba^{2+} had a remarkable effect on water content: Ba^{2+} severely decreased tissue water both in leaf, stem and root of *S. maritima* in the absence of added NaCl to the culture solution (Fig. 5). However, although Ba^{2+} still significantly reduced fresh weight (data not presented) and tissue water in different parts of plants growing in 25 mM NaCl, leaf water status (25NaBa treatment) was much better in the presence than in the absence of salt (0NaBa treatment). Under 150 mM NaCl, Ba^{2+} significantly reduced tissue water in leaf and root, but not in the stem.

In the absence of added NaCl (the culture solution contains a trace quantity of NaCl), Ba^{2+} did not significantly affect Na^+ concentrations in different plant parts of *S. maritima* although it decreased leaf and root K^+ concentrations by 12% and 18%, respectively, compared to control plants. Under 25 mM NaCl, Ba^{2+} significantly decreased leaf and root Na^+ concentrations by 58% and 30%, respectively; and Ba^{2+} significantly decreased stem and root K^+ concentrations by 19% and 26%, respectively. Under 150 mM NaCl, Ba^{2+} significantly decreased leaf and root Na^+ concentrations by 51% and 36%, respectively; and Ba^{2+} significantly decreased root K^+ concentrations by 29% (Fig. 6). However, Ba^{2+} did not significantly affect whole plant K^+ contents under either 25 mM NaCl or 150 mM NaCl (data not presented).

Ba^{2+} significantly decreased whole plant Na^+ content by 56% under 25 mM NaCl and by 49% under 150 mM NaCl; correspondingly, net Na^+ fluxes were lowered by 47% and 29%, respectively (Table 3). Ba^{2+} significantly reduced net ion uptake at both 25 and 150 mM NaCl, in contrast to TEA^+ and Cs^+ where Na^+ uptake was not inhibited under low 25 mM external NaCl. The net Na^+ fluxes were calculated from uptake data obtained over 48 h; to confirm our finding we performed short time $^{22}Na^+$ uptake experiments.

$^{22}Na^+$ influx in *S. maritima* and the inhibitory effects of TEA^+ and Ba^{2+} in 25 mM NaCl

In order to investigate the effects of inhibitors on Na^+ influx, rather than net accumulation, we used whole root systems of *S. maritima* attached to

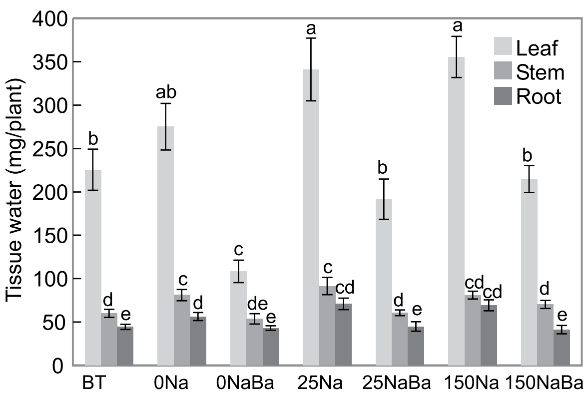

Fig. 5. The effect of different external concentrations of NaCl, with or without 5 mM Ba^{2+}, on the water content of *S. maritima* seedlings. BT represents Before Treatments. The figure preceding Na is its concentration in the culture solution; Ba signifies the presence of 5mM Ba^{2+}. Values are averages±SD (n=24). Columns with different letters indicate significant difference at P<0.05 (Duncan test).

about 4 cm of stem. The cut shoot remained above the level of the loading solution containing $^{22}Na^{+}$ and this arrangement not only facilitated handling root systems but also enabled us to determine influx to the roots and transport to the stem. Influx to the roots was linear over the first two minutes of exposure to $^{22}Na^{+}$, as for arabidopsis (Essah et al., 2003), after that, root $^{22}Na^{+}$ content increased gradually and in the same time $^{22}Na^{+}$ began to accumulate in the remnant of the stem. The influx of $^{22}Na^{+}$ into the root at 1 or 2 minutes was about twice net influx at 5 minutes (Fig.7). Ba^{2+} significantly reduced Na^{+} influx (estimated over a period of 2 min) from 0.44±0.06 mmol g^{-1} fresh weight min^{-1} to 0.26±0.02 mmol g^{-1} fresh weight min^{-1} – an inhibition of 41%; TEA^{+} did not have a significant effect on influx (an influx of 0.41±0.04 mmol g^{-1} fresh weight min^{-1} in the presence of 10 mM TEA^{+}).

Na^{+} alleviation of wilting of *S. maritima* induced by Ba^{2+} or TEA^{+}

We observed that plants of *S. maritima* wilted severely after adding Ba^{2+} (5 mM) for 48 h in the absence of NaCl; in the presence of 25 mM NaCl, Ba^{2+} treatment brought about only slight wilting and in 150 mM NaCl the plants did not wilt at all when treated with Ba^{2+}. This observation was in accordance with leaf water status shown in Fig. 5, where for plants grown in the presence of Ba^{2+}, leaf water content was higher in the higher external Na^{+}. Na^{+} concentrations in leaf, stem and root of 25NaBa treatment increased 2.3, 3.6 and 5.5-fold in comparison with the corresponding parts of 0NaBa treatment; and for 150NaBa treatment, Na^{+} concentrations increased by 5.2, 7.1 and 10.3 fold, respectively (Fig. 6). However, K^{+} concentrations in leaf and root of 25NaBa or 150NaBa treatment were not significantly different from the corresponding parts of plants in the 0NaBa treatment; only stem K^{+} concentrations were lowered - by 15% for the 25NaBa treatment and by 17% for the 150NaBa treatment (data not shown). It appears that Na^{+} alleviates the wilt symptom of *S. maritima* caused by Ba^{2+}.

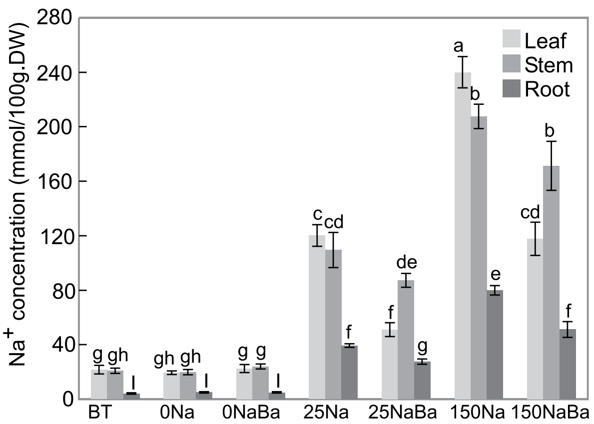

Fig. 6. Na^{+} concentrations in *S. maritima* seedlings treated under different concentrations of NaCl with or without 5mM Ba^{2+}. BT represents Before Treatments. The figure preceding Na is its concentration in the culture solution; Ba signifies the presence of 5mM Ba^{2+}. Values are averages±SD (n=8). Columns with different letters indicate significant difference at P<0.05 (Duncan test).

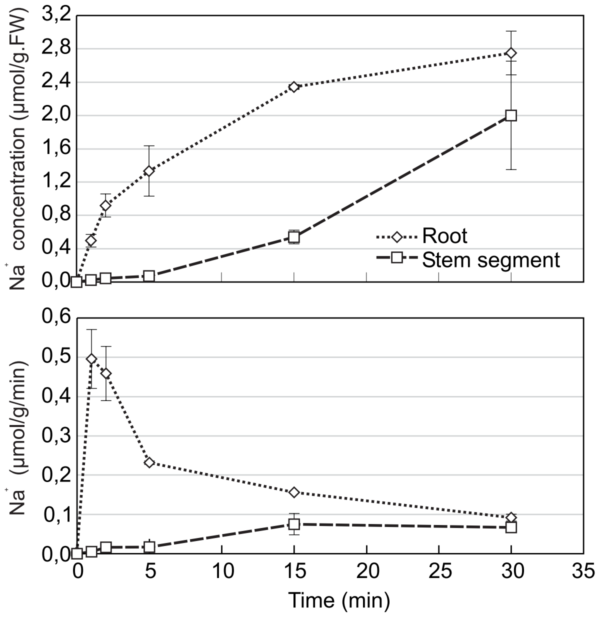

Fig. 7. $^{22}Na^{+}$ concentration (per unit fresh weight) and $^{22}Na^{+}$ in excised root and stem segments of three-week-old *S. maritima* seedlings after transfer into 25 mM NaCl labeled with $^{22}Na^{+}$. Values are averages±SD (n=3).

Table 3. Effect of Ba^{2+} on whole plant Na^{+} content (µmol/plant) and root net Na^{+} flux (µmol g^{-1} fresh weight root min^{-1}) of *S. maritime.* Different letters within the same row indicate significant differences at P<0.05 (Duncan test).

	BT	25Na	25NaBa	150Na	150NaBa
Na^{+} content	6.96±0.56 d	49.90±5.61 b	21.93±1.35 c	99.85±7.73 a	51.13±4.40 b
Na^{+} flux		0.19±0.02 c	0.10±0.01 d	0.43±0.02 a	0.31±0.03 b

A similar phenomenon was also observed in the presence of TEA$^+$ (10 mM): with decreasing external NaCl concentrations from 150 mM to 0 mM, wilting increased. Na$^+$ alleviated TEA$^+$-induced wilting of *S. maritima*. These visible symptoms again reflected changes in plant water content (Fig. 8): leaf water content increased 11-fold in 75 mM NaCl when compared to plants grown in the absence of NaCl; leaf water content increased 25-fold under 150 mM NaCl in comparison with the absence of external NaCl. In plants grown in 25 mM NaCl, Na$^+$ concentrations in leaf, stem and root increased 2.2, 2.0 and 3.1-fold, respectively; in 75 mM NaCl the increases were

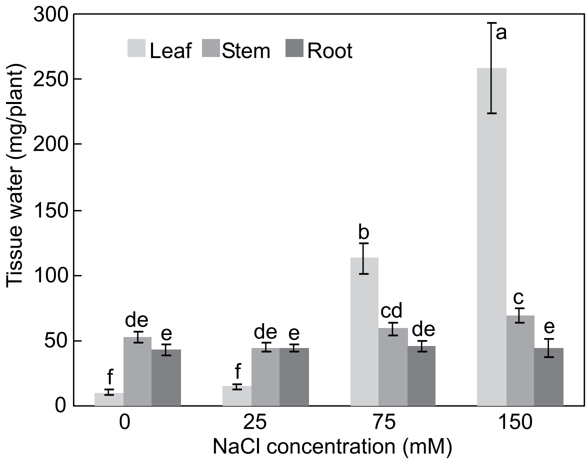

Fig. 8. Tissue water content in *S. maritima* seedlings treated with 10 mM TEA$^+$ and different concentrations of NaCl. Values are averages±SD (n=24). Columns with different letters indicate significant difference at P<0.05 (Duncan test).

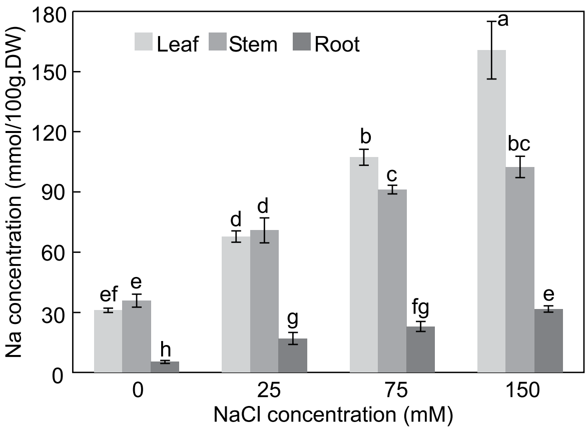

Fig. 9. Na$^+$ concentrations in *S. maritima* seedlings treated with 10 mM TEA$^+$ and different concentrations of NaCl. Values are averages±SD (n=8). Columns with different letters indicate significant difference at P<0.05 (Duncan test).

3.4, 2.5 and 4.3-fold and in 150 mM NaCl, 5.2, 2.9 and 5.9 fold - all in comparison with plants growing in the absence of external NaCl (Fig. 9). K$^+$ concentrations in leaf and stem in plants grown in 25, 75 and 150 mM NaCl treatments were not significantly different from the corresponding parts of plants grown without external NaCl, only in the root was the K$^+$ concentrations of plants grown in the absence of NaCl lower than in salt-treated plants (data not shown).

Discussion

S. maritima is a halophilic member of the Chenopodiaceae, a family characterized by the tolerance of many of its members towards salinity (Flowers et al., 1977). *S. maritima* not only tolerates high levels of salinity (at least 300 mM NaCl), but also makes its optimal growth in saline conditions (Yeo and Flowers, 1980; Clipson, 1987). The accumulation of salt in vacuoles is particularly evident in *S. maritima*, which has succulent leaves with enlarged cells in which the vacuoles occupy most of the volume (Hajibagheri et al., 1984); the degree of vacuolation of its root cortical cells was also greatly increased under saline conditions (Hajibagheri et al., 1985). Interestingly, *S. maritima* does not survive on concentrations of KCl that would be optimal for NaCl (Yeo and Flowers, 1980), perhaps due to the higher leakage of K$^+$ than of Na$^+$ from the leaf cell vacuoles (Yeo, 1981). *S. maritima* shows a marked contrast in its response to potassium and sodium.

All plants are able to discriminate between Na$^+$ and K$^+$ and most show high selectivity for K$^+$ over Na$^+$ (Pitman, 1988; Maathuis and Amtmann, 1999). Amongst 15 species of the Chenopodiaceae tested for Na$^+$ and K$^+$ accumulation under similar conditions, *S. maritima* had amongst the highest accumulation of Na$^+$ and the lowest K/Na ratio (Reimann and Breckle, 1993). Net accumulation of Na$^+$ (and Cl$^-$) in a plant is the end result of processes of both passive influx and active efflux (Tester and Davenport, 2003). For *S. maritima*, there is evidence that once accumulated in vacuoles, Na$^+$ is largely retained within the plant (Yeo, 1981) due to the low permeability of its vacuolar membranes to Na$^+$ (Leach et al., 1990). Although the flux of Na$^+$ through the roots of *S. maritima* has been calculated and an argument for the importance of the symplast in transport across the root made (Yeo and Flowers, 1986), the means by which ions enter the symplast is as yet unknown.

The evidence *in planta* did not support NSCCs and LCT as the major pathways for Na^+ entry into root cells

It has been considered that voltage-independent channels (VICs) or non-selective cation channels (NSCCs) and a low-affinity cation transporter (LCT) are the major pathways for Na^+ uptake (Schachtman et al., 1997; Amtmann and Sanders, 1999; Tyerman and Skerrett, 1999; Amtmann et al., 2001; Demidchik et al., 2002). NSCCs and the LCT are characterized by Ca^{2+}, cAMP and cGMP inhibition of ion conductance and Na+ influx (Clemens et al., 1998; Maathuis and Sanders, 2001; Demidchik and Tester, 2002; Tyerman, 2002; Essah et al., 2003; Antosiewicz and Hennig, 2004). However, our results indicate that Ca^{2+} and cAMP did not significantly affect whole plant Na^+ contents of *S. maritima* under either 25 mM or 150 mM NaCl treatment for 48 h or 144 h. The absence of any effects of Ca^{2+} suggests that LCT is not involved in the uptake of sodium by *S. maritima*. As far as NSCCs are concerned these are also unlikely conduits for Na^+ as they are not inhibited by Cs^+ and TEA^+ (Demidichik and Tester, 2002, Table 1 shows that both Cs^+ and TEA^+ actually permeate the channel, so they don't block and in *T. halophila*, neither TEA^+ nor Cs^+ block the voltage-independent current; Volkov and Amtmann, pers. comm.).

Pathway 1 of low-affinity Na^+ uptake might be mediated by a HKT-type transporter

Over 48 h in 25 mM NaCl, the K^+ channel blocker Ba^{2+} significantly decreased (by 47%, Table 3) the net flux of Na^+ by the roots of *S. maritima*, but two other K^+ channel blockers, TEA^+ and Cs^+, were without effect (Table 2). $^{22}Na^+$ influx measurements made over 2 min exhibited exactly the same characteristics: Ba^{2+} significantly reduced $^{22}Na^+$ influx (by 41%), but TEA^+ had no effect. This finding is in agreement with previous reports about the influx of $^{22}Na^+$ into the roots of *A. thaliana* where neither TEA^+ nor Cs^+ had any inhibitory effect, but Ba^{2+} significantly reduced uptake in 50 mM NaCl (Essah et al., 2003). Essah et al. (2003) reached the conclusion that Na^+ influx did not occur via HKT1 or a K^+ channel, as neither a mutant disrupted in *HKT1* (*hkt1-3*) nor a root K^+ channel knockout mutant (*akt1*) differed in Na^+ influx from their wild type; also Na^+ influx was unaffected by TEA^+ and Cs^+. Other published results are at variance with this conclusion. In the yeast heterologous expression system and in Na^+ depletion experiments, Garciadeblas et al. (2003) found that Ba^{2+} inhibited Na^+ uptake mediated by OsHKT1 or OsHKT4 and completely inhibited Na^+ uptake in rice roots, but TEA^+ showed no effect under low external Na^+ concentrations. EcHKT1 and EcHKT2 mediating K^+ uptake were also strongly blocked by Ba^{2+} but less so by Cs^+; TEA^+ was ineffective (Fairbairn et al., 2000; Liu et al., 2001). These results demonstrate that HKTs possess the pharmacological property of insensitivity to TEA^+ and Cs^+ and great sensitivity to Ba^{2+}. This makes HKT a prime candidate for mediating the uptake of Na^+ through Pathway 1.

Pathway 2 of low-affinity Na^+ uptake might be mediated by an AKT1-type channel

At a higher concentration of NaCl (150 mM), TEA^+, Cs^+ and Ba^{2+} significantly reduced net Na^+ fluxes in *S. maritima* by 54%, 24% and 29% (Tables 2 and 3); after 48 h treatment, whole plant Na^+ content was decreased 61%, 25% and 49%, respectively (Tables 1 and 3). As mentioned above, HKT is insensitive to TEA^+ and Cs^+, so it could not be involved in Na^+ absorption in conditions of high salinity. The divergence between *OsHKT1* expression and Na^+ accumulation also strongly supports this viewpoint: *OsHKT1* transcription is down-regulated in roots of 3 week old rice seedlings after 150 mM NaCl stress for 24 h; meanwhile Na^+ concentrations in the roots and leaves increased 20 times and 80 times, respectively (Golldack et al., 2002). The inward rectifying K^+ channel AKT1 is sensitive to TEA^+, Cs^+ and Ba^{2+}, and is involved in plant root K^+ uptake from the soil solution (Maathuis et al., 1997; Hirsch et al., 1998). It has also been proposed that AKT1 could mediate a significant Na^+ uptake with an increase in external Na^+ concentrations (Amtmann and Sanders, 1999; Blumwald et al., 2000). This viewpoint was supported by the coincidence of *OsAKT1* expression with Na^+ accumulation in rice (Golldack et al., 2003). Furthermore, plant AKT1-type K^+ channel shows homology to animal Shaker-type K^+ channels both at the sequence and structure levels (Very and Sentenac, 2003). Several studies have shown that substantial Na^+ can permeate animal Shaker K^+ channels at very positive potentials; this Na^+ permeation is often most prominent in the C-type inactivated state of the channels (Lopez-Barneo et al., 1993; Callahan and Korn, 1994; Starkus et al., 1997; Kiss et al., 1998; Ogielska and Aldrich, 1998; Starkus et al., 1998; Yellen, 1998; Kiss et al., 1999; Ogielska and Aldrich, 1999; Starkus et al., 2000; Wang et al., 2000). Taken together, the available data, including our study showing classical K^+ channel blockers TEA^+, Cs^+ or Ba^{2+} strongly inhibit root Na^+ uptake, indicate involvement of AKT1-type channel in the absorption of Na^+ under severe salt stress.

Alleviation by Na^+ of the effects of K^+ channels blockers on tissue water relations

Our data show that TEA^+, Cs^+ and Ba^{2+} significantly reduced leaf water content (TEA^+ by 96%, Cs^+ by 30% and Ba^{2+} by 44% in 25 mM NaCl; and by 48%, 45% and 40%, respectively in 150 mM NaCl for 48 h - Fig. 1, Fig. 3 and Fig. 5). This suggests that the three typical K^+ channels blockers either reduced the hydraulic conductivity of *S. maritima* and caused wilting of the leaves or caused an increase in the ion concentrations in the leaf cell walls, a process that reduces leaf turgor (Clipson et al., 1985). Our results show that under TEA^+ or Ba^{2+} treatments, with increasing external NaCl concentrations, the leaf Na^+ concentrations in *S. maritima* increased (Fig. 6 and Fig. 9), improving leaf water status (Fig. 5 and Fig. 8), and alleviating wilting. Perhaps at the low external Na+ concentration, Na^+ and/or K^+ uptake is blocked at the leaf plasma membrane, leaving these ions in the cell walls and reducing turgor. At higher external sodium concentrations, the higher vacuolar ion concentrations alter the balance between cell walls and the protoplast: such changes are not reflected in tissue ion concentrations owing to the small capacity of the cell wall fraction. However, it has been demonstrated that TEA^+ blocks the water permeability through human aquaporin-1 channels expressed in *Xenopus* oocytes (Brooks et al., 2000), so this effect may also influence the movement of water into the leaf cells.

Acknowledgements

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The impact of irrigation water quality on water uptake by citrus trees

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Abstract

The impact of saline water irrigation on the soil water depletion of the Murcott citrus trees was studied using a greenhouse lysimeter filled with sandy soil. The study was carried out at the Arid Land Research Center, Tottori University, Japan (35° 32' N; 134° 13' E). Two lysimeters were used for three experimental periods (period I, II and III) with duration of about 2 weeks for each. In Period I and III, plants were irrigated with 60 mm of non-saline water. In period II, one lysimeter was irrigated with non-saline water and another with highly saline water (EC = 8.6 dS m-1). During period II water applied was 32 mm, at 70 % field capacity, using the perforated pipe method. ET values of the two lysimeters were similar during period I. However, after irrigation using the saline water, the soil salinity around the root zone increased and the ET rate decreased to 71% of that under the non-saline water treatment. Irrigation with saline water increased the soil water storage and the deep percolation. The cumulative drainage water was 35 % higher under the saline water irrigation than that under the non-saline water irrigation. After application of saline water, there was difference in soil moisture profile in between the two lysimeters. The maximum difference occurred at the soil depth of 0-60 cm, where most of the roots of the trees are growing. After the leaching event, the differences in ET between the treatments become smaller. The results showed that leaching is an effective management strategy for sandy soils to control soil salinity.

Introduction

Water scarcity is becoming one of the major limiting factors in economic development and welfare of the people in the arid and semi-arid regions. About one-third of the world's population lives in countries with moderate to high water stress, i.e. in areas where the withdrawal of fresh water exceeds 10 % of accessible runoff (UNEP, 1999; 2002). To improve water productivity, there are several management strategies such as mulching, drip irrigation, intercropping, agro-forestry, soil fertility management, rainwater harvesting, soil and water conservation, and improved crop varieties (Falkenmark and Rockstrom, 2004).

As competition for fresh water increases, water of better quality is primarily used for domestic purposes, whereas water of lower quality is often used for irrigation (Khroda, 1996). The lack of fresh water is becoming the major limiting factor in the expansion of irrigated agricultural in these regions. Therefore, one challenge for the future will be to maintain or even increase crop production with less water that may often be of poor quality, for example saline and/or brackish water.

Saline water irrigation is practiced in several regions of the world (Shalhevet, 1994) where water scarcity prevents the use of freshwater for irrigation. Nowadays, there is an increasing tendency to use saline irrigation water in arid and semi-arid regions to supplemental water needed to intensify agriculture (Amaya and Yano, 1994). In applying saline and/or brackish water for irrigation, an integrated approach of soil, crop and water management should be adopted. This approach needs calculation of crop water requirements which are essential for water saving, controlling the level of water table and drainage volume, and finally to have higher yields (Ragab, 2002). An understanding of the dynamic components of the soil water balance is important to manage irrigation properly.

Citrus trees, which are known as sensitive to salt, are one of the most important irrigated crops on which considerable studies have been made with saline water (Bar et al., 1996; Gonzalez-Altozano and Castel, 1999; Levy et al., 1999). Most of studies, however, have been conducted for determining the effect of saline water application on fruit set, size, quality and yield (Cole and McLeod, 1985; Francois and Clark, 1980; Howie and Lioyd, 1989). Information about the influence of salinity on water requirement of citrus is lacking, although many investigations (Fares and Alva, 1999; 2000a; 2000b; Grismer, 2000; Hoffman et al., 1982; Syvertsen and Smith, 1996; Yang et al., 2003) have reported on the water requirement under irrigation with fresh water. The latter information is of only little use for the crop grown with saline water because salinity makes it more difficult for plants to absorb soil moisture (Yang et al., 2002a; 2002b). Proper irrigation management and adequate drainage are important measures for the improvement of salty soils as well as for the prevention of salinization (FAO, 1985). Therefore, it is very important to estimate actual water uptake under saline water irrigation.

The objectives of this study were (i) to estimate the components of soil water balance under lysimeter-grown orange trees and (ii) to compare the water uptake from citrus trees irrigated with saline water and fresh water.

Materials and methods

The experiment was carried out at the Arid Land Research Center (ALRC), Tottori University, Japan (350 32' N; 1340 13' E) under glasshouse conditions to prevent the influence of rainfall. The glasshouse was 6 m in height, 20 m in length and 8 m in width with facilities for controlled aeration and regulation of temperature. Two weighing lysimeters, with 1.5 m diameter and 1.6 m depth (details given by Qui et al., 1998; 1999) and filled with sandy soil, were installed in the greenhouse. Average field capacity and permanent wilting point of the soil were 0.074 cm^3 cm^{-3} and 0.022 cm^3 cm^{-3}, respectively. Dry bulk density was 1.50 to 1.55 g cm^{-3}. The lysimeters had a weight resolution of 50 g, corresponding to 0.028 mm of water. They were connected to a terminal computer. Samples were recorded every 15 sec and averaged every 30 min. The lysimeters also had a drainage system with reservoir, and drainage was monitored during the experimental period.

Eight-year-old salt-tolerant 'Maukoto' citrus trees were used in the study. Each lysimeter was planted with one tree and it was surrounded by 8 citrus trees on the same sand in the greenhouse. One lysimeter was to be irrigated with saline water at appropriate stage (details given below), and the other with non-saline water, which served as the ‘control’. The non-saline irrigation water was adjusted to 1.0 dS m^{-1} of electrical conductivity (ECI) by adding chemical fertilizer (ingredient: N: 20%, P: 4%, K: 30%, etc.). The ECI of the saline irrigation water was adjusted to 8.6 dS m^{-1} by adding sodium chloride. The irrigation treatments studied were applied not only to the tree in the lysimeters but also in the surrounding area. The irrigation water was applied on the basis of soil water depletion. The experiment was conducted from 1 August to 15 September 2000. However, for better understanding of the effects of irrigation with saline water and salt accumulation in soil on soil water uptake by the citrus tree, the entire duration was divided into three periods with differential treatments. The treatments indicating lysimeter number and time period are given below:

Period I (1-13 August): Both lysimeters (L1 and L2) were irrigated with non-saline water when average soil water content in 0-120 cm of soil depth was depleted to 70 % of the field capacity (FC) to obtain identical growth conditions before the start of the salinity treatment. A total of 106 kg water, corresponding to 60 mm, was applied.

Period II (14-31 August): L1 (control) received non-saline water when the average soil water content in 0-120 cm of soil depth was at 70 % FC. A total of 56 kg of non-saline water, corresponding to 32 mm, was applied. L2 (saline treatment) received 56 kg of saline water on the same schedule as with L1.

Period III (1-15 September): Both lysimeters in this period were irrigated with non-saline water as in the Period I.

Daily evapotranspiration (ET) was determined from changes in lysimeter weight and converted to the unit of mm d^{-1} based on the lysimeter surface area (1.767 m^2). Daily evaporation from bare soil was measured by microlysimeter method (Boast and Robertson, 1982). The microlysimeters had 13 cm diameter and were 60 cm long. A set of three microlysimeters was fixed under citrus tree outside of each lysimeter. Daily evaporation was calculated from average change in microlysimeters weight.

Soil water content was monitored with two-rod TDR sensors. The sensors were installed at 7.5, 22.5, 45, 75 and 105 cm depths and at 35 cm lateral distance from the trunk of citrus trees in the lysimeters. The sensors were pre-calibrated for the sandy soil used in the lysimeters. Water content was calculated for 15 cm increments between 0-30 cm depth, and thereafter for 30 cm increments to 120 cm depth. The soil bulk electrical conductivity was measured using electrode-salinity sensors installed at depths of 7.5, 22.5, 45 and 75 cm (Rhoades et al., 1976). Electrical conductivity of soil-water (ECS) was determined as a function of the bulk electrical conductivity and volumetric water content by use of an experimentally obtained equation.

The root weight distribution at different depth was investigated by collecting the soil sample at the depths of 0-15, 15-30, 30-60 and 60-90 cm in a diameter of 35 cm. The roots were separated from the soil collected from each layer.

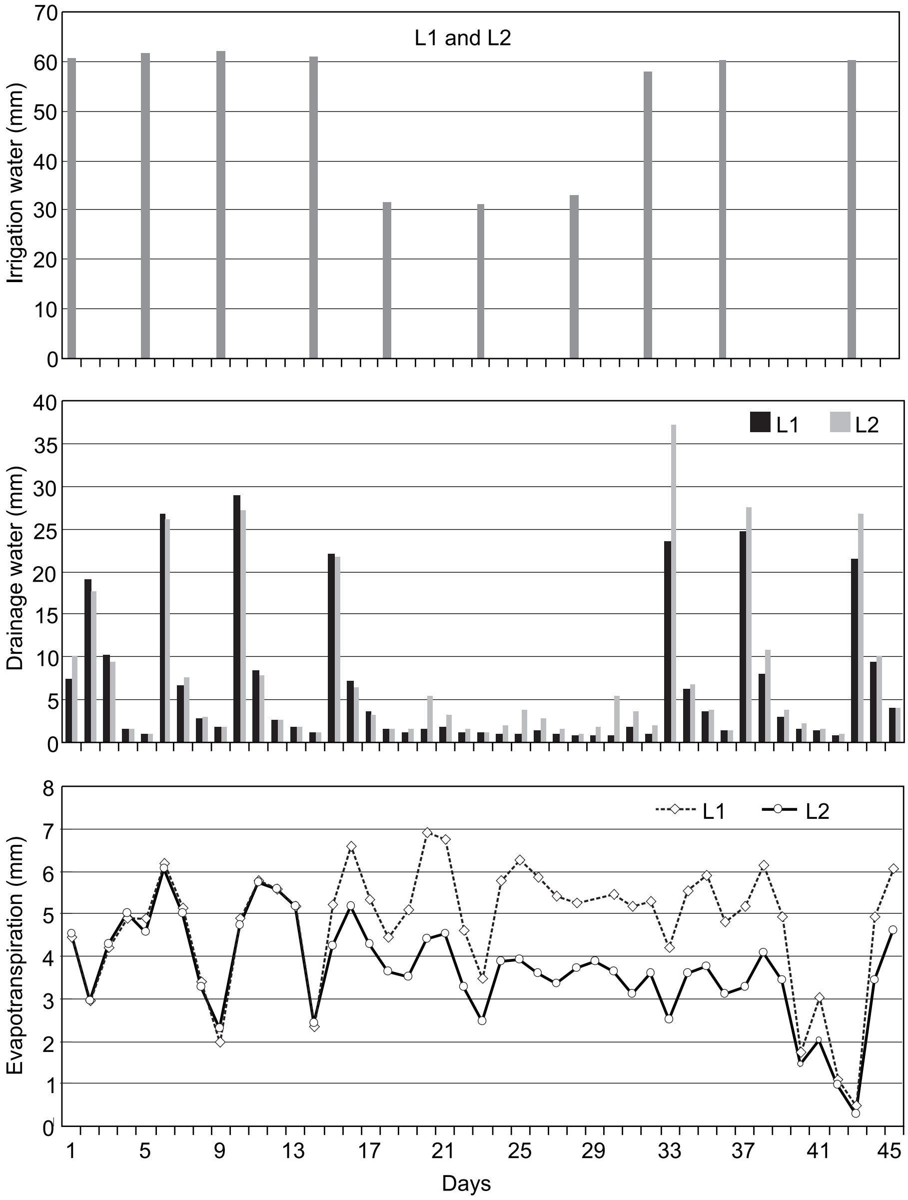

Fig. 1. Irrigation events, daily drainage and evapotranspiration for the two (L1 and L2) lysimeters.

Results and discussion

Irrigation, drainage water and evapotranspiration

The irrigation, drainage and evapotranspiration (ET) are shown in Fig.1. Same amount of the irrigation water (I) was provided to two lysimeters throughout the experiment period. In order to obtain similar soil moisture and nutrition conditions in the two lysimeters during Period I and to leach the accumulated salt in lysimeter during Period II, extra water was applied at Period I and Period III. The daily ET was similar for both lysimeters during the Period I as both were irrigated with non-saline water. During Period II, ET from L1 (irrigated with non-saline water) was consistently higher than that from L2 (irrigated with saline water). Upon leaching the accumulated salts in the L2 during Period III, the difference in ET between L1 and L2 decreased appreciably. The saline water irrigation decreased the ET. This is consistent with the result of Yang et al. (2002b) who reported that the saline water reduced the ET in the case the soil salinity was beyond the critical value. The relative average ET of Period II for L2 was 0.71 of L1. Daily drainage (D) was almost similar for both lysimeters during Period I. During Period II, however, the drainage from L2 was considerably higher than from L1, and the difference between L1 and L2 gradually disappeared during Period III. About 95% of drainage occurred during the first 2 days following an irrigation event. Saline water irrigation increased the drainage volume compared with the non-saline water irrigation under same schedule due to the decrease in the ET. The average leaching fraction (LF) of the two lysimeters during and after irrigation events was approximately 0.6 in the Periods I and III, and 0.2 in the Period II. The cumulative drainage of L2 was 35% greater compared with L1 during Period II.

Transpiration (T) was calculated by the difference between ET and the evaporation (E) measured by microlysimeter during Period II (Fig. 2). No clear influence of water quality was observed on evaporation (E) from bare soil. This result is in agreement with findings of Dasberg et al. (1991) who reported that evaporation from soil was not affected by soil salinity at small amount of salts. Therefore, the difference in transpiration was because of the difference in the ET. In the other words, the difference observed in ET values between the two treatments in Period II was a reflection of the difference in water uptake by the roots. Saline water irrigation interfered with the water uptake of root and resulted in the reduction of ET. The water uptake under saline water irrigation was reduced by 20-40 % compared with non-saline water irrigation.

Soil water storage

The water balance of a citrus tree grown in greenhouse lysimeter can be defined based on the conservation of mass as follows:

S = I – ET – D

where S is the change of water storage compared with the initial state of the experiment in the lysimeter, I is the irrigation water, ET is the daily evapotranspiration, and D is drainage at the bottom of the lysimeter. All of these variables are expressed as millimeters. The water storage (S) calculated by the water balance equation is presented in Fig. 3. A sharp increase and then a

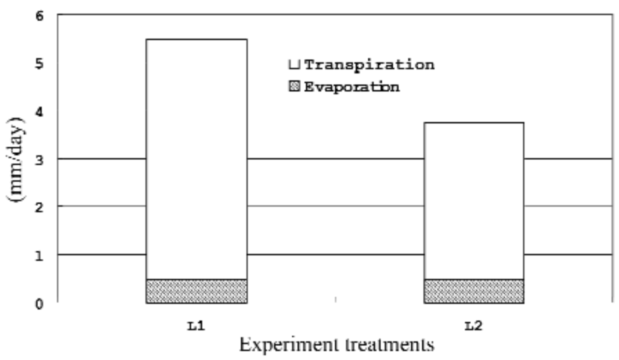

Fig. 2. Average daily evaporation and transpiration during Period II (L1: irrigation with non-saline water; L2: irrigation with saline water).

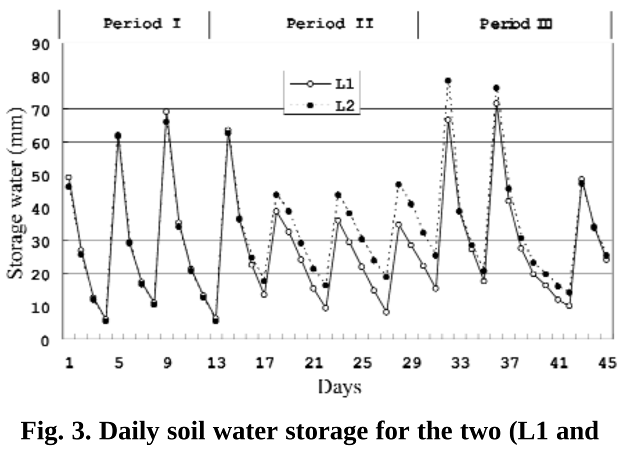

Fig. 3. Daily soil water storage for the two (L1 and L2) lysimeters.

decrease in the S value following each irrigation event clearly demonstrates the low water-holding capacity and high hydraulic conductivity of this soil. All of the irrigation events were managed to add only enough water to replenish the soil water to the full point. S was similar for both lysimeters during Period I. During Period II, the S value in L2 was higher than in L1, and the difference in S value gradually increased with the saline water irrigation events. Saline water irrigation decreased the soil water uptake by the roots; as a result more soil water remained in the root zone. The total S in L2 was 31% higher than in L1 in Period II. This difference tended to close due to leaching the accumulated salt in L2 when non-saline water was given during Period III.

Soil moisture and matric potential profile distribution

Water flows along the potential gradient from the soil, where high water potential exists, through the plant vascular system to the leaves and to the atmosphere, where the water potential is lower. In this study, the soil water potential only included the matric potential and osmotic potential, and they can be estimated from soil moisture and soil water electrical conductivity (EC), respectively.

Soil water profile pattern in the two lysimeters before and after saline water irrigation event are depicted in Fig. 4. Before saline water irrigation,

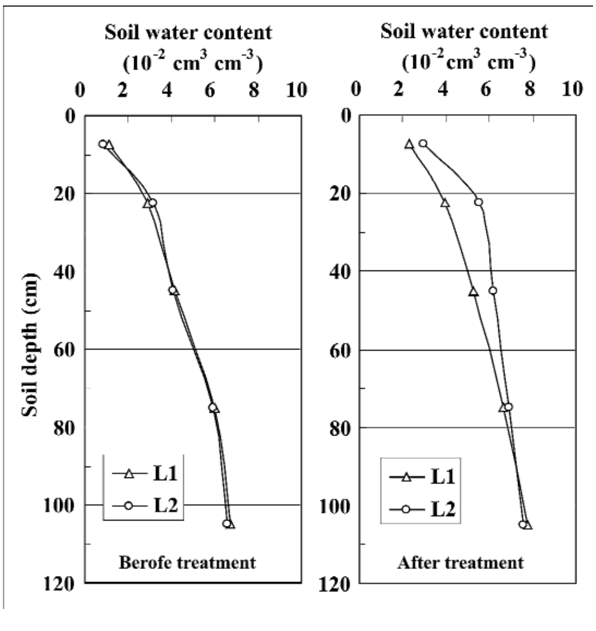

Fig. 4. The soil water content at different depths before and after saline water irrigation.

soil moisture pattern was similar in the two lysimeters because of the similar irrigation schedule. After saline water irrigation, this pattern became different in the two lysimeters. The saline water irrigation resulted in higher soil water content compared to non-saline water irrigation in the root zone. The difference in the soil moisture profile between the two lysimeters resembled the distribution in the root weight percentage (Fig. 5). The difference in the soil moisture content became significant in the 10-60 cm layer where most of the roots were distributed. This reflected the impact of saline water irrigation on the soil water uptake by the citrus tree roots. Saline water irrigation decreased the water uptake and thus more water remained in the rhizosphere.

Soil water EC and osmotic potential profile distribution

Electrical conductivity of soil water (ECS) is depicted in Fig. 7. The ECS values were obtained for the whole profile before and after saline water irrigation in both the lysimeters. While ECS values in the two lysimeters were close before saline water treatment, the ECS value after saline water

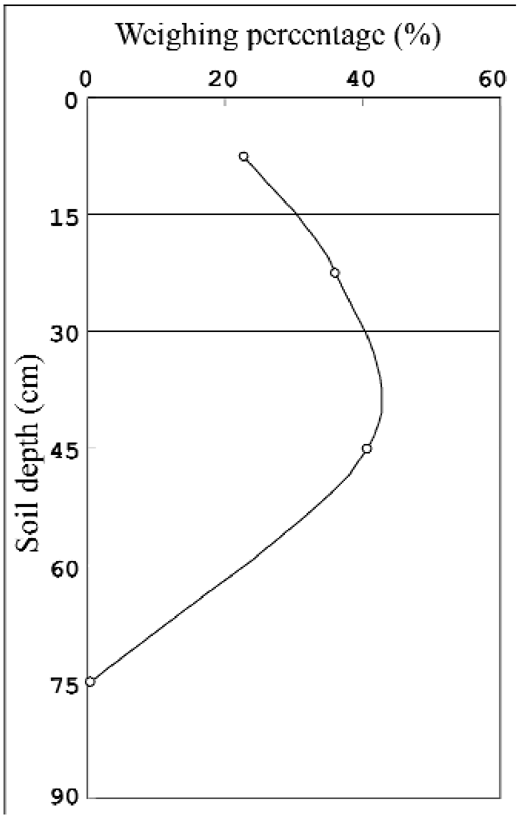

Fig. 5. Root profile distribution of citrus trees grown in lysimeter.

irrigation was consistently higher in L2 than in L1. The trend in the ECS profile with soil depth in both lysimeters was almost same except in the top layer. This is because of the leaching effect and highest amount of water withdrawal in the top layer. The water loss in the top layer is mostly by evaporation. The salt dissolved in the soil water remained while the water evaporated.

Soil water osmotic potential is depicted in Fig. 8.

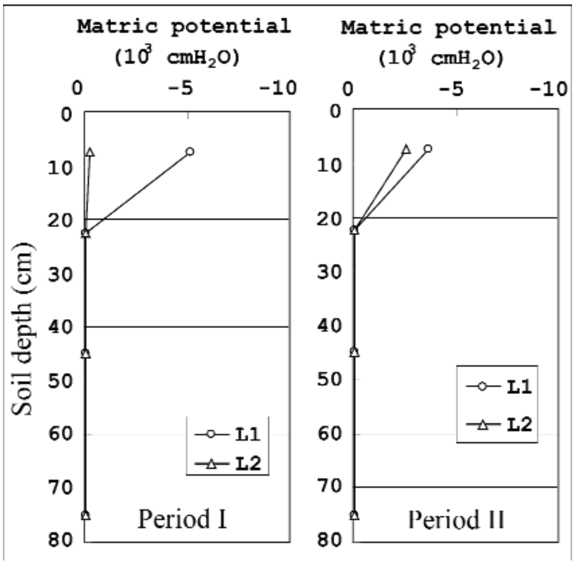

Fig. 6. Soil water matric potential profile during period I and II (potential unit are 10^3cmH$_2$O).

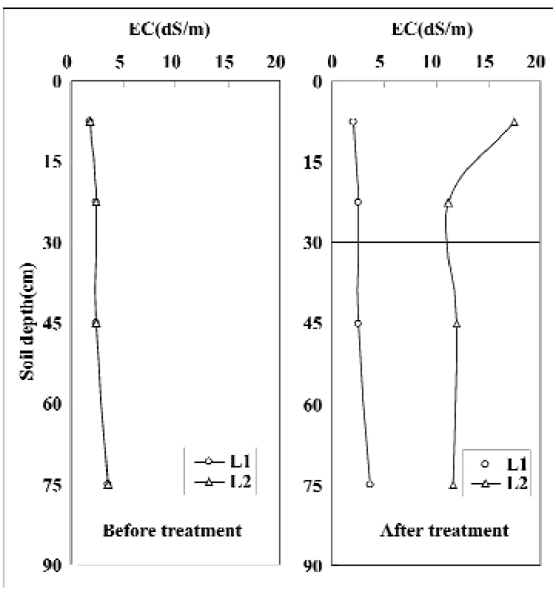

Fig. 7. Soil water electrical conductivity (EC) profile during period I and II.

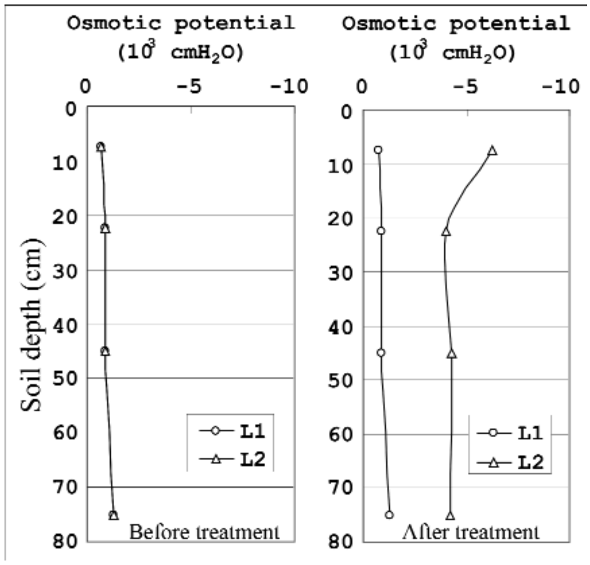

Fig. 8. Soil water osmotic potential representative profile during period I and II (potential unit are 10^3 cm H$_2$O).

It was calculated using the procedure provided by the US Salinity Laboratory Staff (1954) based on the soil water EC values. The osmotic potential decreased after application of the saline water. This is attributed to the fact that saline water irrigation intensified soil salinity. The soil water potential was decreased only by the reduction in the soil water osmotic potential during Period II. Osmotic stress hindered water uptake by the roots, which resulted in reduced transpiration and the ET (see Fig. 1). Dasberg et al. (1991) also emphasized that with saline water irrigation the soil salinity in the root zone increased, which resulted in increased soil water osmotic stress.

Conclusions

The results indicated that saline water irrigation had adverse impact on the water uptake of citrus trees. The irrigation with saline water decreased ET, and increased soil water storage and drainage water. The average ET value from saline water treatment was only 71% of that observed under the control. The cumulative drainage water under saline water irrigation was 35% greater than the control during saline water irrigation period. After saline water irrigation, the soil moisture in the root zone (0-60 cm of soil depth) increased as compared with non-saline water irrigation treatment (control). The soil moisture difference corresponded to the root distribution pattern of citrus trees. Saline water irrigation increased the soil salinity around the root zone and decreased the soil water osmotic potential, which resulted in a decrease in the soil water potential. The osmotic potential is the main factor affecting the soil water uptake by citrus trees grown under full irrigation.

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Estimation of evapotranspiration from maize crop combining sap flow and weighing lysimeter data

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Abstract

A maize field experiment was carried out to compare soil and canopy energy balances at partial cover using two different methods. In the first method, which served as the reference, weighing lysimeter and sap flow sensors were used to measure evapotranspiration and canopy transpiration, respectively. Soil evaporation was determined by difference between evapotranspiration and canopy transpiration. In the second method, a two-layer Bowen ratio energy balance was used to measure evapotranspiration and soil evaporation. The results were compared. Considering the normal variation of field measurements, the agreement among the two methods to determine evapotranspiration components was adequate (r2 were 0.64 and 0.62 for canopy transpiration and soil evaporation, respectively). The second method overestimated canopy transpiration (by about 18 %) and underestimated soil evaporation (by about 31 %) as compared to the reference method. The soil surface sensible heat flux contributed about 19 % to the canopy latent heat flux. The approach used in this study is useful for partitioning evapotranspiration at crop field level. It also provides a framework for studying energy exchange between soil surface and crop canopy. It has the advantage that all measurements are made at the crop field level. However, this approach requires further validation under a wide range of vegetation structures and environmental conditions.

Introduction

Several methods are used to determine evapotranspiration components. These include weighing lysimeters and the Bowen ratio energy balance (BREB) method for evapotranspiration (*ET*), sap flow gauges for canopy transpiration (*T*), and microlysimeters for soil evaporation (*E*) measurements (Jara et al., 1998). The BREB method is considered to be fairly robust for measuring crop *ET*, and has compared favorably with other methods such as weighing lysimeters, where *ET* fluxes from lysimeter and Bowen-ratio values agreed to within 10 % (Prueger et al., 1997). However, this method may not be nearly so accurate under very dry conditions or under conditions of considerable advection of energy (Angus and Watts, 1984). Ashktorab et al. (1989) used a micro-Bowen ratio system for energy balance determination close to the bare soil surface, and recommended its use for under-canopy and small-plot studies to measure soil evaporation.

The relative accuracy of the sap flow method compared with determination of water losses by direct weighing is reported to be about ±10 % in controlled environments (Baker and van Bavel, 1987; Steinberg et al., 1990). However, under field conditions, the comparison between crop transpiration, as determined by sap flow, and evapotranspiration, as estimated from the soil water balance (Ozier-Lafontaine and Tournebise, 1993) or by Penman-Monteith model (Gerdes et al., 1994; Zhang et al., 1997), provides contradictory results about the performance of the sap flow method (Ham et al., 1990; Qiu et al., 1999).

Ham et al. (1991) showed that determination of plant and soil energy balances for cotton could be obtained by combining sap flow with BREB measurements of the surface energy balance. The *ET* from a drip-irrigated vineyard was obtained from separate measurements of transpiration with sap flow gauges and soil evaporation (*E*) at various positions with microlysimeters (Yunusa et al., 2004). However, when different methods are used to determine *ET* components, the consistency among these methods deserves attention (Jara et al., 1998). A rapid decline in the precision of the *E* estimate at low soil evaporation levels indicates that the utility of the approach may be limited when *E* is less than 20 % of total *ET*. This restriction may hinder quantification of surface energy balance relationships and transport processes during certain soil and canopy conditions (Ham et al., 1990). Partitioning latent heat fluxes between crop canopy (λE_c) and the soil surface (λE_s) becomes more complex considering energy exchange between the soil, canopy, and the aerial environment (Ham et al., 1990). In fact, when crops are grown in a row configuration, the crop canopy does not completely cover the soil throughout a large portion of the growing season, and the exposed soil represents an important source and/or sink of energy. Thus, investigating evaporation and energy exchange in the row crop system requires that energy balance of the soil and canopy be examined separately (Ham et al., 1991).

The objectives of this study were to: (i) evaluate the consistency of different methods for measuring evapotranspiration, plant transpiration, and soil evaporation in a maize field, and (ii) compare latent heat fluxes obtained by weighing lysimeter and sap flow measurements with the Bowen ratio technique applied over crop canopy and at soil surface level.

Materials and methods

The experiment was conducted during the 2005 growing season on a 4800 m^2 plot at the experiment station of the Arid Land Research Center, Tottori University, Japan (35° 32' N, 134° 13' E, 23 m above sea level). Maize (var. Pioneer 31N27) was planted on 20 June 2005 at a density of 6 plants m^{-2}. The crop was established on a flat surface within a 0.5 m row spacing and north-south row orientation. No furrows or raised beds were present in the field. The soil was an Arenosol (silicious sand, typic Udipsamment) with 96 % sand. Volumetric soil water content at field capacity (FC) and permanent wilting point of the sand were 0.074 cm^3 cm^{-3} and 0.022 cm^3 cm^{-3}, which correspond to -0.006 MPa and -1.5 MPa in matric potential respectively (Qiu et al., 1999). Sprinkler irrigation system was used and the plot was bordered by other irrigated crop fields. Recommended fertility management practices were used to ensure adequate nutrients for crop growth.

Field energy balance

Method 1: Canopy latent heat flux density (λE_c) was obtained from heat balance measurements of transpiration (Sakuratani, 1981; Baker and van Bavel, 1987). Sap flow gauges (Model SGB 16 and 19, Dynamax, Inc., Houston, TX) were attached to the stems of 8 plants selected randomly within the vicinity of the Bowen ratio system. Stem diameters at gauge locations ranged from 15 to 23 mm. Approximately 0.2 and 0.3 W of power was applied to the stems by gauge heaters for SGB 16 and 19 sap flow gauges, respectively. Insulation was placed above and below the gauges to reduce effects of the environment on stem heat balance. Gauges were sampled every 30 s using a Model CR10X data-logger (Campbell Scientific, Logan, UT) and 10 min averages were computed.

Sap flow measurements were converted to latent heat flux per unit land area by normalizing the measurements on a plant population basis. Mean λE_c (W m^{-2}) was calculated as:

$$\lambda E_c = \lambda \sum (f_i \rho)/n \tag{1}$$

for $i=1,2,...,n$, where λ is the latent heat of vaporization (J kg^{-1}), f_i is the sap flow (kg s^{-1}) of plant *i*, ρ is the plant density (plants m^{-2}) and *n* is the number of plants measured.

Field evapotranspiration (*ET*) was determined by a 1.5 m diameter and 1.5 m deep weighing lysimeter described by Qiu et al. (1999). The water content inside the weighing lysimeter could be measured with a resolution of 50 g, which corresponds to 0.028 mm depth of water. A terminal computer continuously recorded the weight data of the lysimeter at 30 min time interval.

Soil latent heat flux density (λE_s) was calculated as:

$$\lambda E_s = \lambda E - \lambda E_c \tag{2}$$

where λE is the total latent heat flux density obtained by the weighing lysimeter.

Method 2: The surface energy balance of the field (soil and canopy) was determined from a Bowen ratio unit located 10 m from the south edge of the plot to maximize fetch when prevailing northerly winds were present (Fig 1.). Minimum fetch: height ratio within the plot was 36:1, an adequate value for Bowen ratio measurements (Heilman et al., 1989). The surface energy balance of the field can be represented as:

$$R_n + \lambda E + H + G = 0 \quad (3)$$

where R_n is net radiation, λE is latent heat flux density, H is sensible heat flux density, and G is soil heat flux density, all units of W.m^{-2}. In Eq. (3), R_n is positive downward and G is positive when it is conducted downward from the surface. Sensible and latent heat fluxes are positive upward. Air temperature and vapor pressure were determined with two dry and wet bulb ventilated psychrometers. The distance between the two psychrometers was 1 m, and the lowest psychrometer was positioned 0.2 m above the crop canopy. A Q-7.1 net radiometer (Campbell Scientific, Inc., UT, USA) and two soil heat flux plates (MF-180M, EKO, Tokyo, Japan) were used to measure net radiation and soil heat flux respectively. The soil temperature profile was measured with thermocouples (copper-constantan thermocouples) at 0, 3, 5, 7, 10, 20, 30, and 50 cm depths. All data were measured every minute and averaged over 10 minute's interval by a 21X datalogger with an AM416 multiplexer (Campbell Scientific, Inc., UT, USA).

The partition of energy between λE and H is usually obtained by the Bowen ratio-energy balance method (Tanner et al., 1987; Kustas et al., 1996, Perez et al., 1999) by means of the Bowen ratio as:

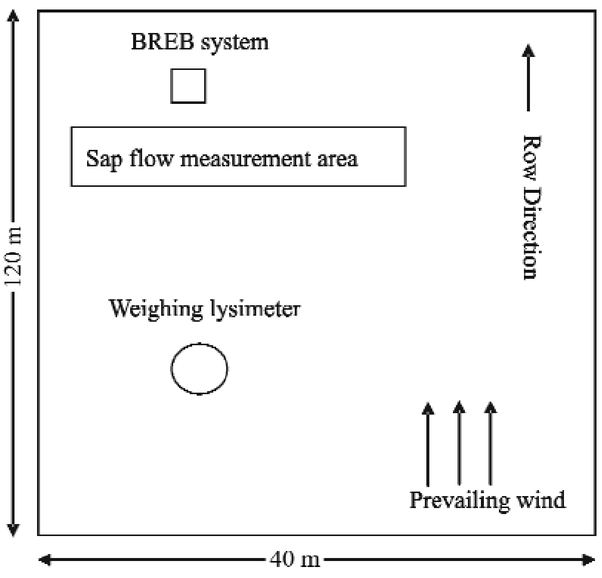

Fig. 1. Diagram showing the position of the BREB system, and the sap flow and weighing lysimeter data collection areas.

$$\beta = \frac{H}{\lambda E} \quad (4)$$

The Bowen ratio is used with the energy balance (Eq. (1)), yielding the following expressions for λE and H:

$$\lambda E = \frac{R_n - G}{1+\beta} \quad (5)$$

$$H = \frac{\beta}{1+\beta}(R_n - G) \quad (6)$$

Over an averaging period, t, assuming equality of the Eddy transfer coefficients for sensible heat and water vapor (Verma et al., 1978), and measuring the temperature and vapor pressure gradients between two levels within the adjusted surface layer, β is obtained as:

$$\beta = \gamma \frac{\partial T / \partial z}{\partial e / \partial z} = \gamma \frac{\Delta T}{\Delta e} \quad (7)$$

where ΔT and Δe are the temperature and vapor pressure differences between the two measurement levels,

$$\gamma = \frac{c_p p}{\varepsilon L_v}$$

is the psychrometric constant, c_p (1.01 kJ kg^{-1} ^{o}C^{-1}) the specific heat of air at constant pressure, p the atmospheric pressure (kPa), ε the ratio between the molecular weights of water vapor and air (0.622), and L_v the latent heat of vaporization (kJ kg^{-1}). The energy balance of the soil surface can be written as:

$$R_{ns} + \lambda E_s + H_s + G = 0 \quad (8)$$

where R_{ns} is R_n reaching soil surface, λE_s is soil latent heat flux density, and H_s is the sensible heat flux from the soil, all units of W.m^{-2}.

The Bowen ratio at soil surface level was determined from air temperature and vapor pressure measured at 5 and 15 cm from soil surface with two ventilated psychrometers.

Net radiation reaching soil surface was obtained from the exponential attenuation equation of R_n with leaf area index (L) (Uchijima, 1976) as:

$$R_{ns} = R_n \exp\left(-0.622L + 0.055L^2\right) \quad (9)$$

The Bowen ratio at soil surface level can be obtained as for that of field level as:

$$\beta_s = \frac{H_s}{\lambda E_s} \quad (10)$$

and λE_s and H_s can be obtained as by Eq. (5) and (6) respectively. The canopy energy balance can be written as:

$$R_{nc} + \lambda E_c + H_c = 0 \tag{11}$$

where R_{nc} is the R_n absorbed by the canopy and λE_c and H_c are fluxes of latent heat and sensible heat from the canopy. Canopy latent heat flux can be obtained as:

$$\lambda E_c = \lambda E - \lambda E_s \tag{12}$$

Results and discussion

Analysis of Method 1 measurements for a sample day

Diurnal trend of maize field, soil surface and canopy energy balances, using Method 1, for 239 DOY are presented in Fig. 2 to show the canopy-soil surface energy balance interactions in detail. The 239 DOY was selected because skies were generally clear with moderate wind speed. Maximum value of R_n was 668 W m^{-2} and wind speed at 1 m above the canopy ranged from 0.5 m s^{-1} at early morning to 2.7 m s^{-1} around noon.

On 239 DOY, most of available energy (R_n-G) at maize field level was used to drive evapotranspiration ($0.05<\beta<0.16$) (Fig. 2A). Only 8.5 % of available energy was used to generate H. Similar results were reported for cotton by Ritchie (1971), who found λE to be within 10 % of R_n when soil surface was wet and soil water was not limiting. During most part of the day, λE was less than R_n-G, except on early morning and late afternoon suggesting that there may be brief periods when advection of sensible heat supported evapotranspiration. Similar observations were reported by Yunusa et al. (2004) on vineyard.

During daytime, λE_s was less than available energy at soil surface. R_{ns}-G was either used to drive λE_s (62 %) or to generate H_s (38 %), with β_s ranging from 0.20 to 0.74 during the day (Fig. 2 B). These results contrasted with the ratios of latent heat flux to net radiation reaching soil surface, greater than unity, reported by Ham et al. (1991). However, we note that these authors used a different soil type with a sandy clay loam surface texture.

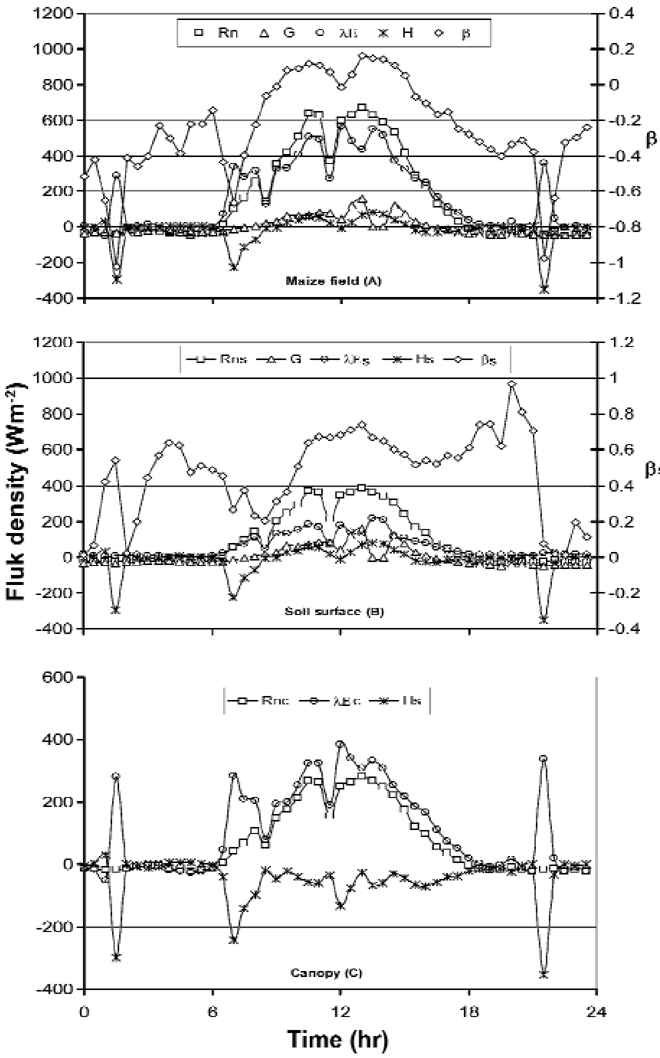

Fig. 2. Diurnal trend of energy balance components for the maize field (A), soil surface (B) and canopy (C) on 239 DOY.

At canopy level, λE_c exceeded R_{ns} during all day-time period. Negative H_c values were obtained (Fig. 2 C) indicating the canopy was absorbing convective heat from the soil surface, which provided supplemental energy for λE_c. This redistribution of available energy by sensible heat transfer occurs when there is (i) abundant supply of soil water (ii) absence of significant physiological restraint of water vapor flux through stomata, and (iii) high evaporative demand (Oke, 1987). In such conditions, this redistribution of energy could supply up to one third of the energy needed for transpiration (Hicks, 1973; Heilman et al., 1989; Sene, 1996). We believe these conditions did prevail during the course of this study, and H_s contributed by 19 % to λE_c.

Comparison of latent heat flux from the canopy as measured by Method 1 and determined from Method 2

Half-hourly canopy latent heat flux as measured by Method 1 and determined from Method 2 for DOY 238, 240, and 241 are shown in Fig. 3. The diurnal fluctuation of λE_c from the two methods agreed reasonably. However, a time lag was observed between λE_c from the two methods at early and late hours of the day. Similar observation has been reported by Stockle and Jara (1998) in a comparison between modeled and sap flow transpiration over maize crop. They concluded that as transpiration simulations are driven by atmospheric demand with no considerations of changes in plant water status, sap flow measurements made at the bottom of the stem include transpiration plus plant water storage. Consequently, because changes in plant water storage tend to buffer sudden fluctuations, the daily evolution of sap flow appears smoother than simulated transpiration.

Crop latent heat flux was overestimated by Method 2 during mid-day time period by about 36 % of sap flow λE_c. Several reasons may have caused such deviations: (i) Lund and Soegaard (2003) suggested that the fraction of net radiation that is available to the vegetation varies over the day. They concluded that the use of a fixed partitioning of the net radiation between the vegetation and the soil in sparse canopies is not well suited for solving the energy allocation throughout the day as it changes with the inclination angle of the sun; (ii) the underlying assumptions about heat flow in the system lose much of their validity as sap flow increases, some authors reported that the sap flow method generally underestimates the volumetric sap flow rate by as much as 50 % (Cohen et al., 1985). Underestimation of flow rate is believed to be caused by interruption of sap flow in the vicinity of the heater and temperature, and, to a lesser degree, by differences between probe and stem thermal properties (Swanson and Whitfield, 1981); and (iii) the errors caused by the problem in sampling in order to take into account the heterogeneous nature of the canopy. Thus, extrapolating the transpiration of several plants to that of the canopy leads to a new increase of uncertainties on the final value of canopy transpiration (Chabot et al., 2005). We note that our

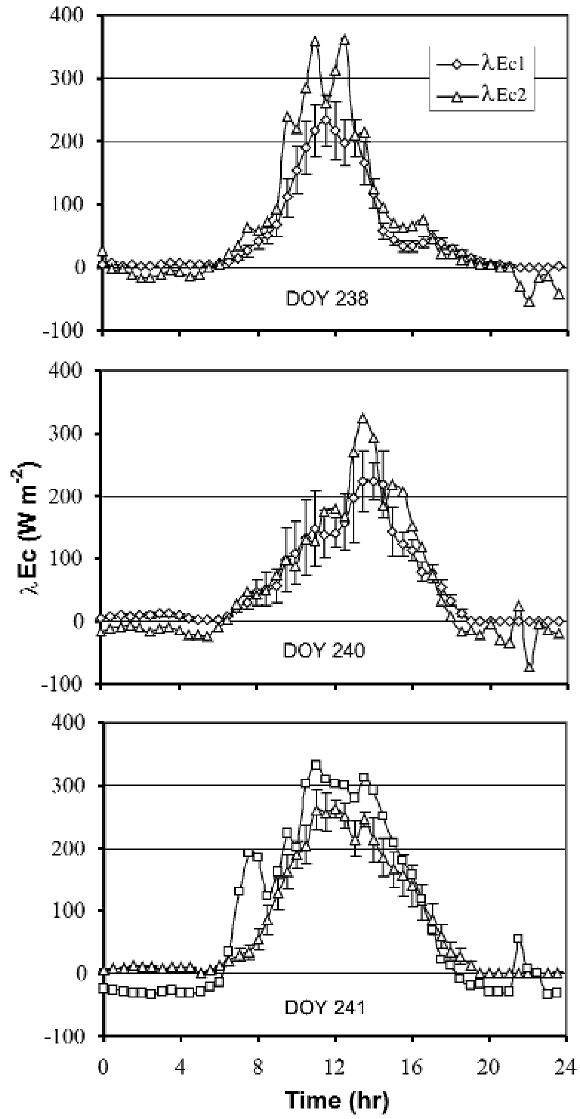

Fig. 3. Diurnal variation of canopy latent heat flux (λE_c) as measured by Method 1 and determined from Method 2 for three days. Vertical bars indicate one standard deviation.

results did not allow for the confirmation of the main reason for these overestimations of crop latent heat flux at mid-day time period.

Comparison of soil surface latent heat flux as measured by Method 2 and determined from Method 1

Diurnal half-hourly soil latent heat flux as measured by Method 2 and determined from Method 1 for the same days as for canopy latent heat flux are shown in Fig. 4. Large differences between the two methods were observed, especially in DOY 240 and 241. Underestimations of soil latent heat

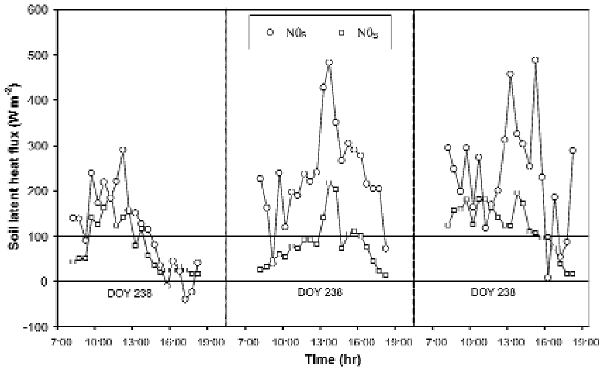

Fig. 4. Diurnal variation of soil latent heat flux (λE_s) as measured by Method 2 ($\lambda E_s 2$) and determined from Method 1 ($\lambda E_s 1$) for three days.

flux by Method 2 were about 56 % of average soil latent heat flux determined from Method 1. Under the conditions of this experiment, we believe these differences were caused by (i) the variability due to different locations of weighing lysimeter and energy balance measurements positions; (ii) differences in crop density, development or leaf area between the two measurement areas; and (iii) differences due to crop management heterogeneities such as irrigation uniformity and fertilization. Use of Method 2 overestimated canopy transpiration and underestimated soil evaporation. Ham et al. (1990), in a review of error analysis for a similar approach as Method 1, concluded that the relative precision of the residual soil evaporation estimate decreases rapidly as soil evaporation becomes a smaller portion of evapotranspiration.

Conclusion

Considering the normal variation of field measurement, the agreement among the two methods used in this study (two layers BREB method vs. sap flow and weighing lysimeter) to determine evapotranspiration components was adequate (r2 were 0.64 and 0.62 for canopy transpiration and soil evaporation, respectively). For the period of this study, the two layers BREB method overestimated canopy transpiration (on average 18 % of sap flow data) and underestimated soil evaporation (on average 31 % of soil evaporation determined from Method 1). We found that soil surface sensible heat flux contributed about 19 % to canopy latent heat flux. The approach used in this study is useful for partitioning evapotranspiration at crop field level. It also provides a framework for studying energy exchanges between soil surface and canopy. It has the advantage that all measurements are made at the same level, "crop field". However, this approach requires further validation under a wide range of vegetation structures and environmental conditions.

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Effects of seeding date and water stress on yield, water-use efficiency and physiological response of two wheat cultivars on the dryland of Pacific Northwest in the United States

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Abstract

Post-anthesis drought stress is a major problem in dryland wheat production in the inland Pacific Northwest. The objectives of this study were to investigate the different responses of soft white (‘Alpowa’) and hard red (‘ID485’) spring wheat (*Triticum aestivum* L.) cultivars grown under 1) fall and spring seeding dates and 2) post-anthesis well-water and water-stress conditions. Field and greenhouse studies were conducted in Oregon of USA in 1998 and 1999. Alpowa and ID485 were planted on October 20, 1998 and on February 26, 1999 in the field experiment. In the greenhouse study, the wheat cultivars were planted in pots and well-watered until the booting stage. Then, water-stress was imposed on one group of the pots while the other group of pots remained in well-watered conditions. Fall-seeded wheat had greater total evapotranspiration (ET) than spring-seeded, but the water use patterns and soil water contents were very similar in the two seasons. Alpowa had faster leaf appearance and elongation as well as biomass accumulation rate, taller plant height, later maturity, and larger but fewer seeds per head than ID485. While planted in the fall and well-watered conditions, Alpowa exhibited yield advantage over ID485. Post-anthesis water stress reduced biomass accumulation in both cultivars. ID485 had a lower carbon-isotope discrimination value than Alpowa, which was related to its greater grain yield, water-use efficiency, and harvest index in water-stress treatment. In addition, it had higher ratio of root to shoot, and of pre- to post heading ET in pot experiment. Early maturing cultivar ID485 could partially avoid post-anthesis drought stress.

Introduction

Wheat yield is particularly sensitive to soil water availability during its reproductive stage (Hukkeriy and Pandey, 1977; Musick et al., 1994). In the semi-arid inland Pacific Northwest (PNW), an average of only 29% of the total precipitation occurs from April to July, when wheat is at flowering and grain filling stages. Terminal drought stress is therefore one of the most important factors constraining spring and winter wheat productivity in this region.

Grain yield under drought conditions is dependent upon many physiological traits related to a cultivar’s capacity to maintain high plant water status over a range of soil water conditions (Ludlow and Muchow, 1990). Measurements that have been related directly or indirectly to plant response to water deficits include total leaf water potential (Ψ_l), carbon-isotope discrimination (D), and water-use efficiency (Martin et al., 1989).

Although Ψ_l has often been used as an indicator of soil water stress imposed upon the plant (Brown and Tanner, 1983), it is not without its drawbacks. Bates and Hall (1981) reported that Ψ_l is often maintained relatively constant over a wide range of soil water potentials, and Tardieu et al. (1991) found that it did not significantly change between 10:00 and 17:00 hours. Jones (1990) suggested that it may be inappropriate to use Ψ_l as an estimate of plant water status. Nonetheless, Ψ_l and its components have often been used in studies of plant response to water deficit (Boyer, 1985), and has been used in practical applications as well, such as irrigation scheduling (Brisson et al., 1993; Gal, 1996).

Leaf water potential is often measured at dawn or midday (Morgan, 1984). Jones (1992) suggested that it be measured pre-dawn, when it approaches equilibrium with the effective mean soil water potential, but midday Ψ_l has been commonly used in other studies (Brisson et al., 1993; Ritchie, 1973).

Water-use efficiency (WUE) is considered an important physiological trait conferring drought adaptation in wheat (Ehdaie, 1995), and has been suggested as a selection criterion for breeders (Ehdaie et al., 1991). Carbon-isotope discrimination (D) has been correlated with WUE in several plant species including wheat (Farquhar and Richards, 1984; Farquhar et al., 1989), and also has been used as a selection criterion (Condon et al., 1987; Farquhar and Richards, 1984; Matus et al., 1996). Lower values of D, which indicate greater WUE, have been reported in wheat under drought-stressed conditions compared to well-watered conditions (Condon et al., 1990; Ehdaie, 1995), and wheat genotypes with lower D have been observed to have more favorable water status for growth under drought conditions. Johnson and Bassett (1991) found that cool season grasses with higher leaf water potential, osmotic potential and turgor pressure had lower D and higher WUE.

Planting date has a large effect on wheat yield (Chen et al., 2003; Kerr et al., 1992), and influences the growth stage at which the crop encounters terminal drought. Optimal planting date (Campbell et al., 1991) and use of drought-tolerant cultivars are

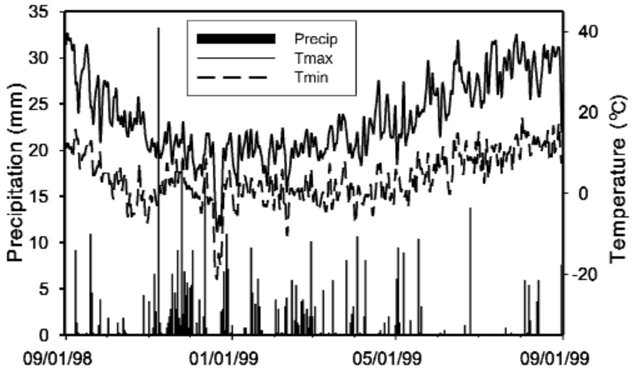

Fig. 1. Precipitation, maximum and minimum temperatures for the study site at Pendleton, Oregon in 1998-1999 cropping year.

two key features of successful dryland cropping systems (Ashraf et al., 1992).

Different classes of wheat responded differently to agricultural managements and available water (Guy et al., 1995; Major et al., 1992). Major et al. (1992) found that soft white and Canadian Prairie Spring (CPS) wheat yielded more and responded more to irrigation than hard red and durum wheat. Soft white and CPS also have higher harvest indices than the hard red and durum wheat, particularly under irrigation. Traditionally, soft white spring wheat is commonly grown in the inland PNW, but recent variety evaluations found that some hard red spring wheat cultivars had good yield potential and milling quality. However, the differences in the response to water stress and agronomic managements of these two classes of wheat grown in the inland PNW environment are not well documented.

The objective of this study was to investigate the differences of two (soft white and hard red) spring wheat cultivars, in terms of leaf water potential, biomass accumulation and partition, grain yield and yield components, harvest index, water-use efficiency and carbon-isotope discrimination, when they were grown under 1) fall and spring seeding dates and 2) post-anthesis well-watered and water stress conditions.

Materials and methods

This study included a field and greenhouse experiments conducted at the Columbia Basin Agricultural Research Center (CBARC), near Pendleton, OR, USA. The mean annual rainfall for the experimental site is ~400 mm, and the soil is classified as Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxeroll). The land was fallowed in the previous year. The soil is spatially uniform in physical properties and fertility (Allmaras et al., 1977; Chen et al., 2003).

Field experiment

A seeding date experiment was conducted at the CBARC from 1997 to 1999 for winter and spring wheat cultivars (Chen et al., 2003). Among the eight spring and winter cultivars and seven seeding dates used in the study, leaf water potential, water use, biomass partitioning and yield components were measured on ‘Alpowa’, a commercial

soft white spring wheat variety, and 'ID485', an experimental hard red spring variety for two seeding dates on October 20, 1998 and February 26, 1999. Due to the mild winter in the inland PNW, spring wheat can survive over the winter.
The wheat cultivars were seeded at a rate of 280 seeds per square meter in 0.15 m spaced rows. The agronomic experiment had a split-plot design where seeding dates were assigned to the whole plots and cultivars were completely randomized within each seeding date. Other details are provided in Chen et al. (2003).

Soil water content was measured once or twice weekly at depths of 0.25, 0.40, 0.55, 0.85, and 1.15 m with a CPN 503DR neutron moisture probe (CPN Corporation, Pacheco, CA). The amount of evapotranspiration was estimated based on the equation: $ET=Wt_2-Wt_1+R$. Where ET is evapotranspiration; Wt_1,Wt_2 is water stored in 1 m depth soil at t_1 and t_2, respectively; R is the precipitation between t_1 and t_2. No irrigation was applied, rain events were never more than 11 mm, the field water-holding capacity was 0.25cm^{3}cm^{-3}, and the land was flat, so runoff and leaching below the measurement profile did not occur during the entire wheat season.

Leaf water potential (Ψ_l) was determined at midday (12:00 to 14:00 h local solar time) using a pressure chamber (PMS Instrument Company, Corvallis, OR). Measurements were made on the three uppermost, fully expanded leaves of three different plants in each plot. Excised leaves were quickly placed in the pressure chamber with the cut end of the petiole just protruding from the chamber through a rubber seal.

Leaf area was measured by a portable area meter (Li-COR, Model Li-3000, Lambda Instruments Co.), and leave appearance and growth were determined using Haun stage (Haun, 1973). Leaf, stem and head dry weight of the plants from one row of 0.3 m long per plot were sampled several times during the growing season. Samples were measured after drying at 65°C for 72 h. Grain yield, straw yield, and harvest index were determined by hand harvesting 1 m^2 area of sub-sample from each plot. Water-use efficiency on grain yield basis (WUEg) was calculated as the amount of dry grain mass produced divided by total ET between planting and harvest.

Pot experiment

This experiment was conducted in a greenhouse with daylight augmented with artificial light provided by high pressure sodium lamps with 12-h light period. The day/night air temperature was maintained at 20/15°C. The pots were 23.5 cm of height, 25 cm of top inner diameter, and 22 cm of bottom inner diameter. In each pot, there was 13 kg of soil packed at a bulk density of 1.2 g cm^{-3}. At the bottom of each pot, 1.7 kg of gravels (~2 cm height) were used to prevent root from twisting. A layer (~1 cm) of quartz sands was placed on the top of each pot to reduce surface evaporation. The pots were arranged randomly on the benches in a split-plot design with four replicates. Water treatments were assigned as the main plots, cultivars were randomized within each water treatment.

The two water treatments were defined as well-watered (WW) and water-stress (WS) treatments. WS was initiated at booting stage. Soil water was decreased gradually from 90% of water-holding capacity to ~50% at anthesis stage and ~10% at maturing stage. WW treatment was maintained at 80-90% of water-holding capacity through out the experiment.

The spring wheat cultivars were planted on September 19, 1998 at 25 plants per pot. The plant density was maintained at 18 plants in each pot which is equivalent to the seeding rate (280 seeds m^{-2}) in the field at the two-leaf stage. Pots were weighed and placed back randomly every 2 or 3 days. For the water-stress treatment, a gradually decreased amount of water was added based on the loss weight of the pots, while in the well-watered treatment an amount of water equal to the loss weight of the pots was added. The pots were spaced at about 30 cm which allowed leaves to overhang on all sides of the pots. Equivalent to the amount of fertilizer applied in the field, 0.5 g N per pot was applied at the booting stage on 10 November, 1998. Three plants in each pot were taken for every measurement of leaf water potential, Haun stage, and biomass. Totally, four pots per treatment were measured. The measurement methods were the same as in the field experiment. Three flag leaves from each pot were dried and ground for carbon-isotope measurement. The measurement was conducted in a research laboratory of Oregon State University. The isotopic

ratios (R = $^{13}C/^{12}C$) of leaf sample (Rsample) and of standard (Rstandard) were determined using ratio mass spectrometer. The R values were converted to $d^{13}C$ using the relation:
$d^{13}C$ = (Rsample/Rstandard -1) ´ 1000‰
D = ($d^{13}Ca$-$d^{13}Cp$)/(1-$d^{13}Cp$/1000)‰
where a and p represent air and plant, respectively (Akhter et al., 2003).

Data were subjected to statistical analysis. Since only two cultivars were measured under two seeding dates in the field agronomic study, Student-t test at P = 0.05 significance level was used to compare the cultivars within each seeding date. For greenhouse pot experiment, analysis for variance (ANOVA) for split plot design was performed, and main treatment means were separated and compared using Fisher's protected LSD range test at P = 0.05 significance level.

Results and discussion

Field experiment

Total precipitation was 466 mm in the 1999 cropping year (September 1 to August 31), but only 115 mm of precipitation was received between March and July in 1999. The precipitation and air temperature distributions are shown in Figure 1. Plants were therefore heavily dependent upon soil-stored water. Although both cultivars used all the available water in the soil at the harvest time, patterns of water use were slightly different (Fig. 2b). Soil water depletion was faster for Alpowa than for ID485 for the October 20 planting date, while the soil water extraction was faster for ID485 than for Alpowa for the February 26 planting date. At harvest, total water storage in the upper 1 m of soil was approximately 95 mm and there was little difference either between seeding dates or between cultivars. Leaf water potential decreased with decreasing soil water and with plant development. At late stages of the growing cycle, Alpowa had lower water potential than ID485 for the October 20 seeding date, but ID485 exhibited lower water potential than Alpowa for the February 26 seeding date (Fig. 2a). This apparently matched the amount of soil available water under each treatment. At the same time period, the October-seeded wheat tended to have lower leaf water potentials than the February-seeded wheat even though the soil water contents were similar. This was likely due to the difference of plant development stages. The October-seeded wheat had advanced growing stages and matured earlier than February-seeded. Given the same soil water content, spring wheat at tillering stage tended to have higher leaf water potentials than at heading stage (Chen, 1995; Moustafa et al., 1996).

Lower Ψ_l was consistent with lower soil water content and greater ET (Fig. 2c), which demonstrated that Ψ_l at solar noon is valid indicator of wheat water status. Values of Ψ_l lower than –2.0 MPa for all treatments in the late growing stage indicated that wheat experienced severe water stress. The Ψ_l decreased progressively with time. The Ψ_l of Alpowa and ID485 did not differ before heading stage (around June 15) in the February 26 planting date treatment.

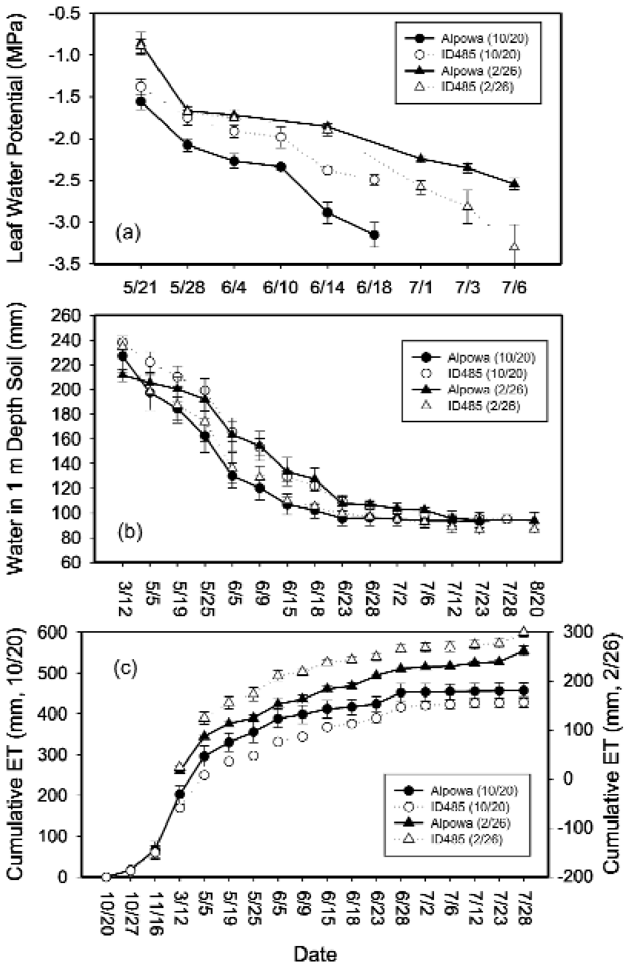

Fig. 2. Leaf water potential (a), water stored in 1.0 m soil (b), and cumulative evapotranspiration (c) of two spring wheat cultivars (Alpowa and ID 485) seeded on October 20, 1998 and February 26, 1999.

Although the October-seeded wheat used up 100 mm more water than the February-seeded wheat during the entire growing cycle, the October- and February-seeded spring wheat had similar cumulative ET during the spring and summer from March to July (Fig. 2c). This indicates that fall-seeded crops had taken the advantage of using the winter precipitation. Otherwise, most of the winter precipitation would have been lost through soil surface evaporation, because the soil stored water were similar for the two seeding dates in the spring (Fig. 2b).

Alpowa had greater above-ground biomass, grain yield, harvest index, and water use efficiency than ID485 for the October 20 seeding date, but there was no difference between the two cultivars in biomass, grain yield, harvest index, and WUEg for the February 26 seeding date (Table 1). Alpowa planted in October 20 had more heads per unit area, fewer seeds per head, more height than ID485, but had no difference in seed size (Table 2). For the February 26 seeding date, the head densities were similar for the two cultivars. However, Alpowa had fewer but larger seeds per head and taller plants than ID485. Therefore, Alpowa has grain yield advantage over ID485 when they are planted in the fall in the inland PNW.

Figure 3 shows the relationships between growth degree day (GDD) and leaf appearance and growth, and above-ground total dry matter (TDM) accumulation for the wheat seeded on two dates. Based on the measurement on March 22 and May 5, 1999 for October-seeded and on May 5 and June 2, 1999 for February-seeded wheat, leaf Haun stages for ID485 were consistently lower than those of Apowa, which can also be seen in the greenhouse study (Fig. 6a). Thus, Alpowa leaves appeared and grew faster than ID485. Alpowa had 11 total leaf and ID485 had 8. Above-ground biomass accumulations were very similar between Alpowa and ID485 for the February 26 seeding date, but for the October 20 seeding date Alpowa consistently had a greater biomass accumulation, until the very late growing cycle (Fig. 3b). October-seeded wheat did not match the February-seeded wheat in the graphs of Haun stage vs. GDD and the graphs of above-ground TDM vs. GDD (Fig. 3). This was likely due to the bias in the calculation of growing degree days. We calculated the GDD using the following formula:

$GDD = \{(T_{max}+T_{min})/2 - T_b\}\times days$

where T_b is base temperature for plant growth. The T_b was set as 0°C (Frank and Bauer, 1996; Rickman et al., 1996) in this calculation. Values of T_b for wheat have been reported to vary in different plant ages and phenological stages (Angus et al., 1981; Slafer and Savin, 1991).

Biomass partition for the two spring wheat seeded on October 20 and February 26 in Figure 4

Table 1. Mean grain yield (GY), total dry matter (TDM), harvest index (HI), and water use efficiency (WUE) of two wheat cultivars grown in a field in Oregon.

Planting date	Cultivars	TDM ($kg\ ha^{-2}$)	GY ($kg\ ha^{-2}$)	HI	WUEg ($kg\ ha^{-2}\ mm^{-1}$)
10/20/98	Alpowa	8390a§	4721a	0.54a	9.7a
	ID485	6842b	3012b	0.42b	6.4b
2/26/99	Alpowa	7761a	3581a	0.47a	13.4a
	ID485	8350a	3330a	0.41a	11.5a

§Numbers in each column within the same seeding date followed by different letters are significantly different ($P \le 0.05$) according to Student-t test.

Table 2. Yield components of two spring wheat cultivars at two planting dates in the field.

Planting date	Cultivars	Heads per m^2	Seeds number per head	1000-seed weight (g)	Plant height (cm)
10/20/98	Alpowa	373a§	25b	35.14a	83a
	ID485	203b	41a	35.32a	71b
2/26/99	Alpowa	308a	29b	41.32a	80a
	ID485	297a	37a	29.01b	72b

§Numbers in each column within the same seeding date followed by different letters are significantly different ($P \le 0.05$) according to Student-t test.

demonstrated that a greater proportion was accumulated in stems in the early stages and declined in late stages. Leaves had only a small proportion of the total biomass. Alpowa had a considerably greater amount of stem biomass than ID485 at the early growing period for the October 20 seeding date, but at the end of the growing season the stem biomass reached the same level for both cultivars. This means that Alpowa had more biomass transferred to seeds than ID485, as a result, Alpowa had a greater head biomass than ID485. The leaf biomass was similar for both cultivars and declined at the late growing season (Fig. 4a).

Alpowa and ID485 had a similar stem biomass accumulation until the very late growing stage, whereon the stem biomass of ID485 declined faster than Alpowa because ID485 matured earlier than Alpowa for the February 26 seeding date. The growth stages of ID485 were found almost 7-10 days ahead of Alpowa at both planting dates (data not shown). The biomass accumulation in heads was similar between the cultivars, but biomass of leaves was slightly greater for ID485 than for Alpowa, because ID485 had bigger leaf areas than Alpowa (data not shown), even though Alpowa had more leaf numbers than ID485.

Sowing time also greatly affected crop phenology, the maturity of both Alpowa and ID485 grown on February 26 was delayed more than 20 days compared to the October 20 planting date, which exposed wheat to water stress for longer duration at late flowering stages. However, compared to

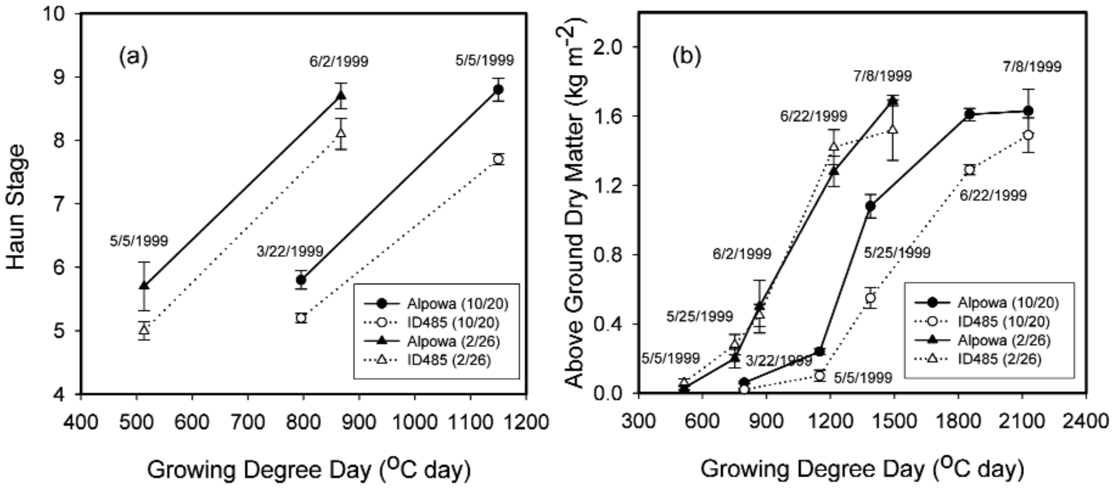

Fig. 3. Leaf appearance and growth measured by Haun stage (a) and above-ground dry matter accumulation (b) of two spring wheat cultivars (Alpowa and ID 485) seeded on October 20, 1998 and February 26, 1999.

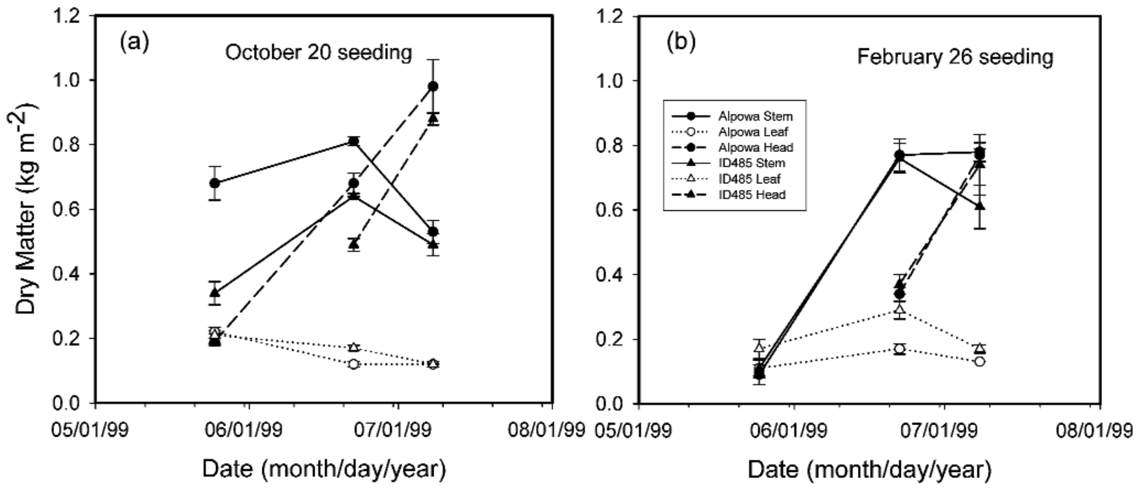

Fig. 4. Dry matter accumulation of the stems, leaves, and heads of two spring wheat cultivars (Alpowa and ID 485) planted on (a) October 20, 1998 and (b) February 26, 1999.

the later maturing cultivar Alpowa, the early maturing ID485 did not take the advantage of longer growing season and ample winter precipitation to reach higher yield potential (Table 1).

Pot experiment

Leaf water potential Ψ_l fluctuated with soil water depletion and recharge in the pots (Fig. 5). Water-stress treatment had consistent lower leaf water potentials than well-watered treatment after the water-stress treatment was initiated. The Ψ_l for Alpowa and ID485 measured at noon ranged from –0.7 to –2.5 MPa for the well-watered and from –1.4 to –3.3 MPa for water-stress treatments, respectively. There was little difference between the two cultivars either under well-watered or under water-stressed treatment until very end of the growing cycle whereon the Alpowa tended to have lower Ψ_l than ID485 under the water stress treatment (Fig. 5). The leaf water potential trended to decline with plant maturing, which agreed with the above field experiment and other greenhouse studies (Chen, 1995; Moustafa et al., 1996). Haun stages of wheat leaves were nearly linearly related to GDD (Fig.6). The Haun stage value on November 25, 1998 for ID485 curved away from the straight line probably due to the bias in the measurement after booting stage and fully expansion of flag leaf. Haun (1973) used a different scoring system after heading stages. Similar to the field experiment, Alpowa showed a faster leaf appearance and growth rate than ID485, and Alpowa produced 3 more total main stem leaves than ID485 during the growth cycle.

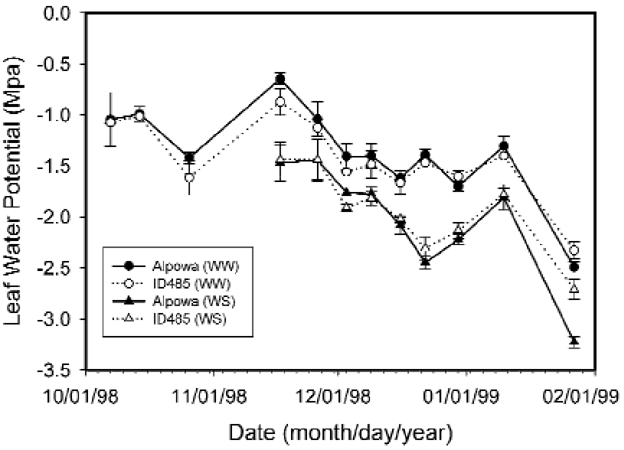

Fig. 5. Leaf water potential of two spring wheat cultivars (Alpowa and ID 485) grown in a greenhouse under well-watered (WW) and water-stress (WS) treatments.

The effects of water-stress on biomass accumulation were obvious (Fig. 6b). Above-ground biomass accumulation was greatly reduced under water-stress treatment for both cultivars. Alpowa tended to have a faster biomass accumulation than ID485 at both well-watered and water-stress treatments (Fig. 6b).

The biomass partitions for well-watered and water-stress treatments are displayed in Figure 7. Alpowa had greater leaf, stem, and head biomass accumulation under the well-watered treatment. Under the water-stressed treatment, however, Alpowa had greater leaf and stem but not head biomass accumulations. The biomass production was greatly reduced in water-stress treatment

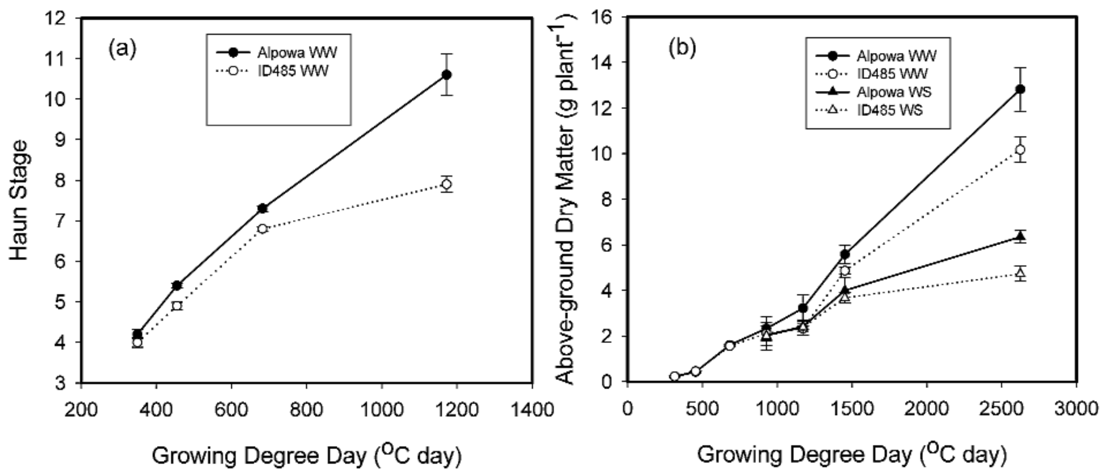

Fig. 6. Leaf appearance and growth measured by Haun stage (a) and above-ground dry matter accumulation of two spring wheat cultivars (Alpowa and ID 485) grown in a greenhouse under well-watered (WW) and water-stress (WS) treatments.

compared to well-watered treatment, especially for the stems and heads (Fig.7a, b). Although Alpowa had a faster leaf development, the leaf-area of Alpowa was less than ID485 during their early growth stages, but Alpowa maintained significantly greater leaf area than ID485 after booting and heading stage, mainly due to its greater numbers of leaves (data not shown).

Under well-watered treatment Alpowa had greater shoot dry matter (SDM), root dry matter (RDM), grain yield (GY), total ET than ID 485, but there was no difference in root/shoot ratio (R/S), water use efficiency (WUEg), and harvest index (HI). Under water-stress treatment, however, Alpowa had greater SDM than ID485, but ID485 had greater R/S, GY, WUEg, and HI than Alpowa (Table 3). A greater root/shoot ratio is often considered to be one of drought tolerant traits in literatures.

ID485 also was found to have a lower D than Alpowa under both well-watered and water-stress conditions (Table 4). Lower D was related to greater GY, WUEg, and HI of ID 485 in water-stress treatment in Table 3. Wheat genotypes with lower values of D have been related with greater WUE and more favorable water status under drought-stressed conditions (Condon et al., 1990; Ehdaie, 1995).

Yield components in Table 4 show that Alpowa produced more heads per plant, less seed numbers, and bigger seeds than ID485. Alpowa had taller plant heights than ID485 under well-watered conditions, but the plant heights did not differ under water-stress conditions.

Conclusions

Leaf water potential measured at noon reflected water status of plants and of the soils where the plants grew. Fall-seeded wheat had greater total ET, but the water use patterns and soil water contents were very similar in the spring and summer seasons for both seeding dates, indicating that a substantial amount of soil water was lost from the

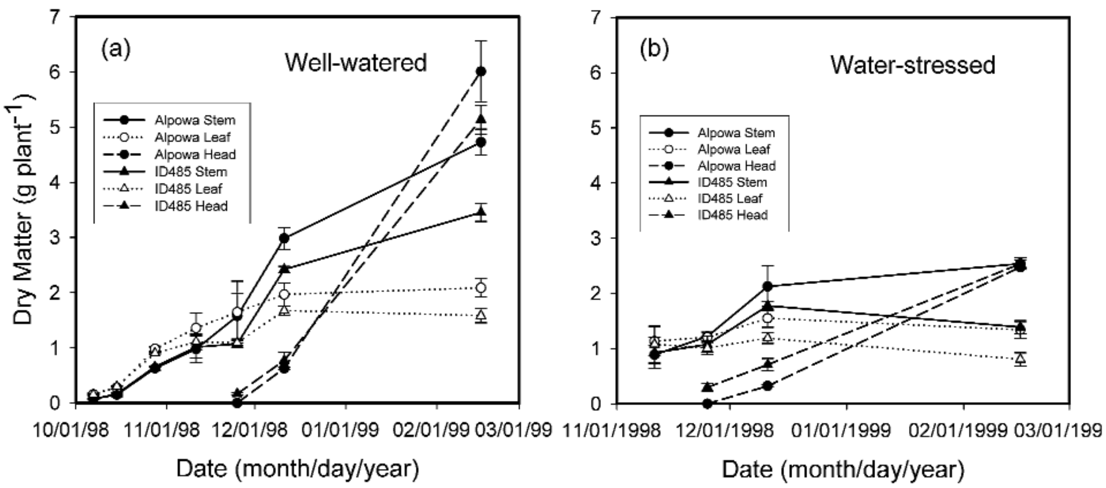

Fig. 7. Dry matter accumulation of stems, leaves, and heads of two spring wheat cultivars (Alpowa and ID 485) grown in a greenhouse under well-watered (WW) and water-stress (WS) treatments.

Table 3. Shoot and root dry matter (SDM, RDM), root and shoot ratio (R/S), grain yield (GY), evapotranspiration (ET), seed yield water use efficiency (WUEg) and harvest index (HI) of Alpowa and ID485 at harvest under well-watered and water-stressed conditions in a greenhouse pot experiment.

Water treatments	Cultivars	SDM (kg m^{-2})	RDM (kg m^{-3})	R/S	GY (kg m^{-2})	ET (mm)	WUEg (g m^{-2} mm^{-1})	HI
Well-watered	Alpowa	1.50a[§]	0.59a	0.40a	0.76a	806a	0.94a	0.51a
	ID485	1.21b	0.52b	0.43a	0.65b	757b	0.86a	0.54a
Water-stress	Alpowa	1.11a	0.42a	0.38b	0.36b	462a	0.78b	0.33b
	ID485	0.59b	0.29a	0.49a	0.42a	453a	0.91a	0.70a

[§]Numbers in each column followed by different letters are significantly different ($P \leq 0.05$) according to Fisher's PLSD test.

plots through evaporation over the winter even without any plant growing. The soft white spring wheat Alpowa had faster leaf appearance and growth as well as biomass accumulation rate, taller plant, later maturing, and larger but fewer seed numbers per head than the hard red spring wheat ID485. While planted in the fall and well-watered conditions, Alpowa exhibited yield advantage over ID485. Post-anthesis water stress reduced biomass accumulation in leaves, stems, and heads for both cultivars. The difference in grain yield became narrower between the two cultivars when they were planted in the spring or subjected to terminal water stress. The hard red spring wheat ID485 had a lower D value than Alpowa, which was related to the greater GY, WUEg, and HI of ID 485 in water-stress treatment.

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Effect of soil matric potential on waxy corn (*Zea mays* L. *sinesis* Kulesh) growth and irrigation water use under drip irrigation in saline soils of arid areas

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Abstract

The decreasing availability of good farmland makes saline soil a valuable alternative resource for agriculture in North West China. In order to obtain high yields and economic benefits, it is essential to develop suitable management procedures for farms to better cope with soil water scarcity and water stress under salinity. A field experiment was carried out to investigate the effect of soil matric potential on waxy corn growth and water use under drip irrigation in saline soils of North West China in 2005. The experiment included five treatments, which involved control of soil matric potential (SMP) at 20cm depth immediately under drip emitter higher than -5.5, -10.5, -15.5, -20.5, and -25.5 kPa. There were significant differences among the five treatments regarding the waxy corn growth. The higher the target SMP value was, the higher the yields of waxy corn. Plant height, stem circumference, LAI and above-ground biomass all increased with increasing SMP. But the highest irrigation water use efficiency was achieved with SMP of –10.5kPa. The SMP of -10.5kPa at 20cm depth immediately under drip emitter can be used for corn drip irrigation scheduling on saline soil in the arid areas of North West China.

Introduction

There are currently some 37 million hm^2 under saline soils in China. Approximately 60% of such areas are in North West China. Among the saline soils in China, about 2 million hm^2 suffer from irrigation-induced salinity problems, and 70% of these lands are in North West China (Wang, 2003). It is generally accepted that the arid climate necessitates use of intensive irrigation under conditions of soil salinity for raising successful crops.

Waxy corn (*Zea mays* L. *sinesis* Kulesh) is a starch variant of normal corn, containing 100% amylopectin in its starch whereas the normal corn contains 75 percent amylopectin and 25 percent amylose. Waxy corn is largely used industrially although it is also suitable for food or feed. Area under waxy com is small as compared with regular dent corn in China. Corn is moderately sensitive to salinity, tolerating an EC of the saturated soil extract up to 1.7dS/m or an EC of irrigation water up to 1.1dS/m without any yield reduction when leaching fraction is 15-20% (Ayers and Westcott, 1985).

Drip irrigation can apply water precisely, uniformly and frequently compared with other irrigation techniques, thus enabling to control soil salinity and increase yield under such conditions (Elfving, 1982). In arid and semiarid regions, evaporation rates increase considerably under drip irrigation due to the wet soil surface resulting inevitably in salt buildup under saline soil environments. This problem can be overcome by applying mulch with drip irrigation or by using sub-surface irrigation system. It is, however, unadvisable to irrigate crops with sub-surface irrigation system in North West China where the local farmers find it a difficult practice because of high cost and relatively complex technology. A mulched drip irrigation system is easier to manage and is also cheaper than a sub-surface irrigation system. Mulches improve soil temperature and soil physical and chemical properties significantly (Tumulhairwe and Gumbs, 1983). Moreover, soil evaporation losses decrease due to mulch, thereby preventing salt accumulation on soil surface.

Under high drip irrigation frequency, the effect of water on soil salinity was great, especially near the drip source, where at last the soil salinity became nearly the same as the salinity in the irrigation water (Goldberg et al., 1976). In the absence of a convenient and reliable plant water stress indicator that could be used for scheduling irrigation, the only rational solution is to rely on soil matric potential (SMP) measurements (Klein, 2004). Soil matric potential, a measure of the strength of the soil matrix for holding water, is a critical variable in determining crop yield, runoff, erosion, evapotranspiration and irrigation scheduling (Phene et al., 1989).

Tensiometer can be used to monitor SMP in field in real time and to control drip irrigation system by initiating irrigation when a preset threshold is exceeded. Many studies have been done on the use of tensiometers for scheduling irrigation in different crop species such as onion (Shock et al., 2000), banana (Hegde and Srinivas, 1989), corn (Rhoads and Stanley, 1973; 1974), and radish (Hegde, 1987; Kang and Wang, 2005). Rhoads and Stanley (1973, 1974) reported that the highest yield of corn could be obtained when SMP in the upper 30 cm was maintained above -10 kPa (for sandy soils) to -40 kPa (for clay soils).

The objectives of this study were: (1) to measure the effects of different SMP on waxy corn growth, yield, and irrigation water use efficiency under mulched-drip irrigation; (2) to test if mulched drip irrigation was a good technique to exploit saline lands in North West China; and (3) to define the basis for drip irrigation scheduling of waxy corn and water resource planning under saline lands and arid conditions in North West China.

Materials and methods

Experimental site

Field experiment was conducted on saline soil at Jinshawan farm in the middle of Hetao plain of the Ningxia autonomous region in the upper Yellow River Basin, China (latitude: 37°36´N, longitude: 105°39´E, 1156m a.s.l.).The annual precipitation is about 185mm, and the potential evaporation is about 2086mm. The average annual temperature is 8.5°C, and the accumulated temperature above 10° is 3070°. The length of the frost-free period is 130-186 days. The average groundwater table is about 1.5m. The electrical conductivity of irrigation water is about 0.68dS m^{-1}. The organic matter content in the surface soil is about 0.3%, and available N 21% of the total, active P 0.5ppm, and active K 53.1ppm. More physical and chemical characteristics of the soil are presented in Table 1.

Experimental designs

Five treatments of soil matric potential (SMP) were used for this study with SMP at 20cm immediately under emitter higher than -5.5kPa (S1) -10.5kPa (S2), -15.5kPa (S3), -20.5kPa (S4), and -25kPa (S5). A complete randomized block design with three replications was used. Each treatment was provided separately by a ball valve, a flow meter, three pressure gauges, a gate valve, a screen-mesh filter and a pressure differential fertilizer tank, for the control and measurement of water, fertilizer application and filteration. ∅16 thin-wall drip tapes, with 20cm emitter spacing and a flow rate of 3.75L $m^{-1}h^{-1}$ at the operating pressure of 0.03MPa, were placed in the center of raised beds.

Agronomic practices

Each plot was 3.2m×15m, and contained four raised beds, 15m long each. The spacing between the raised beds was 0.8m. A single-row of the corn was planted in the center of each bed with interplant spacing of 20cm. N, P and K fertilizer was applied (at the rate of 150, 85 and 12 kg·hm^{-2}, respectively) when the soil was plowed. Topdressing of soluble fertilizer of K and N was given with irrigation water. Seeds of waxy corn cv. ‘Zhongnuo No.1’ were planted on 22 May 2005. After emergence, seedlings were thinned to leave only one seedling at each location maintaining a plant density of approximately 62,500 hm^{-2}. The crop was harvested on 31 August 2005.

Observations and equipment

Soil matric potential: Three tensiometers were installed at the depth of 20, 35 and 50cm immediately under drip emitter for each treatment to observe soil matric potential. Observations were made daily at 8:30 a.m., 11:30 a.m. and 3:30 p.m. Once the plant density was established, the tensiometer at 20cm was checked to determine the

Table 1. Some physical and chemical characteristics of the soil at the experiment site

Soil depth (cm)	Soil texture	Soil bulk density ($g\ cm^{-3}$)	Total dissolved solids* ($g\ kg^{-1}$)	pH*
0-20	silt loam	1.54	19.4	7.3
20-40	silt loam	1.53	27.4	7.2
40-90	sandy loam	1.53	22.4	7.1
90-100	sandy	1.55	16.9	7.0
100-140	sandy	1.71	12.9	7.0

**Total dissolved solids and pH were measured in 1:5 (w/v) soil water extract.*

irrigation time. The amount of irrigation water each time was about 5mm or 10mm according to the water requirement of plant at different stages of growth.

Corn growth and yield: Ten plants were randomly selected and tagged in one plot of each treatment for plant height and stem circumference measurement at 10-day intervals during the growing season. Three of these plants were selected for leaf area measurement at the same intervals. Two plants in another plot of each treatment were randomly selected and sampled for above-ground biomass. Twenty consecutive plants in the middle two rows of each plot were harvested for the determination of yield and ear characteristics.

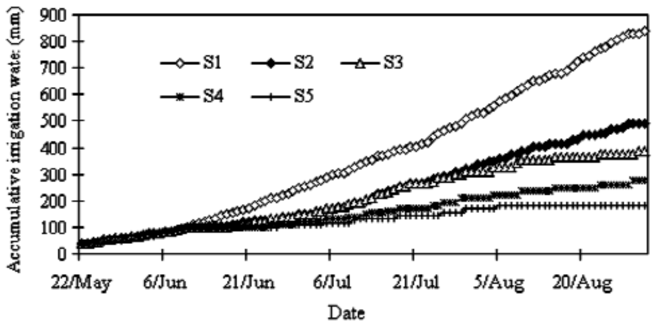

Fig. 1. Cumulative irrigation water for different treatments during corn growing period.

Results and discussion

Weather and irrigation

Before the plants emerged, all the plots were irrigated with the same amount of water to ensure uniform germination. In order to leach out the soil salt, the first depth of water after seeding was six times of normal depth of 5mm. Differential irrigation treatments were initiated on 11 June (21 days after seeding) on which date the seedlings were thinned. After that, irrigation was applied only when the soil matric potential reached the target values for S1, S2, S3, S4 and S5 treatments. The depth of water for each irrigation event in all the treatments changed during the growing season and varied from about 5 to 10mm. Total irrigation amount for S1, S2, S3, S4 and S5 was 666, 388, 307, 216 and 145mm, respectively (Fig. 1). Total irrigation days for S1, S2, S3, S4 and S5 were 89, 53, 45, 33 and 25, respectively. Fig. 2 shows the amount of irrigation water given per day during the growing season for each treatment.

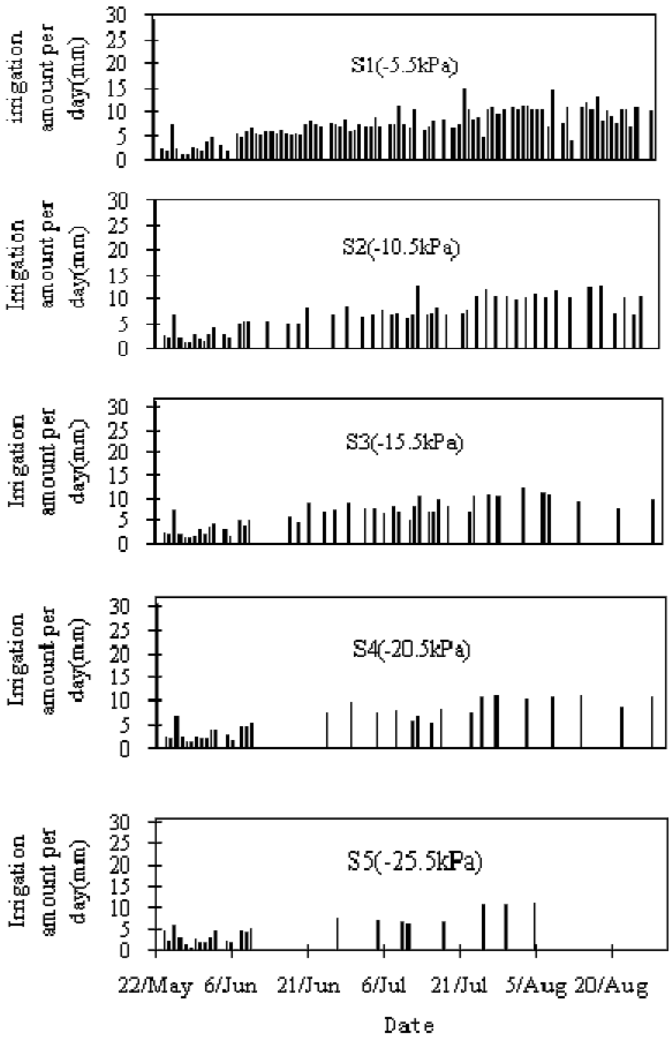

Fig. 2. Application irrigation water per day for different treatments during corn growing period.

The average weekly temperature, rainfall, and pan evaporation are shown in Table 2. There were six rainfall events during the experiment and total rainfall was 24.5 mm. The maximum rainfall was 5.9 mm. The maximum average weekly mean temperature occurred in the third week of the growing season. The maximum average weekly pan evaporation was 16.6mm, which occurred in the fourth week.

Soil matric potential

Fig. 3 illustrates the soil matric potential at 20, 35 and 50cm depths immediately under the drip emitters for different treatments. The soil matric potential at the depth of 20cm was as per the target value of soil matric potential. From the 8th to 11th week after seeding, although the pan evaporation did not increase, plants in S1 plot grew faster and their water requirement increased. Consequently, the applied irrigation water was insufficient to maintain the target soil matric potential, and the soil matric potential for S1 decreased rapidly. For the S5 plot, plants grew under unfavorable soil water conditions, which were controlled by lower soil matric potential after ninth week from seeding. Water use became smaller because plant growth was inhibited, which could explain why the soil matric potential could not decrease to target value. In order to balance the nutrient application with other treatments, plants were irrigated several times passively, which resulted in the soil matric potential for S5 treatment to become higher than the target values from the 9th week to the end of growing season. The soil matric potential of all treatments at 35 and 50cm depth only varied from -5 to -15kPa and from -5 to -10kPa, respectively, obviously affected by the upward flow of shallow ground water.

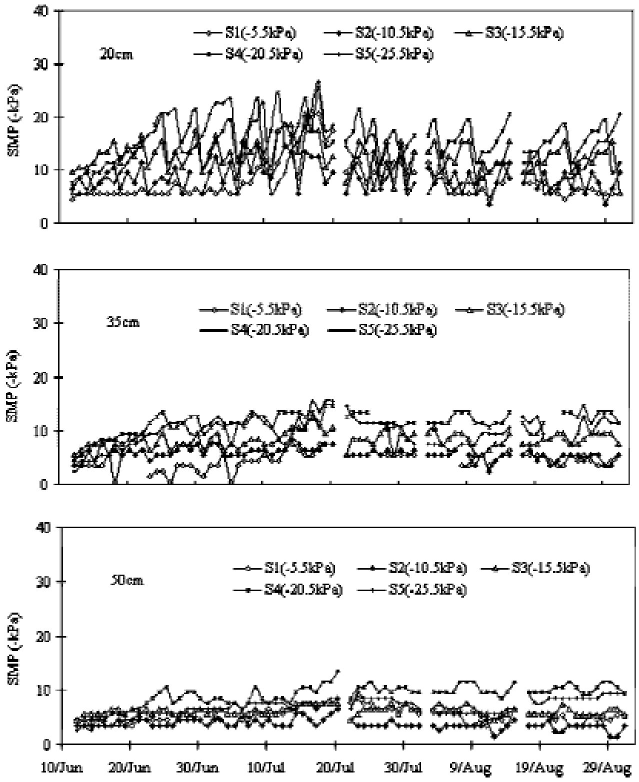

Fig. 3. Change in soil matric potential in 20, 35 and 50 cm depths immediately under emitters for different treatments.

Table 2. Weather data during the growing period of the crop in 2005

Week	Temperature(°C)			Cumulative rainfall	Pan evaporation
	Maximum	Mean	Minimum	(mm)	(mm·day^{-1})
1	31.3	26.7	22.1	0.6	11.9
2	33.1	29.1	25.1	0.0	15.1
3	33.6	29.5	25.4	0.0	15.6
4	33.5	26.0	18.6	0.0	16.6
5	34.0	26.7	19.3	0.0	16.0
6	31.3	22.9	14.4	0.0	10.9
7	32.0	26.2	20.3	0.0	11.3
8	35.6	26.8	18.0	4.3	14.7
9	29.3	23.9	18.4	9.4	12.3
10	35.1	27.6	20.0	0.0	12.7
11	32.4	24.9	17.4	5.5	10.6
12	31.7	23.8	15.9	0.0	8.8
13	27.3	21.3	15.2	4.7	8.8
14	29.6	21.6	13.6	0.0	9.8
15	30.4	23.2	16.1	0.0	11.9

Corn growth

The plant height increased with the increasing soil matric potential and the development of plant during the growth periods.

The stem circumference versus time relationship for the five treatments was sigmoid. The biggest difference in the treatments occurred during the shooting period (20 days after treatments, June 30); the stem circumference in S1 was bigger than in S5. It began to decrease in the middle stage of tasselling and grain filling for all the treatments because with the onset of reproductive growth more photosynthate was mobilized from stem and leaf to kernel. Lower the soil matric potential, lesser was the decrease in the stem circumference. It can be concluded that for lower soil matric potential treatment, the amount of nutritive material migration was little, which adversely affected the ear characteristics and yield.

The leaf area index (LAI) also followed the same sigmoid shape for the five treatments. In the earlier stage of growth LAI was small; it began to increase with the development of plant, reaching the maximum value at the vigorous growth stage and then decreased at the end of that growth. LAI increased with the increasing soil matric potential, but the time for reaching the maximum value differed with treatments. The lower soil matric potential, the earlier the maxima was reached. It was because the crop growth was weakened and the leaf got scorched and started senescing because of lower soil matric potential (-25.5 and -20.5kPa at 20cm depth).

The cumulative above-ground biomass had similar trends; the higher the soil matric potential more was the above-ground biomass at different growth stages.

Corn yields and ear characteristics:

From Table 3 it can be seen that the yield (three layers of subtended leaves for fresh weight) was significantly affected by the different soil matric water potential treatments. The higher the soil matric water potential, the larger the yields. The increase in the soil matric water potential also resulted in increased ear kernel number and fresh 100-kernel weight. The yield relationship could be shown by the following regression equation:

$$y = -7622.5 \, \mathrm{Ln}\,(x) + 25278, \text{ with } R^2 = 0.998,$$

where y is the waxy corn yield (kg hm^{-2}) and x is soil matric water potential (-kPa).

Irrigation water use efficiency

Irrigation water use efficiency (IWUE) is the relationship between yield and the quantity of irrigation water applied. It was 18.5, 19.1, 13.5, 11.6, and 3.47 kg hm^{-2} mm^{-1} for S1, S2, S3, S4, and S5 regimes, respectively. IWUE thus increased with the increasing of SMWP, reached the maximum when the SMP was about -10.5kPa, and then began to decrease as the SMP further increased. Following equation illustrates the general relationship between IWUE and the SMWP:

$$y = 17.28 + 0.49\,x - 0.04\,x^2, \text{ with } R^2 = 0.998,$$

where y is the IWUE of waxy corn (kg $hm^{-2}mm^{-1}$) and x is soil matric potential (-kPa).

Summary and conclusions

As a new irrigation method in China, mulched-drip irrigation has many advantages compared with other irrigation techniques. It can save water,

Table 3. Ear characteristics and yield of waxy corn as effected by soil matric potential.

Treatment	Ear length (cm)	Ear diameter (cm)	Barren tip length (cm)	Ear weight (g)	Ear kernel number	100-kernel weight (g)	Yield (kg hm^{-2})
S1	16.9	4.5	2.3	180	$416^{a,A}$	$31.3^{a,A}$	$12300^{a,A}$
S2	15.8	4.0	2.1	140	$381^{a,A}$	$23.9^{b,B}$	$7420^{b,B}$
S3	14.0	3.6	2.6	100	$274^{b,B}$	$21.9^{c,B}$	$4150^{c,C}$
S4	13.0	3.3	2.4	70	$205^{c,C}$	$18.8^{d,C}$	$2520^{d,C}$
S5	13.6	2.8	3.7	40	$113^{d,D}$	$17.9^{d,C}$	$502^{e,D}$

Superscript small and big letters respectively represent significance at á=0.05 and á=0.01 probability levels. Same letter shows no significant difference.

control soil salt concentration in the root zone and thus help in exploiting saline soils, and increase yield. Waxy corn plant height, stem circumference, LAI, above-ground biomass, yields and irrigation amount all increased with increase in the soil matric water potential (SMWP). Irrigation water use efficiency increased with the increase in soil matric potential, and reached maximum when soil matric potential threshold was -10.5 kPa, and then decreased with further increase in SMWP. Increase in SMWP increased the fresh yield through increase in the number of kernels per ear and the 100-kernel weight. Using tensiometer to control the drip irrigation was convenient and cheap.

Considering the irrigation amount and the yield, the soil matric potential between -5kPa and -10kPa at 20cm depth can be used as an indicator for scheduling drip irrigation in waxy corn in the arid areas of North West China. Many other studies have shown that the SMWP between -10kPa and -30kPa is generally considered optimal for the crop growth. That could be explained on the basis of the differences in the environmental conditions. These are only 1-year data, and more studies should be done in the future to get conclusive results.

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Effect of genotype variability on nitrate uptake and assimilation in wheat

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Abstract

Nitrate uptake and assimilation and dry matter production of a range of wheat cultivars were examined in a hydroponics system. Seedlings were grown at 2 rates of nitrates (0 and 1.0 mM) for 26 days. Significant genetic differences in growth and nitrate uptake were identified. The cultivars 'Atila' and 'Uavarous' consistently produced larger seedlings, which took up large quantities of nitrate from solution whereas 'Falat', 'Star' and 'Seri 11' produced small seedlings and took up small amounts of nitrate. However, there was evidence that one group of cultivars was more efficient physiologically in assimilating nitrate because for a comparable amount of nitrate taken up from solution they produced more total dry matter than the rest of the cultivars. The genetic differences in nitrate uptake between cultivars were mostly related to the size of the plant, especially the root system. However, the importance of greater nitrate uptake by the seedling because of greater early vigor was not clearly established because this was not always beneficial to final yield.

Introduction

Nitrate is the most common form of N taken up by cereal plants growing in the field, and efficient utilization of soil and fertilizer N is an important and desirable agronomic character in wheat (*Triticum aestivum*). Under most soil conditions, even the ammonium fertilizer is rapidly nitrified to nitrate by soil organisms (Ehdaie and Waines, 2001). It would therefore be desirable that the plants are able to take up as much of nitrate as possible. There are clear indications that absorption of nutrients by plants is under genetic control (Epstein, 1972; Banziger et al., 1992; Moghaddam et al., 1998), and therefore there are considerable differences in nutrient uptake between cultivars. The variation is because of several factors including differences in the size and morphology of the roots, demand for mineral elements caused by differences in relative growth rate (Schimansky and Marschner, 1971; Isfan, 1993), uptake and transport (Rroco and Mengel, 2000), and use efficiency.

The present study aimed to evaluate the level of genetic variation in nitrate uptake and assimilation in wheat cultivars at the seedling stage. Fathi (unpublished data), on the basis of differences in nitrate uptake and dry matter accumulation, categorized different wheat cultivars in two main groups. Cultivars 'Fong', 'Star' and 'Falat' had small seedlings, which took up less nitrate but had higher relative growth rates than the semi-dwarf cultivars 'Atila', 'Atrak' and 'Showa'. It was thought that these differences could be related to the pedigrees of the cultivars. Therefore, the preliminary experiments were extended to look at a greater number of cultivars representing four genetic groups. The aim of the present study was to further verify the differences in the response of the wheat cultivars to nitrate in a larger number of cultivars.

Material and methods

The study was conducted as 3 separate experiments in 2003. Nineteen cultivars of wheat were obtained from the collection of the Ahwaz Agricultural Station, Khusestan. Each cultivar is a commercial variety or advanced breeding line. The cultivars were classified into four groups, each with a similar or common pedigree:

Group 1: Cultivars derived form semidwarf parents, with high nitrate uptake characteristics. 'Atila' and 'Showa' were assigned as the leading cultivars.

Group 2: Cultivars mostly derived form Khusestan wheat breeding cultivars. The leading cultivar of this group 'Falat' has been found to have low nitrate uptake characteristics in the early stages of growth.

Group 3: Cultivars derived either from 'Veenac' or 'Atrak'. 'Star', the leading cultivar in this group, has low nitrate uptake characteristics.

Group 4: This group consisted mainly of variety 'Research' as a common parent. The leading cultivar 'Fong' has been recognized having high nitrate uptake characteristics.

In each experiment the Group 1 was compared with one of the other groups. In Experiment 1, Groups 1 and 2; in Experiment 2, Group 1 and 3; and in Experiment 3, Group 1 and 4 were compared. Seeds were sterilized by immersing in 70% ethanol for 1 min, soaked for 5 min in 1% sodium hypochlorite (8 ml 100^{-1} ml de-ionized water) and thoroughly rinsed with deionized water. The seeds were then sown in square plastic pots containing sterilized sand and watered with de-ionized water in a glasshouse set at 20 ± 4°C and a 12 hr photoperiod. Eight days after emergence the seedlings were removed from the sand and transferred to 6 L round plastic pots with plastic lids. Each lid had 25 holes. Seedling were supported by inserting their roots through holes in the base of Eppendorf tubes (7-ml capacity), which were placed in the holes in the lid. Twenty-four seedlings were placed in each pot and grown for 26 d using a hydroponics system with an l mM nitrate solution with a pH of 7.0. The last hole was used for forced aeration at the rate of 0.9L min^{-1} for each pot. The nutrient solution in each pot was renewed at 10, 15 and 19 d after seedling transfer. At day 20, the plants were transferred to a 1mM nitrate free solution for 24 hr after which 12 plants in each pot were harvested (H_1). The remaining plants were transferred to a 1 mM nitrate solution for 6 day during which time the solutions were changed every 48 hr. At day 26 (H_2) the remaining 12 plants were harvested and partitioned into root and shoot and their dry weights measured. The experimental design was a randomized complete block with 4 replicates.

The nitrate concentration of the nutrient solution was measured each time solutions were renewed before first harvest (H_1), and between H_1 and the final harvest (H_2). The absorbance of this solution was measured in a spectrophotometer (model lambda 5) at 210 nm. Nitrate concentrations in the plant parts at H_1 and H_2 were measured as unreduced nitrate by the *E. coil* method (McNamara et al., 1971). Relative growth rate (RGR), nitrate assimilation, nitrate assimilation efficiency (NAE), and nitrate uptake efficiency (NUE) were determined. Growth rate was calculated from the increase in total dry weight during 6 days. Analysis of variance was conducted for each experiment on all data. Linear regressions were calculated for relationships between (a) the increase in nitrate between H_1 and H_2 and the increase in dry weight over the same time, and (b) the total nitrate uptake over 26 d and total dry weight at H_2. To compare the response of different groups of cultivar, the slopes and intercepts of the regressions were compared using SAS methods.

Plants were partitioned into shoot and root after harvest, dried at 80°C for 2 days and the dry weights measured. The relative growth rate was calculated as $RGR= (LnW_2-LnW_1) / (t_2-t_1)$, where W_1 and W_2 are total plant dry weights at t_1 and t_2. Nitrate accumulation was calculated from the difference between nitrate content in root and shoot at H_1 and H_2. Nitrate concentration of the root and shoot was measured as unreduced nitrate by the *E. coli* method. Nitrate assimilation was estimated by subtracting the nitrate accumulation in both shoot and root from total nitrate taken up by the plants.

Results

Experiment 1

There were significant differences in root and shoot growth among the cultivars, which were not related to their cultivar groupings (Table 1). 'Seri 11' and 'Chenalter' (Group 1) and 'Arvand' and 'Chenab' (Group 2) produced significantly more root growth than the other cultivars at both harvests. A similar difference, although not as large, was observed also with shoot growth. 'Falat' had the greatest RGR and the smallest plants. The growth rates of the 10 cultivars were not significantly different from one another; however, there were differences in the RGR. 'Seri 20' is not a semidwarf but had quite a different RGR.

Table 1. Effect of 1 mM nitrate supplied hydroponically on root, shoot and total dry matter production and growth rate of 10 wheat cultivars in Experiment 1.

Cultivar	Root DW (mg plant^{-1})		Shoot DW (mg plant^{-1})		Total DW (mg plant^{-1})		RGR	GR
	H_1	H_2	H_1	H_2	H_1	H_2		
Group 1:								
Atila	62	114	176	401	237	514	13.2	46
Uavarous	53	102	171	398	223	501	13.4	46
Seri 11	67	114	168	420	234	532	13.1	50
Seri 20	87	142	222	447	308	588	10.8	47
Chenalter	75	138	188	480	262	618	14.3	59
Group 2:								
Falat	39	94	106	311	144	406	17.4	44
Darab2	48	95	163	407	210	501	14.3	48
Chenab	83	163	230	464	313	627	11.6	52
Coleah	70	114	196	370	266	484	9.9	36
Arvand	77	165	225	512	303	679	13.5	63
LSD (5%)	16	23	38	80	53	95	3.8	NS

H_1 = Harvest 1; H_2 = Harvest 2; RGR = Relative growth rate; GR = growth rate

Table 2. Total nitrate uptake (μmol per plant) in 26 days, increase in nitrate uptake (μmol/plant) in 6 days between H1 and H2, increase in nitrate uptake (μmol) per g root dry weight and indices of N use efficiency of wheat cultivars in Experiment 1.

Cultivar	Total NO_3^- uptake (μmol/plant)	Increase in NO_3^- uptake in 6 days	NO_3^- uptake in 6 days per g root dry wt	$\Delta DM/\Delta NO_3^-$ uptake in 6 days	Total DM/total NO_3^- uptake
Group 1:					
Atila	1838	956	3699	0.301	0.286
Uavaraous	1812	937	4002	0.305	0.283
Seri 11	1758	856	317	0.337	0.299
Seri 20	2234	1185	3461	0.233	0.263
Chenalter	2169	1181	3695	0.306	0.286
Group 2:					
Falat	1450	827	4100	0.346	0.282
Darab2	1659	857	4022	0.339	0.305
Chenab	2246	1202	3340	0.264	0.279
Coleah	1918	952	3465	0.230	0.254
Arvand	2450	1374	3774	0.274	0.276
LSD (5%)	285	216	NS	NS	NS

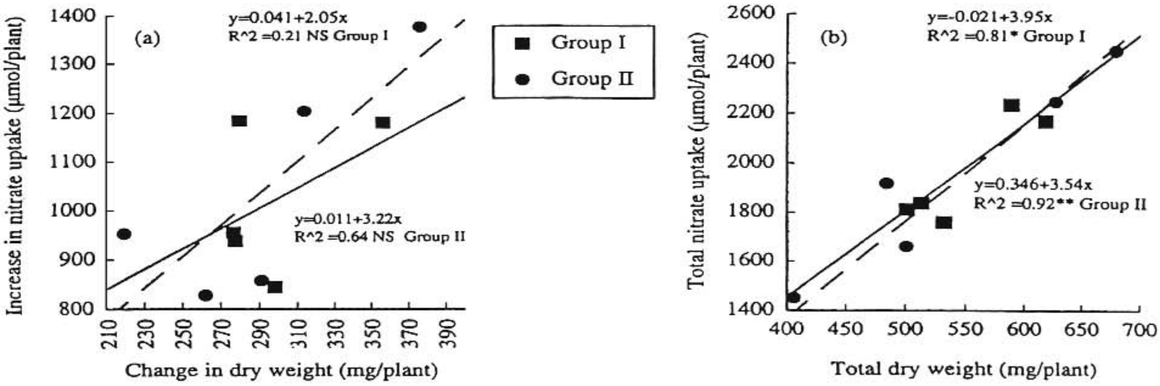

Fig. 1. Relationship between increase in dry weight and nitrate uptake over 6d (a), and total dry weight and total nitrate uptake over 26d for 10-wheat cultivars (b) in Experiment 1.

There were significant differences between cultivars both in the total amount of nitrate taken up over the 6 days and in the nitrate, which accumulated in the plant tissue (Table2). However, as with the dry matter and growth rate data, there was no clear distinction between the 2 groups. There was no significant difference between cultivars in Groups 1 and 2 in nitrate uptake per g root dry weight (Table 2). Total nitrate uptake per plant did not differ significantly between 'Seri 20' and cultivars 'Chenalter', 'Arvand' and 'Chenab' but 'Seri 20', 'Arvand' and 'Chenab' took up significantly more nitrate than the other cultivars. 'Flatat' and 'Darb2' had the lowest total nitrate uptake (Table 2). The relationship between the increase in plant dry matter and uptake of nitrate over the 6 days for the 2 groups were not significant (Fig. 1a). There were significant linear relationships between the total nitrate uptake of the plants and the total dry weight at H2 (Fig. 1b), but comparison of the regressions showed that they were not significant.

Experiment 2

There were significant differences between the ten wheat cultivars in root, shoot and total plant dry weights at both harvests (Table 3). At H1, 'Seri 20' and 'Maron' had significantly higher root dry weights than the other cultivars. The remaining cultivars did not differ significantly. At H2, root dry weights of 'Veenac', 'Atrak', 'Showa', 'Uavarous', 'Star', 'Seri 11' and 'Atila' were not significantly different but those of 'Maron' and 'Seri 20' were again greater. Shoot dry weight was higher in 'Maron', 'Seri 20', 'Atila' and 'Uavarous' than in the others at H1. It was higher in 'Maron' and 'Seri 20' and the lowest in 'Showa', 'Star' and 'Veenac' at the H2. The differences in growth were between cultivars rather than between the two groups. RGR was significantly different between cultivars and ranged from 14.1d^{-1} in 'Star' to 9.7d^{-1} in 'Seri 20'. Within Group1 cultivars, the RGR of 'Seri 20' was significantly lower than 'Seri 11' (Table 3). The high RGR for 'Star' is consistent with the results of the preliminary experiment. The growth rates of the semidwarf cultivars in this experiment were similar to those in Experiment 1. The significant difference in growth rate is largely due to the value for 'Maron'; there was no significant difference in the growth rates of the other cultivars. Total nitrate uptake per plant differed between cultivars but nitrate per g root dry weight did not. 'Maron' had a significantly higher nitrate uptake than the other cultivars, while 'Veenac' had the lowest uptake (Table 4). There were positive relationships between total nitrate content and total plant growth for cultivars in both groups (Fig. 2b). 'Maron' was different from the other Group 2 cultivars because of its high dry matter production and high nitrate uptake. The relationships between nitrate uptake and plant dry matter for Groups 1 and 3 were similar.

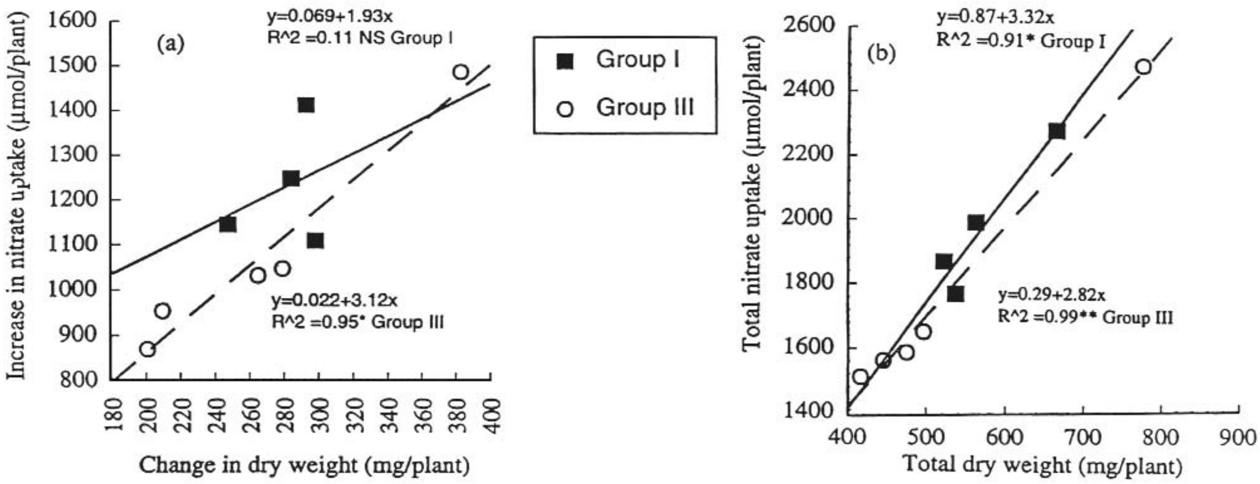

Fig. 2. Relationship between increase in dry weight and nitrate uptake over 6d (a), and total dry weight and total nitrate uptake over 26d for 10-wheat cultivars (b) in Experiment 2.

Table 3. Effect of 1mM nitrate supplied on root, shoot and total dry matter production (mg / plant) and growth rate of wheat cultivars in Experiment 2.

Cultivar	Root DW		Shoot DW		Total DW		RGR	GR
	H_1	H_2	H_1	H_2	H_1	H_2		
Group1:								
Atila	88	168	192	396	280	563	11.80	47
Uavaraous	86	140	189	382	276	522	10.71	41
Seri 11	69	150	170	386	239	537	13.61	50
Seri 20	130	198	242	468	371	663	9.75	49
Chenalter	95	163	204	481	305	667	13.62	55
Group 3:								
Star	71	147	148	351	218	497	14.11	47
Maron	121	234	268	538	390	773	11.44	64
Atrak	78	127	157	318	235	445	10.88	35
Veenac	66	122	149	295	216	416	11.63	33
Showa	65	130	146	337	210	475	13.64	44
LSD (5%)	28	49	52	90	80	129	2.73	13

H_1 = Harvest 1, H_2 = Harvest 2, RGR = Relative growth rate, GR = growth rate

Table 4. Total nitrate uptake (µmol per plant) in 26 days, increase in nitrate uptake (mmol/plant) in 6 days between H_1 and H_2, increase in nitrate uptake (mmol) per g root dry weight and indices of N use efficiency of wheat cultivars in Experiment 2.

Cultivar	Total NO_3^- uptake (µmol/plant)	Increase in NO_3^- uptake in 6 days	NO_3^- uptake in 6 days per g root dry wt	$\Delta DM/\Delta NO_3^-$ uptake in 6 days	Total DM/total NO_3^- uptake
Group1:					
Atila	1994	1249	3272	0.227	0.282
Uavaraous	1871	1146	3373	0.218	0.289
Seri 11	1771	1110	3360	0.269	0.303
Seri 20	2282	1413	2920	0.208	0.291
Chenalter	2156	1091	3519	0.302	0.279
Group 3:					
Star	1655	1047	3292	0.266	0.300
Maron	2484	1487	2836	0.259	0.311
Atrak	1563	954	3108	0.225	0.289
Veenac	1511	870	3062	0.244	0.275
Showa	1589	1031	3368	0.262	0.310
LSD (5%)	481	296	NS	NS	NS

Experiment 3

The 9 wheat cultivars differed significantly in dry matter production at both harvests (Table5). Root dry matter production was significantly higher in ‘Seri 20’ than the other cultivars at the first harvest (H1). ‘Fong’, ‘Zagrous’, ‘Cemareh’ and ‘Uavarous’ had the lowest root dry weight at H1. At the second harvest (H2), root dry weight was higher in ‘Seri 20’, ‘Kavir’ and ‘Atila’ and lower in ‘Uavarous’, ‘Chenalter’ and ‘Zagrous’. Shoot dry weight did not differ between ‘Seri20’, ‘Atila’, ‘Kavir’ and ‘Seri 11’ but was significantly higher for these than the others at H1. There were also no differences between ‘Seri 11’, ‘Fong’, ‘Kavir’ and ‘Atila’ in shoot growth at H2, but shoot dry matter was low in ‘Seri 11’, ‘Zagrous’, ‘Cemareh’ and ‘Uavarous’ (Table 5). Total plant dry weight at H1 was not different between ‘Seri 20’, ‘Atila’, ‘Kavir’ and ‘Seri 11’ but it was lower in ‘Zagrous’, ‘Fong’, ‘Cemareh’ and ‘Uavarous’. At H2, plant dry weight did not differ between ‘Seri 20’, ‘Fong’, ‘Atila’ and ‘Kavir’ but was in ‘Zagrous’, ‘Cemareh’, ‘Seri 11’ and ‘Uavarous’ (Table5). The period of Experiment 3 was shorter than the other two experiments and the semidwarf cultivars

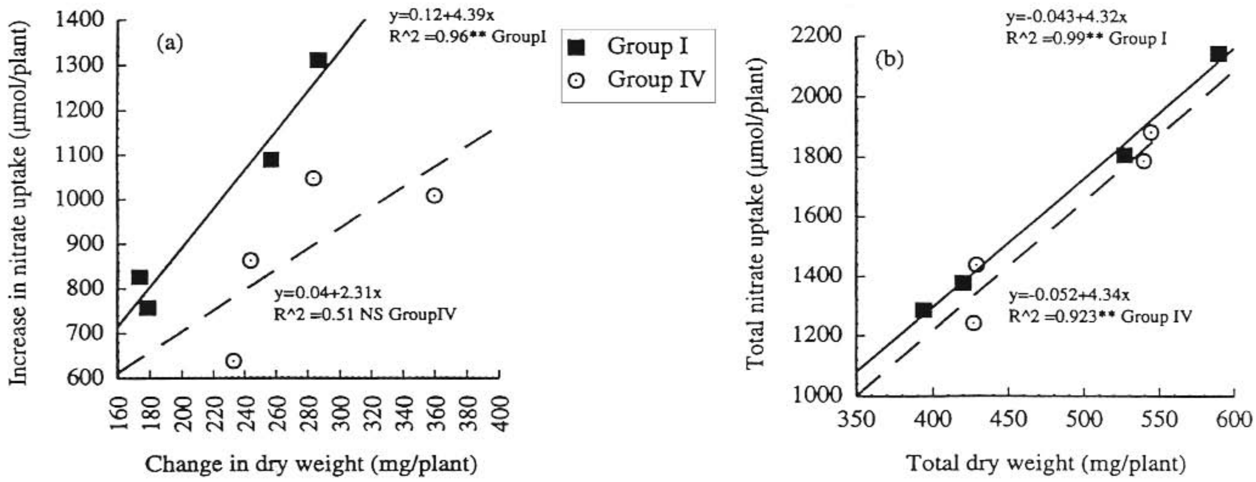

Fig. 3. Relationship between increase in dry weight and nitrate uptake over 6d (a), and total dry weight and total nitrate uptake over 26d for 9-wheat cultivars (b) in Experiment.

Table 5. Effect of 1mM nitrate supplied hydroponically on root, shoot and total dry matter production (mg / plant) and growth rate of wheat cultivars in experiment 3.

Cultivar	Root DW		Shoot DW		Total DW		RGR	GR
	H_1	H_2	H_1	H_2	H_1	H_2		
Group 1:								
Atila	85	161	186	367	269	528	11.62	44
Uavaraous	62	105	153	290	216	394	10.30	30
Seri 11	80	131	166	291	246	420	8.12	29
Seri 20	110	173	192	411	303	590	11.37	49
Chenalter	99	160	195	409	304	385	12.33	50
Group 4:								
Fong	54	145	129	400	184	545	19.67	59
Zagrous	53	124	130	304	183	429	14.12	40
Cemareh	59	117	134	310	192	427	12.70	39
Kavir	83	172	174	368	256	540	11.96	48
LSD (5%)	22	23	30	81	43	90	6.1	15

H_1 = Harvest 1, H_2 = Harvest 2, RGR = Relative growth rate, GR = growth rate

Table 6. Total nitrate uptake (µmol per plant) in 26 days, increase in nitrate uptake (µmol/plant) in 6 days between H_1 and H_2, increase in nitrate uptake (µmol) per g root dry weight and indices of N use efficiency of wheat cultivars in Experiment 3.

Cultivar	Total NO_3^- uptake (µmol/plant)	Increase in NO_3^- uptake in 6 days	NO_3^- uptake in 6 days per g root dry wt	$\Delta DM/\Delta NO_3^-$ uptake in 6 days	Total DM/total NO_3^- uptake
Group1:					
Atila	1807	1090	2993	0.241	0.296
Uavaraous	1286	758	2940	0.250	0.323
Seri 11	1377	828	2545	0.192	0.303
Seri 20	2143	1307	3053	0.222	0.277
Chenalter	2012	1200	2913	0.202	0.289
Group 4:					
Fong	1883	1007	3341	0.461	0.294
Zagrous	1439	863	3151	0.290	0.301
Cemareh	1242	638	2230	0.404	0.335
Kavir	1786	1047	2659	0.266	0.315
LSD (5%)	261	161	590	NS	NS

showed lower growth rates and nitrate uptake than 'Seri 11' and 'Uavarous', which is consistent with Experiments 1 and 2. RGR was significantly different between cultivars because of the higher RGR of 'Fong'; otherwise there were few significant differences (Table 5). There were also significant differences between cultivars in growth rate.

There was a significant difference between the cultivars in total nitrate uptake, nitrate uptake between H1 and H2, and the nitrate uptake per g roots dry weight (Table 6). Cemareh had a significantly lower uptake than the other cultivars. There were no differences among 'Uavarous', 'Atila', 'Seri 20', 'Zagrous' and 'Fong' which all had high uptake. Nitrate uptake per plant also differed between the cultivars. 'Seri 20' had a significantly higher uptake than all the other cultivars except 'Fong'. Uptake was low in 'Zagrous', 'Seri 11', 'Uavarous' and 'Cemareh'. The linear correlation between the change in plant dry weight and uptake of nitrate over the 6 days was significant for the Group 1 but not for Group 4 (Fig. 3a). There were significant linear correlations between the total nitrate uptake and the total dry weight at H2 (Fig. 3b). A comparison of the regression indicated that the Groups 4 and 1 had the same slopes but different intercepts. Therefore, nitrate uptake by the cultivars in Group 4 was lower for the same amount of dry matter production, or conversely, the dry matter production was higher when similar amounts of nitrate are taken up.

Discussion

The present study showed that 1 mM nitrate in the solution promoted difference in dry weight of the root and shoot, nitrate uptake and nitrate assimilation in the seedling of different wheat cultivars. The result of the experiments suggested that at least 2 groups of cultivars could be identified. The first group included 'Star' and 'Falat,' which produced small seedlings and took up small amounts of nitrate. The second group comprised of the semidwarf cultivars including 'Atila' and 'Uavarous', which took up greater amount of nitrate. The trend in increased nitrate uptake with greater plant dry weight over 6 days in Experiment 1 was not statistically significant between the 2 groups (Fig. 1a), which suggests that the differences between cultivars were related to the size of the plant. There were differences in dry matter production, which were reflected in differences in nitrate uptake. The results of the preliminary experiments and Experiment 1 were consistent with respect to the differences between the cultivars, namely that 'Atila' had high nitrate uptake and dry weight, but 'Falat' had low nitrate uptake and dry weight (Tables 1 and 2). The genetic differences in nitrate uptake appeared largely to be due to the differences in the size of the plants, particularly roots, rather than in the ability of different cultivars to assimilate nitrate.

There were few differences in the rate of nitrate uptake per g root, suggesting that differences in uptake were caused by the size of the root system. Perby and Jensen (1983) also found that the differences in N uptake of wheat cultivars were related to root size. In addition to root size, differences among cultivar of wheat in net ion uptake may also be due to different flux rates into and out of the roots (Glass and Perely, 1980; Webb and Bradley, 1995; Sinclair, 1998; Rroco and Mengel, 2000). In all the three experiments, cultivars that appeared to grow more vigorously and produce more roots took up more nitrates. These results agree with those of Ehdaie and Waines (2001) for wheat and Reed and Hangman (1980) for corn who found that high nitrate uptake was associated with a more extensive root system. Results from our field experiment (unpublished data) indicate that dry matter production at 10 week for 'Fong' and 'Atila' was higher than that of 'Falat' and 'Star'. Therefore, there the response of the cultivars to N in early growth was different from that late in the season. The responses in early growth in 'Atila' and 'Fong' in this field experiment are consistent with the responses observed in the hydroponics studies, however, only 'Atila' showed a response in grain yield to N. The greater early growth of 'Fong' did not prove beneficial for its grain yield. The yield responsiveness of cultivars will also depend on the characteristics of their response to environmental conditions during latter stages of growth, particularly to water and temperature stress.

In conclusions, the genetic differences in nitrate uptake between wheat cultivars can be explained mainly by differences in plant growth. The difference in growth and nitrate uptake characteristic could be related to pedigree of these cultivars, mainly through the size of the seedling. However, Group 4 cultivars do appear to have physiological differences as shown by the results of the hydroponics studies and measurements of early vegetative growth in a field experiment (unpublished data). The differences in vegetative growth may not necessarily be linked to yield. 'Atila', 'Fong', 'Falat' and 'Star' all had high growth rates and nitrate uptake, but in the field experiment the grain yield of 'Atila', and 'Falat' increased with N application, whereas 'Fong' and 'Star' showed little or no grain yield response to N. Therefore, high vegetative growth early in the growing season, although promoting uptake of nitrate from the soils, is not always related to the final grain yield response. However, it is possible to have a cultivar such as 'Atila' that can take up nitrate more efficiently and which can also be more responsive to increased nitrate in the soil during the latter growing season.

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Effect of drought stress and harvest time on seed vigor and germination of wheat cultivar in Khuzestan province, Iran

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Abstract

The effects of drought stress during seed development and ripening stages on the seed germination of different wheat cultivars harvested at different stages of seed development was investigated. The experiment was arranged in a split-split plot design with three levels of irrigation (full irrigation, drought stress during flowering, and drought stress during grain filling period) as the main plots, three wheat cultivars (two durum and one bread wheat) as sub plots, and the seven seed harvest times as sub-sub plots. The germination and seed vigor tests were carried out after the harvest was complete. The results indicated that only the harvest time affected the germination percentage significantly. The highest and the lowest germination values were obtained when seed was harvested at 44 days after anthesis (99.8%) and 12 days after anthesis (76.2%), respectively. The effects of the cultivar and drought stress on germination were not significant. Cultivars and harvest times significantly affected the seedling dry weight. The two durum wheat cultivars had the highest seedling dry weight (328 mg). The highest level of seed vigor and germination was obtained when harvesting was done at physiological maturity (44 days after anthesis, when seed dry weight reached maximum). At this stage the seed moisture was lower than 15% which is suitable for mechanical harvesting without any damage to seed quality.

Introduction

Seed quality is an important consideration for getting successful crop production (Rashed-Mohasel and Kafi, 1992). Germination percentage and seed vigor are important quality characteristics of seed. Uniform emergence and development of normal seedlings under a wide range of field conditions depends on the germination percentage and the seed vigor. However, these traits are affected by ecophysiological factors during the development of seeds (Roberts and Osei-Bansu, 1988). It has been reported that yield of fall-planted wheat and barley decreased with low seed vigor due to long period of germination.

The factors that affect the growth and development of the parent plant are likely to have influence on the quality of seeds produced (Dell' Aquila and Tritto, 1991; Khodabandeh and Galilian, 1997; Rashed-Mohasel and Kafi, 1992; Sohraby, 1998; Ghassemi-Golezani et al., 1996). The stage of maturity of the seed at the time of harvest is also very important in determining the seed vigor (Ayre, 1980). Seed vigor in different crops is reported to be gradually acquired as the seed develops on the maternal plant, and it reaches maximum when the plants reach physiological maturity (Tekrony et al., 1980; Dell'Aquila and Tritto, 1991; Tekrony and Hunter, 1995). The seed viability and vigor steadily decline thereafter due to initial decay process (Harrington, 1972). Studies in pearl millet (Kamesvara-Rao et al., 1991), barley (Ellis and Pieta-Filho, 1992) and wheat (Ghassemi-Golezani et al., 1996) have indicated that maximum seed vigor was obtained in the end of grain filling period. Pieta-Filho and Ellis (1991) used the dry weight of developing seed as an indicator of maturity and the end of the grain filling period was considered as the physiological maturity of the seed. In several studies the seed quality was found to be high at or before physiological maturity (Rasyad et al., 1990) and some researches suggested that the desirable time for harvest was after this stage (Ghassemi-Golezani et al., 1996; Dell'Aquila and Tritto, 1991). The water deficit during the seed development can also influence the seed vigor. The objective of this study was to determine the effects of water stress at various development stages and level of seed maturity on the seed quality (seed vigor) in two durum and one soft wheat cultivars.

Materials and methods

The experiment was conducted in the 1999-2000 season at the Ramin Agricultural and Natural Resources University farm (31° 36´ N, 48°50 E) in Iran. This region is considered as semi-arid area with an average annual rainfall of 263mm over the past 30 years. The soil was clay loam, free of salinity and had a pH of 7.5. A split-split plots design with four replications was used to study the effect of moisture stress and the stage of maturity of the seed at time of harvest on seed quality in three wheat cultivars. Moisture stress variables were in the main plots and included three irrigation regimes: no stress (6 irrigations in all, I1), drought stress during flowering stage(4 irrigations in all, I2), and drought stress during grain filling period (three irrigations in all, I3) by withholding irrigation at these stages and protecting the stressed plots from rain by plastic cover. Three wheat cultivars were in the sub-plots. They included two durum cultivars, 'Chenalter' (V1) and 'Showa' (V2), and one bread wheat cultivar 'Seri 82' which is also called 'Flat' (V3). Seven different harvest times (12, 18, 25, 31, 38, 44 and 58 days after anthesis; anthesis occurred 120 days after seeding) served as the sub-subplots. Seed quality was evaluated based on ISTA (1999) standards as seed germination (SG) and seedling growth (SGR).

Results and discussion

The time of harvest significantly affected the germination percentage and the percentage of normal seedlings. The interaction between variety and harvest time was significant indicating that varietal reaction was different to change in the harvest time. The harvest time x drought stress interaction was also significant. Under full irrigation germination percentage and normal seedling percentage were higher for the first and second harvest times than under moisture stress treatments. Germination test of stressed-seeds generally showed that the time of drought stress (flowering vs. reproductive stage) had no effect on germination percentage. These results agree with the results reported by others.

The main effects of various treatments on germination percentage, percentage of normal seeds, rate of germination and seedling dry weight are shown in Table 1.

There was no significant difference between varieties and moisture stress treatments on germination percentage and normal seedling percentage. Harvesting stage affected these characters significantly. Maximum value for both germination per-

Table 1. Means of effects of irrigation, cultivars and time of harvesting treatments on some seed quality parameters

Treatments		Germination (%)	Normal seedling (%)	Germination rate	Seedling dry weight (g)
Moisture stress:					
Control	I1	94.00 a	93.33 a	0.209 a	0.274 a
Stress in flowering	I2	93.90 a	93.38 a	0.215 a	0.286 a
Stress in seed filling	I3	94.24 a	93.81a	0.216 a	0.313 a
Cultivars:					
Chen eltar	V1	94.82 a	94.42 a	0.204 a	0.304 a
Showa	V2	93.33 a	93.00 a	0.214 b	0.328 b
Falat	V3	93.95 a	93.09 a	0.221 a	0.240 c
Harvest time:					
12 DAA	D1	76.22 c	76 c	0.165 g	0.050 c
18 DAA	D2	93.33 b	93 b	0.125 e	0.135 d
25 DAA	D3	94.11 b	93.3 b	0.205 f	0.256 c
31 DAA	D4	99.78 a	97.55 a	0.219 d	0.357 b
38 DAA	D5	95.33 b	95.44 b	0.230 b	0.359 a
44 DAA	D6	99.89 a	99.88 a	0.235 a	0.444 a
58 DAA	D7	99.67 a	99.33a	0.223 c	0.445 a

Means with same letters in each column are not significantly different at 5% level of probability. DAA= days after anthesis.

centage and normal seedling percentage was 99.8% for the 6th harvest time (44 DAA). Lower germination percentage and normal seedling percentage at earlier stages of harvest can be attributed the premature condition of the developing seeds (Bewley and Black, 1985; Powel, 1988) and these results are in agreement with those of Ghassemi-Golezani et al. (1996) and Ellis and Pieta-Filho (1992).

A significant interaction between variety and harvest stages in affecting seedling dry mater observed in this study is in agreement with results on other crops (Khodabandeh and Galilian, 1997; Bishnoi, 1974). Khodbandeh and Galilian (1997) showed that there was no significant effect of drought stress during reproductive growth on seedling dry matter, which is in agreement with our results.

ANOVA revealed that germination rate was significantly affected by cultivars and by the time of harvest but not by drought stress. 'Seri82' had higher germination rate than the other two cultivars. This trend was particularly apparent up to the 6th maturity stage (44 DAA). Similar results have also been obtained by other researchers (Sohraby, 1998; Ghassemi-Golezani et al., 1996; Pieta-Filho and Ellis, 1991). Seeds with low germination rate cause variation in the emergence and growth of plants in the field.

Conclusions

The results of this experiment show that the developmental stage and maturity of seed at the time it is harvested had a significant effect on seed quality traits such as germination percentage, normal seedling percentage, seedling growth and the rate of germination. Drought stress during growth and development of seed on the mother plant did affect the seed quality. Therefore, based on the results it can be concluded that for getting good and uniform establishment of crop stand, the seed should be harvested when it has reached full physiological maturity.

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Theme: Renewable Energy

An experimental study on water-making system using natural energy in Tottori Sand Dune

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Abstract

A simple and small water-making system was built by using eight Peltier devices to prepare the cold surfaces, where the vapor in the air was condensed into water. The electric power needed for making water can be supplied from the wind turbine and solar cells. The system is installed in a closed chamber, where the temperature and humidity conditions can be varied. It was further tested in the outdoor conditions at the Tottori Sand Dunes, on the Japan Sea coast, in the Tottori prefecture. The water production in relation to the meteorological parameters was investigated and the efficiency and problems of the system studied. The quality of produced water was also tested. The results showed that it was possible to produce water by the tested system using solar energy. The optimum time period for producing water was from midnight to early morning for which enough electric supply should be available. The produced water however had more nitrous acid than rain water and this was traced to be coming from the rusting of the copper heat exchanger. Therefore, it is necessary to build the heat exchanger using rust-proof material such as aluminum.

Introduction

This study was carried out by the ‘Utilization of Natural Energy’ group in the ‘Program of Arid Land Science’, which is one of the ‘Twenty-first Century Center of Excellence (COE)’ programs of Japan and is mainly executed at the Arid Land Research Center (ALRC), Tottori University. The group is engaged in the development of new technology using renewable sources of energy for combating desertification and improving the living condition of people who live in arid lands.

Conventional water resources, such as ground water or rainfall, are limited regionally or seasonally in the arid areas. However, the moisture in atmospheric air could be a valuable water resource in such areas. This study aimed to develop a system which could produce fresh water from the air in arid regions using renewable energy (such as solar and wind energies available aplenty in the region) as a source of electric power.

It is possible to produce water via cooling and condensing the moisture in atmospheric air. Peltier devices were used as the cooling device in this study. A Peltier device can pump heat from one surface to another and make temperature difference between the surfaces when direct electric current flows through it (Doolittle, 1959). It has the advantage of being small-sized and lightweight, and having no moving parts. Moreover, it does not use refrigerants like chlorofluorocarbon although its freezing ability is as small as its coefficient of performance (COP=0.3-0.6) (Soo, 1962).

Our group previously made a simple water production system using the eight Peltier devices and conducted the performance test in a controlled chamber under several conditions of constant temperature and relative humidity (Hayashi et al., 2004; 2005). As a second step, the system was installed in a site that is a part of the Tottori Sand Dunes on the Japan Sea coast, and the photovoltaic modules were used as the source of electricity for the system. The results of the field tests are reported here and the performance of the system is analyzed in order to identify the optimal operational conditions. Moreover, the quality of the water produced by the system has been inspected using a simple method and the factors involved in affecting the quality are examined.

Experimental system

Figure 1 shows the schematic diagram of the water making system using Peltier devices. The heat exchanger (80×80×80 mm^3) is composed of 27 sheets of copper plates (80×80×1 mm^3), which is arranged with a space of 2 mm. Four Peltier devices (S.T.S. T150-40-127, 40×40×4 mm^3) are stuck on each side of the heat exchanger. The eight Peltier devices, in total, consume about 200W (12V, 2.1A per one device). The cooling fin and fan units (Alpha, FH9040A) are attached to the high temperature surface of the Peltier devices in order to dissipate the heat. A ventilation fan is placed over the heat exchanger for ventilation. The water making system is put in a box, which is surrounded with filters to protect against sand or dust.

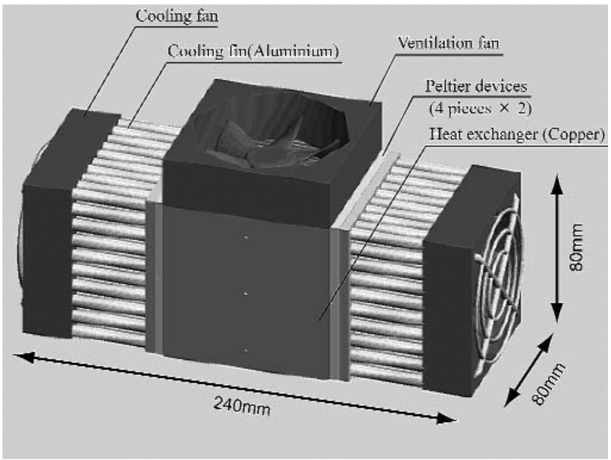

Fig. 1. Schematic diagram of the water-making system.

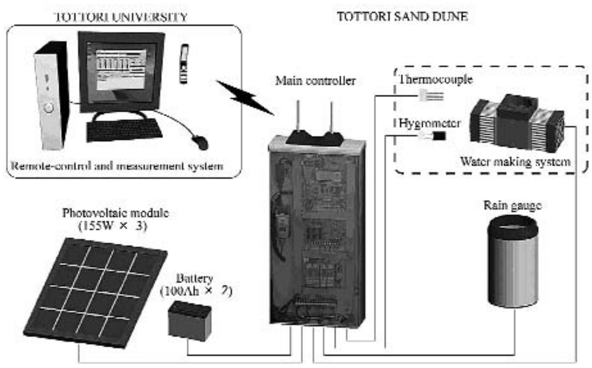

Fig. 2. Schematic diagram of the experimental setup.

Figure 2 is the schematic diagram of the experimental setup and the photograph in Figure 3 depicts the experimental site (the Tottori Sand Dunes). The 4.5-m mast, which exists at the site (Fig.3), is an independent meteorological observation system measuring wind speed and direction, temperature, relative humidity, solar radiation and rainfall. The electricity is supplied to the experimental setup (water making system, measurement system, control system, and communication system) by three photovoltaic modules (155 W×3, SHARP, ND-155AN). The main controller regulates the supply of electricity and the charge of the batteries (100Ah×2: Concord, GPL-31).

Water production, temperature in the heat exchanger, and temperature and humidity in the box including the water making system are measured every 10 minutes by the measurement system. The amount of water produced is measured by a tipping bucket rain gauge (ϕ160, 0.1mm, YOUNG, MODEL 5502), which provides one pulse signal per 2g accumulation of water. The main controller controls the water making system according to the obtained information. The measurement system and the control system are from Hikari Denki Tsusin System Corp. This system performs automatic operation control of the water making system and enables the remote monitoring of the experimental setup and the collection of data via cellular telephones. The water making system is run by ON-OFF control based on the control conditions regarding relative humidity, dew point and battery voltage. Table 1 shows the control conditions which were set during the measurement period from August to December 2005.

Fig. 3. Experimental setup installed on the Tottori Sand Dunes.

Experimental results and discussions

Figure 4 shows results of the field test conducted from August to December 2005. The temperature and the relative humidity data are monthly averages of the data obtained by the meteorological observation system. The dew point was calculated from the temperature and the relative humidity. The electric power generated by the photovoltaic modules in each month is expressed as the average value per day. Water production is the total amount produced each month. Operation rate, together with the water production, was defined as the ratio of actual working hours of the water making system to the total hours of each month. The system produced 12.7 kg water in August 2005. However, the water production decreased after August. This is related to the decrease in the air temperature and dew point, i.e. the decrease of absolute humidity. For example, average dew point in December became lower than 0°C which was the control condition on the dew point for stopping the water making system (Table 1) and, therefore, the operation rate was almost zero. However, the main reason of the decrease in water production from September to November was the decrease in the amount of electric power generated. Although enlargement in scale and more improvements in the performance are necessary, the results of water production in August demonstrate the potential of the system using renewable energy alone if the operation conditions are satisfied.

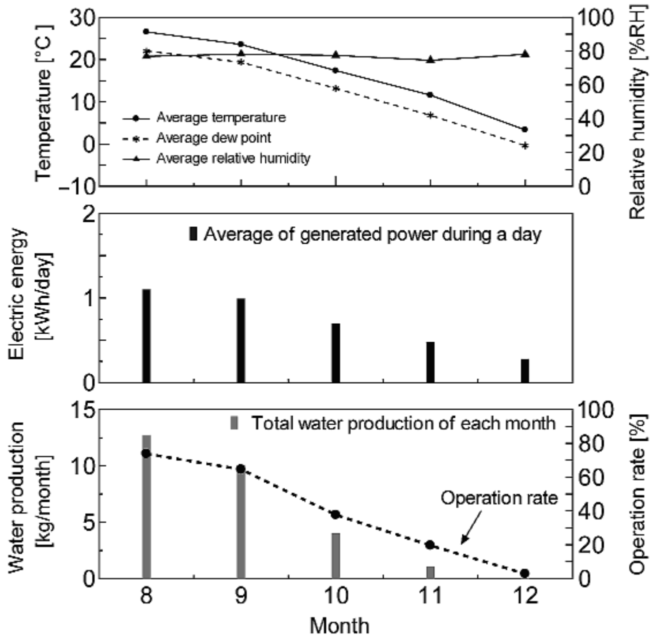

Fig. 4. Field test results for water production, energy generated and the environmental conditions of the system for five months.

Table 1. Control conditions

	Relative humidity [%RH]		**Dew point [°C]**		**Battery voltage [V]**	
	ON	**OFF**	**ON**	**OFF**	**ON**	**OFF**
Default	70	60	3.0	1.0	12.5	11.5
11/15	70	60	3.0	1.0	**12.0**	**11.0**
11/18	70	60	3.0	**0**	12.0	11.0
12/1	**65**	**35**	3.0	0	12.0	11.0

The daily water production in August 2005 is shown in Figure 5 together with air temperature, dew point, relative humidity and the operation rate. The temperature and the relative humidity were measured in the box containing the water making system. The maximum production of water in a day in August was 744 g. The production depended on the operation rate of the system and it varied day by day. The relative humidity and the dew point in August were high enough to satisfy the operational conditions. Since the relative humidity and the dew point do not change drastically, the operation rate of the water making system depends only on the battery voltage. If the generated electric power, or solar radiation, had been steadier, the water production could have been more steady. In other words, if the capacities of the photovoltaic modules and the battery are increased, the water production is also expected to increase.

Figure 6 shows the monthly average data of water production in August, calculated every 10 minutes. The dotted line in the lower part of the figure shows the monthly average operation rate. The black-circle symbols show the water production per 10 minutes, which were calculated by dividing the monthly accumulated water amount during each 10-minute interval by the number of days of a month; therefore, they depend on the operation rate. On the other hand, the white-circle symbols are the 10-minute water production independent of the operation rate, which were obtained by dividing the monthly accumulated water amount during each 10-minute interval by the number of days when the water making system was working in the concerned interval. The 10-minute water production independent of the operation rate becomes higher from midnight to early morning. If the water making system operates

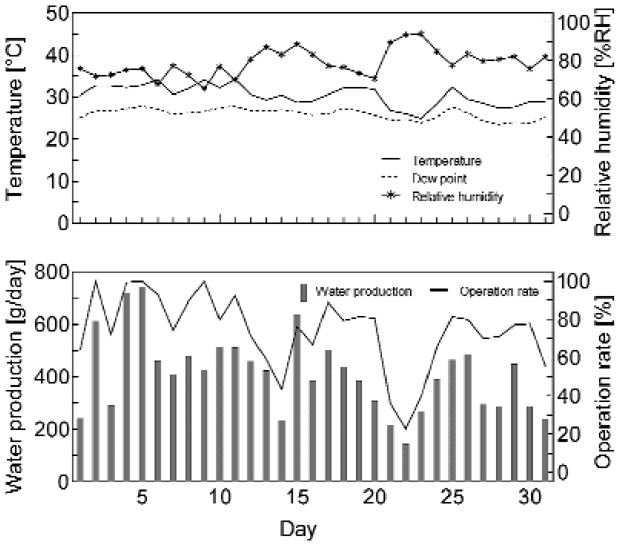

Fig. 5. Daily results of water production and envi ron mental conditions of the system in the field test in August.

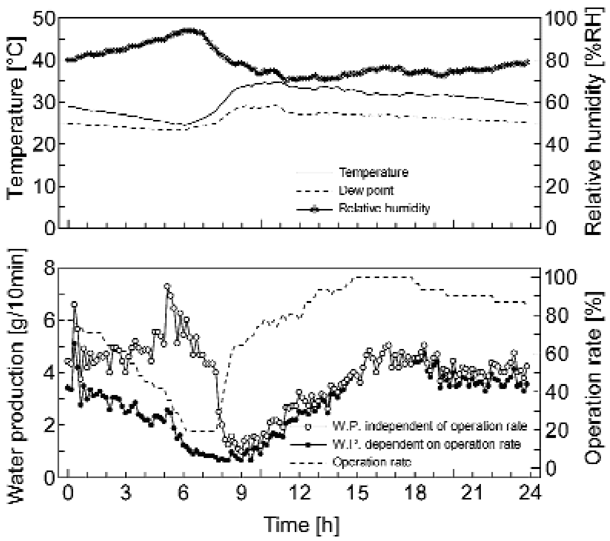

Fig. 6. Monthly average data of water production and environmental conditions of the system every 10 minutes at different times of the day in August.

for this period, the water production is expected to increase. Therefore, the period from midnight to early morning is the optimum time zone for producing water. However, the operation rate during the period of 03:00-08:00 hrs decreased, that is, the water making system did not operate fully in the optimum time zone in the present experiment. This was because of the shortage of electric energy. Therefore, it is possible to increase the water production by increasing the capacity of energy source or changing the control conditions so as to let the system fully operate in the optimum time zone.

For explaining what is the optimum condition for producing water, water production rate (see Equation 1 below) was determined by dividing the amount of monthly accumulated water during each 10-minute interval by the total electric energy consumed to produce water during the concerned interval. Figure 7 shows the graphs of the water production rate of August as a function of the air temperature, the relative humidity and the dew point. The water production rate tends to increase with decreasing temperature and dew point and increase with increasing relative humidity. The data points can be divided into two groups, i.e. the high rate group and the low rate group, by drawing a boundary at 3.5×10^{-5} g/Wh. In this case, the boundary values of the temperature, relative humidity, and dew point are 32.5°C, 75%, and 26.7°C, respectively.

Water production rate [g/Wh] = (Monthly accumulated water amount during each 10-minute interval)/(Total electric energy consumed to produce water during the concerned interval) (1)

The water production for 10 minutes is obtained by counting the number of output pulses from the

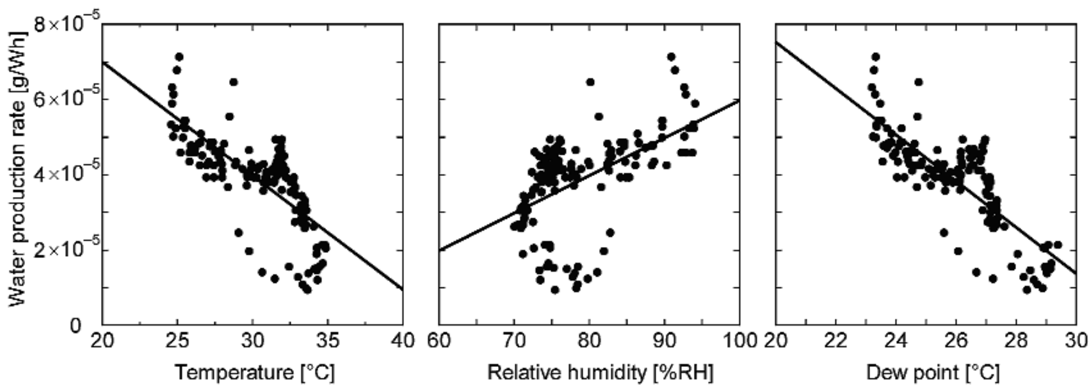

Fig. 7. Water production rate in August expressed as the function of air temperature, relative humidity and dew point.

rain gauge, each pulse corresponding to 2g water. Figure 8 shows appearance ratio of the number of counted pulses, i.e. water production at 2g intervals during 10 minutes, in August. The upper graph uses dew point and the lower shows relative humidity as the parameter. Therefore, each graph shows the frequency distribution of dew point or relative humidity in each number of counted pulses. The frequency distribution of dew point in each pulse count is almost symmetrical having the center at 27°C, excluding the case of 8g water production (4 pulse count). On the other hand, the frequency distribution of relative humidity in each pulse count shows asymmetry and the relative humidity that gives the maximum in each frequency distribution becomes high with increasing number of pulse count. As shown in Figure 8, the 4g water production occurs most frequently and, in this case, the relative humidity that gave the maximum in the frequency distribution is 75%.

Although the control conditions on the relative humidity in August were set as 60% for stopping and as 70% for restarting (Table 1), under these conditions, the water making system did not work enough during the optimum time zone due to the shortage of electric energy. If the control conditions on the relative humidity had been set as 75% for both stopping and restarting, the water production would have increased by reducing ineffective operation during the daytime and by increasing effective operation in the optimum time zone.

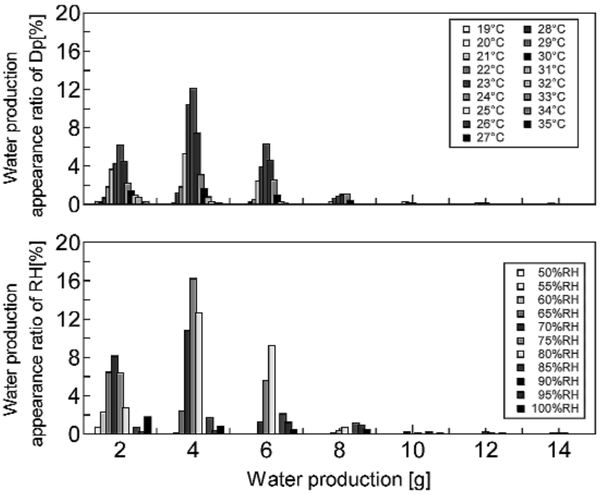

Fig. 8. Appearance ratio (frequency) of the number of counted pulses, i.e. water production at 2g intervals during 10 minutes, in August.

Water quality test

The quality of the water produced in this field test was investigated with simple inspection methods using the *Escherichia coli* Pack Test and the well water inspection set (TPA-CG and AZ-2W, Kyoritsu Chemical-Check Lab., Corp). The results were compared with the results for the rain water obtained at the site and for the city water. The tests were as follows:

- *Escherichia coli*
- pH
- Fe [mgFe/L]
- Total Hardness (TH) [mg$CaCO_3$/L]
- Chemical Oxygen Demand (COD) [mgO_2/L]
- Nitrous acid (NO_2^-) [mgNO_2^-/L]

Results (Table 2) on pH, Fe and TH showed that the quality of the produced water was not much related to the rain water. *Escherichia coli* were detected from the rain water, but not in the produced water. The COD of the produced water was almost twice as high as the rain water. The remarkable difference between the produced water and the rain water was in the nitrous acid content. As nitrous acid in drinking water is not good, it was necessary to investigate the origin of the nitrous acid. In the system used for producing water, the air containing the moisture firstly passes through the dust filter and goes through the ventilation fan. Then, it comes in contact with a copper plate of the heat exchanger and the humidity present in the air condenses to form water. To test the hypothesis that the COD and nitrous acid contamination was occurring in the system, their content was investigated in distilled water after bringing it in the contact with the dust filter, the ventilation fan, the heat exchanger, and the copper plat. The values were compared with original (uncontaminated) distilled water. The results are shown in Table 3.

COD was detected in all the cases except in the original distilled water; especially the distilled water after contact with the dust filter or the copper plate (which was rusted) showed high content of COD. Nitrous acid was detected only when water came in contact with the rusted copper plate. Therefore, the origin of nitrous acid in the produced water was from the rust of the heat exchanger. This suggests that it is necessary to build the heat exchanger using material which is rust proof, e.g. aluminum, instead of copper.

Table 2. Results of inspection of water for different quality parameters. The units used for each test are given in the text.

Item	Produced water	Rain water	City water
E. coli	No	Detected	No
pH	6.1	5.7	7.3
Fe	0.02	0.02	0.0
TH	5.0	10.0	20.0
COD	40.0	18.0	0.0
NO_2^-	1.0	0.05	0.0

Table 3. Chemical Oxygen Demand (COD) [mgO/L] and NO_2^- [mgNO_2^-/L]results of the distilled water after contact with parts of the system.

	Filter	Fan	Heat exchanger	Rusted copper plate	Distilled water
COD	11.0	2.0	2.0	17.0	0.0
NO_2	0.0	0.0	0.0	0.05	0.0

Conclusions

The field test of the water making system, using the Peltier devices supplied with electricity from photovoltaic modules, was carried out at the Tottori Sand Dunes. The results are summarized as follows:

- The possibility of water production by the system using renewable energy alone was demonstrated. The optimum time period for producing water by condensation of moisture in the air is from midnight to early morning.
- It is necessary to increase the capacity of energy source or to change the control conditions so as to let the water making system operate only in the optimum time period.
- Nitrous acid detected in the produced water came from the rusting of copper heat exchanger. It is necessary to build the heat exchanger using rust-proof material such as aluminum.

Acknowledgements

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Windmill, the only viable option for Thar, Pakistan

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Abstract

Thar region of Pakistan has a geographical area of about 22,000 sq km, and according to 1998 census 1.1 million people were living in it. The livestock population is 1.5 m. Average annual rainfall ranges between 200 to 350 mm. It is revealed from studies that Thar has been formed in recent geological times. Due to blowing of sand, silt, salt and shells from the sea through Runn of Kutch by southwestern wind the sand hills are formed. The soil is however fertile and if water becomes available, good productivity could be achieved. Studies have shown that there is good underground water resource in the area; however the cost of pumping water using electricity or fossil fuel is exorbitant. The area has very high wind velocity (up to 45 km per hr for some 3,000 hrs per year), particularly during the warmer months when demand for water is the highest. The average wind speed is 15 to 30 km per hour. On this wind velocity 25 feet diameter Low Speed Windmill can pump 12,000 gallons water per day from a depth of 120 to 150 feet. Installing wind mills can be an economically feasible preposition for the development of the Thar region.

Introduction

About 48% (around 68,000 sq km) of the total area of the Sindh province in south-east Pakistan is arid (SAZDA, 2004). This area, called Sindh Arid Zone (SAZ), covers Kohistan, Nara and Thar desert regions. The Thar region is spread over 22,000 sq km and as per the 1998 census has a human population of 1.167 million (56.3% of the total population of the Sindh arid zone, SAZ) and 4.6 million heads of the livestock. Kacho/Kohistan is spread over 23,000 sq km and has a human population of 0.593 million (28.63% of SAZ). Nara is spread over 23,000 km and has a human population of 0.311 million (15.03% of SAZ).

Although SAZ covers over 48% of geographical area of the Sindh province, it has only 1% of the total fresh water supply of the province. It therefore suffers from sever drought (SAZDA, 2004). The annual precipitation in a good year ranges between 200-300 mm, mostly in the monsoon season. There is no canal water for irrigation and rain-fed agriculture and livestock husbandry are the main sources of income.

Prolonged periods of drought have affected the socioeconomic development of SAZ. During rainy season the sites in the natural depressions, the ponds (locally called *Tarai*), get filled with rain water, which serves as a source of water to the people for their own use as well as for their animals. *Tarai* water is available for not more than two months; some times it could be only for one week, depending on the soil type. After this water dries out, there is only ground water available for use.

SAZ is characterized by a widely scattered population with low literacy rate, and the communication gap causes major problem for any development. The population in these backward areas has no access to modern sources of energy. The implementing agencies lack proper approach to solve their problem and often projects are started without considering their sustainability. No doubt these areas are rich in mineral resources, but common people are not in a position to get benefit from these resources.

Easy availability of water is a major problem of SAZ. Bringing water from distant sources needs time, animal/man power and energy. Fetching water for meeting the daily need of a family of 6-8 members might consume 5-7 hours of time of three persons per day (Akbar, 2000). Because of the unavailability of water, shortage of fodder for animals, and high unemployment, people from SAZ migrate out to irrigation command areas.

Among all migrating population, 12% are from Nara, 30% from Kacho and 58% from Thar area (SAZDA, 2004). The drought not only causes the migration but also creates adverse effect on social, political, economic, environmental and psychological conditions of the people. Due to migration, school-going children face problems of discontinuity in their education and the pregnant women suffer from malnutrition and often have abortion.

Thari people are simple living and their needs are limited, perhaps because of limited choices. They collect themselves water and fire wood and their livestock provides them milk and milk products to meet their daily needs. They need cash only for purchasing flour, sugar and factory made consumables. This they generate from the rain-fed agriculture and selling animal products. However, during drought years they lose their production and hence they have to migrate in search of work. Relief agencies provide inadequate solutions, and problem worsens. The conventional approach for providing safe drinking water by deep tube wells, diesel engines and mechanized sources are not in favor of Thari people and therefore the efforts of SAZDA in this regard have failed and some 52 tube-wells are lying useless, and billions of rupees have gone in vain. An alternative approach is needed that would be feasible and socially acceptable to Thari people.

Water resources in Thar desert

Thar does not have any planned canal network and this, added to the low rainfall and scarcity of potable water, makes water the most precious commodity. Both surface and ground water is available only through rainfall.

Rain is the major source of water, which recharges the wells and fills the *Tarais* (ponds) with run-off. However, this rain is limited (ranging from 0-300 mm) and only occurs during the monsoon season, between June–September and mostly July and August. High evaporation rate reduces water storage. Rainfall is also very variable; according to local experience, water scarcity occurs once in three years and famine caused by severe water shortage can be expected once in ten years.

Many areas of Thar are not considered suitable for grazing due to scanty fresh water. However, there are signs of existence of fresh groundwater in many places, although a thorough groundwater survey of the area has yet to occur. The depth of ground water in different parts of Thar ranges widely (Kesani, 1979, Table 1). Panhwar (1969) stated that along the edge of Rann of Katch water is found at the depth of 8 to 10 m and as one moves away from there the water table becomes deeper. The level, as a rule, rises towards Aravalli hills and therefore in the Thar area it rises as one goes eastwards from the Indus plains or northwards from Nangarparkar. Near the western fringes of the desert along Eastern Nara or old Hakra, water is available in plenty at shallow depths. This water had its origin from the river Hakra which dried out about six centuries ago and as such the original sweet water has been replaced by brackish water; 30 miles eastward from Nara bed, water is reached at the depth to 65 m. Near the Indian border in Chachro Taluka it is more than 100 m deep. On both sides of Hakra or old Nara, water is sweet up to the depth from 15 to 21 m.

Table 1. The depth of groundwater in different parts of Thar

Village	Depth of wells (m)
Diplo	3 to 15
Nangarparkar	6 to 18
Viravah	13 to 27
Mithi	30 to 50
Islamkot	40 to 50
Chelhar	33 to 100
Kantio	37 to 100
Chachro	37 to 100
Gadro	100 to 118

It is clear from the above that there is a great scope for tapping the ground water resource in Thar area provided a cheap and sustainable source of energy could be made available for lifting the water.

The proposed approach

Thar is rich in renewable energy resources, i.e. wind, solar and biomass. Among these resources, wind is a sustainable source of energy and Thar falls in high wind velocity belt. A local civil society organization (CSO), 'Association for Water, Applied Education & Renewable Energy' (AWARE), has proved by demonstrating a pilot project near Umerkot city, that a single windmill can lift adequate amount of water to fulfill the need of 60 households around the year. The mill needs only one maintenance service in a year. The technology is appropriate, environment friendly and less technical/mechanized in comparison to other available options of diesel engine etc. for lifting water. The details are as under:

Winds in Sindh are caused by heating of air in Rajasthan and Thar deserts and rising of this hot air up and its replacement by cooler air blown from surface of the Arabian Sea, moving in west-south-west to east-north-east direction to the desert. A high wind velocity belt exists between Karachi and Keti Bunder and runs from Keti Bunder to Mithi and from Karachi to Hyderabad, and beyond to the desert. Wind velocity data from some stations in India and Baluchistan show that the wind velocity reduces south and north of these belts. It also reduces as one moves inland i.e., east wards. Chore has less wind velocity than Hyderabad which has less than Karachi. In the same way Bhuj and Rajkot in India have less wind velocity than Dwarika. The wind velocity at Dwarika and Viraval in Kathiawar and further to Mumbai keeps reducing as one moves south of Keti Bunder. Wind velocity also reduces if one moves from Karachi along the Baluchistan coast to Soanmiani Ormara and Pasni. The wind velocity at Dwarika and Viraval are less than at Karachi, because Karachi and Keti Bunder are nearest to center of Rajasthan and Thar Desert.

There are long term data for wind velocity at Manora, Karachi. It appears that wind velocity data for the whole Sindh coast will be similar ± 5%. Whether wind mills will be feasible in Sindh can be determined from wind velocity patterns of Manora through out the year. The wind velocity at Manora in a year is 12-20 kph (average 16 kph) for 2,716 hours, 21-30 kph (average 25 kph) for 1,344 hours and 31-40 kph (average of 35 kph) for 282 hours.

According to the Computerized Data Processing Center, Pakistan Metrological Department, Karachi the average annual wind velocity in Thar for five year (1997-2001) was 8.96, 9.76, 12.00, 13.76 and 12.64 kph (Table 2).

Panhwer (1984) states that Thar lies in the belt of high wind velocity, which may reach even 48 kph for few hours annually but an average value would be between 17 to 20 kph during the year. The wind velocities are particularly high during the summer months when the water consumption is at its maximum. The dominant direction during the summer months is southwest or west and during the cooler parts of the year it is from north or northeast. The highest mean monthly wind speed is 12 kph during April at Nagarparkar, 16 kph during June at Umer Kot and 15.5 kph during June at Chhor. The lowest wind speed is during November, which is 1.5 kph at Nagarparkar, 4.5 kph. at Umer Kot and 2.4 kph at Chhor. Towards the end of April and in May, when the wind is most violent, the whole atmosphere is charged with sand.

The average relative humidity at Umer Kot, Chhor and Nagarparkar is 60, 56 and 49 percent, respectively. The mean daily maximum temperatures reach 42.8°C during May at Nagarparkar, 42.2°C at Umer Kot and 41.7°C at Chhor. The mean daily minimum temperature during the months of January and February is 25.7°C at Nagarparkar, and 8.0°C at Umer Kot and Chhor.

From these data it is clear that the wind speed and growing temperatures are favorable during the summer months, when under early and good start of monsoon, good vegetation tends to grow in the Thar desert. The renewable energy available from the wind during the summer months can be harnessed for running windmills for lifting under-ground water available in renewable aquifer not only for domestic use but also for agriculture to supplement the scanty rainfall. During the other parts of the year, the wind speed is sufficient for running the windmills to provide water for domestic use.

Table 2. Wind velocity in Thar desert (kilometers per hour).

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1997	6.65	6.56	7.04	5.92	15.84	12.64	14.4	12	10.24	4.64	5.12	6.08	8.96
1998	8.48	8.64	7.52	8.96	14.08	14.72	17.92	17.14	7.04	4.48	3.52	2.56	9.76
1999	4.64	5.76	8.8	11.68	13.28	20.8	22.4	20.96	18.56	5.92	6.24	2.72	13.76
2000	7.2	9.44	9.12	16.16	28	27	16.32	16	14.24	8.64	5.44	6.56	13.76
2001	6.37	9.12	7.2	14.88	23.2	23.04	17.92	19.2	13.12	6.88	4.8	4.96	12.64

Source: Computerized Data Processing Center, Pakistan Metrological Department, Karachi, Pakistan

Conclusion

The wind velocity and underground water studies in Thar desert have shown that lifting underground water with windmills can be a single viable option to cushion the Thari inhabitants from the hardship of water scarcity. The windmill technology is environment friendly, sustainable, has little recurring cost and is easy to maintain by the local Thari people. Introduction of windmills for lifting water would not only reduce the problem of water scarcity but would also help in reducing the vulnerability of the local communities to drought and free up time for them to engage in economic activities rather than in bringing water from long distances. Assuring dependable fresh water supply in the vicinity of their dwellings would bring indirect benefits to the communities of improved education for the children and better health and nutrition to the vulnerable sections of the society. Adding small kitchen gardens to the household, because of the availability of water, could further help in over coming the problem of malnutrition and improve the livelihood of the people. Improved opportunities for economic activities would prevent migration of people from the rural to urban areas, and they would be able to improve the environment by planting adapted shrubs and trees around their dwellings and on community lands. It is therefore recommended that the federal, provincial and district governmental agencies should give priority in their five year plans for the introduction and use of windmills in the Thar region. The national and international organizations involved in sustainable development of the Thar desert communities should give high priority to the introduction of this technology in the remote areas of Thar Desert. All the organizations working on advocacy and awareness about environmental problems and sustainable development have to play a major role in highlighting the importance of this use of renewable energy for the benefit of the neglected communities in Thar and other neighboring arid areas of Sindh, Pakistan.

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Potential renewable energy sources in Indian Thar desert

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Abstract

The importance of renewable energy sources is discussed for dry lands in view of present energy crisis in Indian arid region. The computations have been made for Thar Desert to be covering about 20 million ha drylands in arid region of western Rajasthan in India. The status and potential of different renewable energy sources viz. solar, wind, bio-gas and bio-mass have been enumerated. Extensive work on the utilization of solar energy carried out at the Central Arid Zone Research Institute (CAZRI), Jodhpur for various domestic, industrial and agricultural applications in order to meet the energy demand is highlighted. Harnessing wind power, biogas and biomass energy under Indian Thar desert have also been suggested as potential source of energy. Exploring the potential of renewable energy in arid region would be of help in making desert dwellers more self-dependent with respect to energy and providing them livelihood in such difficult and harsh environment.

Introduction

Burgeoning population and rapid pace of development in Southeast Asian countries, especially India and China, has created a scenario of energy crisis due to limited availability of conventional energy. The situation is precarious under arid drylands on account of low availability of biomass and interregional competition for civil services with semi-arid and dry sub humid regions, which are relatively better off. Hence sources of renewable energy become very important under dry land situations.

Drylands cover 76% of total geographical area of India. Arid region area is about 32 million ha, of which 82% lies in south-western part of country in the state of Rajasthan. Thar Desert occupies 20 million ha of arid land in western Rajasthan and further extends to Tharparkar district of Pakistan, from where the name Thar Desert seems to have originated. The development of any region is reflected in its quantum of energy consumption. In this context, the situation in arid region is gloomy where, because of the shortage of alternative usable sources firewood, agricultural waste and cow dung cakes are burnt for cooking rather than recycled back in the soil causing irreparable damage to the fragile eco-system of arid zone. Kerosene is used for lighting and fast depleting diesel for running agricultural machinery including pumps. In general there is lack of energy resources to run appropriate devices in arid region. Inadequate and erratic electrical power supply further makes the situation difficult in rural setting. Farmers are unable to add value to their agricultural products due to nonavailability of energy for post harvest processing units, which limits their economic benefits.

A lot of spare time is available to farmers after harvest of crops, but it is not gainfully utilized for generation of additional income. In the absence of hydropower and other conventional energy sources, it is essential to provide an alternative source of energy for the sustainable development of arid dry lands. In this context, renewable energy sources offer viable solution for the desert area, which has high potential of solar energy, wind power and biogas.

The average solar radiation in desert region is 6 kWh/m^2/day with more than 300 clear sunny days compared to country's average of 5.6 kWh/m^2/day. Wind power is also a manifestation of sun's energy. Wind potential in Rajasthan has been assessed at 5,400 MW compared to 45,195 MW for the whole country (MNES, 2004). In nature, solar energy is utilized by plants in producing biomass; however, scarcity of water in arid regions limits this kind of harvest of solar radiation. Nevertheless, *Prosopis juliflora*, an extremely drought hardy, profusely coppice plant, has adapted well under harsh conditions. The biomass of this prolific growing tree can be used fruitfully as fuel or through conversion to coal or generation of electricity by gasification.

Due to frequent crop failures, economic survival in arid region is mainly animal based. A high cattle population is therefore common. It offers a potential of installing 12 million family type biogas plants to provide fuel needs for cooking and lighting. As many as 3.67 million biogas plants have been installed in the country and of these 66,552 are in Rajasthan (MNES, 2004).

It is estimated that solar energy of 1 per cent of land area, wind power of 5 per cent of land area and biogas at 80 % collection efficiency can provide 1,504 kWh/year energy per capita in Thar desert while the average per capita total energy consumption of India is 370 kWh/year, which is hardly one-tenth of potentially available renewable energy. Therefore, the issues involved are harnessing alternative renewable energy sources, and their cost effectiveness, efficiency and competitiveness in the open market compared to other available sources of energy. The paper presents the status and potential of these renewable energy sources in the arid region of India.

Solar energy utilisation

Technologically the abundant solar energy can be harnessed either in the form of thermal energy by using flat plate collectors/concentrators or by generating electricity using photovoltaic (PV) cells. Extensive research work (Pande et al., 1998) has been carried out at the Central Arid Zone Research Institute (CAZRI), Jodhpur to harness solar energy to meet the energy demand and a few solar-energy based gadgets developed are described below.

Solar thermal devices

Solar dryers: Solar dryer is a convenient device for fast and efficient dehydration of vegetables, fruits (for preservation) and industrial chemicals under control conditions while eliminating the problems of open courtyard drying like dust contamination, insect infestation and spoilage due to rains. CAZRI designed solar dryers, a low cost tilted type solar dryer costing about \$94 per m^2 (Thanvi and Pande, 1989), has been extensively tested for drying vegetables and spices (onion, okra, carrot, garlic, tomato, chillies, spinach, coriander, mint), fruits (salt coated *amla*, jujube *ber*, dates), magnesium carbonate (used for making talcum powder), etc. The powdered products from some of these solar dried materials have been tested for instant use. Based on this design, inclined solar dryers of variable capacities (10–100 kg) have been adopted by local entrepreneurs and a scaled-up solar dryer of 400 kg capacity has been installed in village Kankani. Acceptability of solar dryers is increasing because of the export potential of better quality dried products like garlic, onion, mint, coriander, spinach, green chillies and jujube. One can save about 290 to 300kWh/m^2 equivalent energy by the use of such dryers and farmers can add value and accrue higher benefits from solar dried products.

Cool chamber: Maintenance of low temperature is problematic in the desert region during summer season when the temperature is very high and dependable electric supply is not available in the rural areas. The high ambient temperature decreases shelf-life and spoils the vegetables, milk and milk products. A low-cost passive cool chamber, based on the water evaporative cooling, reduces temperature fluctuations and helps in successfully preserving vegetables for short period (Chaurasia et al., 2005). The maximum temperature is lowered by about 15°C and humidity is kept more than 90%. The passive cool chamber can be used to preserve vegetables for a period of 3-5 days in summers and 4-7 days in winter. Shelf life of milk and milk products can also be increased for reasonable time. A small size cool chamber costs about \$70, which can preserve 30-50 kg vegetables, reducing their spoilage and enabling the farmer to fetch good price in the market. It is easy to fabricate by village technicians using local material. There is negligible maintenance cost and no requirement of electricity.

For growing vegetables under harsh arid conditions, green houses have a lot of potential for the off-season vegetable production. In arid region, the requirement is to reduce the temperature and maintain humidity. For this, a green house with fan and pad systems for evaporative cooling will be of great utility. Such a system is being developed using locally available material.

Solar candle making machine: A candle machine, with 0.5 m^2 surface area for absorbing solar radiation, has been found useful for production of candles by rural women, farmers and unemployed youth as a source of income. The machine melts the paraffin wax used for making candles (Chaurasia, 1991). The device can produce 10-16 kg candles per day during summer and 6-9 kg per day in winter and is a safe process having the advantage of reducing labor and vaporization losses associated with conventional method. One can start the solar candle business with an initial investment of $ 300, generating an average income of $35 a month. National Research Development Corporation, New Delhi has licensed the machine for commercialization through private entrepreneurs.

Solar polish making machine: The machine provides a gainful engagement to villagers during off-season for preparing different kinds of wax-based polishes for leather goods, automobiles and floor, which are in great demand in the market. The machine, comprising a cylindrical melting chamber, is provided with an especially designed stirrer-cum-heat exchanger that can be operated with ease in stationary mode, providing sufficient temperature to melt different waxes, facilitating the addition of ingredients from outside and mixing for getting the desired texture of the polish. The cost of this machine is about $115 and a person can earn US $ 70 a month by making polishes of all kinds.

Solar still: Solar still (Thanvi and Pande, 1988) is a convenient device for producing distilled water required for use in the laboratories and the maintenance of chemical batteries and for desalination of water to make it potable. Step-basin tiled-type solar stills of different sizes, (capacity 3 to 3.5 liter/m^2/day) have been adopted by railways, army units, schools and other commercial units. The production of distilled water is possible round the year because of its special design and the cost of water produced is less than 2 cents per litre compared to market rate of 10 cents. Fragrant waters such as rose water can also be prepared using the solar still for generating additional income.

Solar cookers: Solar cookers can be used for boiling rice, lentil, vegetables; roasting groundnut, potato etc., baking vegetables and cooking local food and feed for animals. With the use of such cookers one can save about 30-40% of fuel requirement. Various types of CAZRI solar cookers are: (1) solar oven, better for cooking food for a family quickly but requiring tracking of the device after every half an hour, (2) double mirror box type solar cooker with sun tracking for extended time of three hours and (3) a stationary cooker with optimised width to length ratio for using it without sun tracking. On community level, large type solar cooker is recommended to prepare food for 80 persons in temples, hostels etc. Army and Air Force Women Welfare Association in Jodhpur have adopted such a solar cooker for their use in the mess. For automatic tracking, light sensitive solar tracker has been designed which senses light through LDR and small PV cell and triggers circuit to mobilise tracking platform with cooker to capture maximum irradiance with the help of 12 volt DC motor, battery and mechanical drive. It facilitates the orientation of the cooker towards the sun giving 25% higher output compared to untracked cooker.

An especially designed animal feed solar cooker can be used to prepare cattle feed by 3 pm every day (Nahar et al., 1994). A large number of farmers have adopted such cookers, enabling them to save firewood used for this purpose. These are easy to fabricate by village artisans using locally available material.

Solar water heaters: Substantial amount of fuel can be saved by using solar water heaters for domestic purposes and in textiles and dairy industries. The natural circulation type solar water heaters with flat plate collector using GI pipe header and riser and aluminium sheet as absorber, save 30% cost in contrast to commercially available copper pipes and copper sheet flat plate collectors giving comparable performance. Many units of such water heaters have been installed in hotels, hostels, guest houses, etc. Collector-cum-storage solar water heaters cost almost half as much as the conventional solar water heaters and provide 100 L hot water with a temperature of 50-60°C in the evenings and 40-45°C next day mornings (winter season) when the storage device is insulated (Garg, 1975).

Integrated solar appliances

Integrated solar device is a unique three in one system, which can be used throughout the year for different purposes (Pande, 2003). The geometry of the device enables one to cook food for a family without sun tracking. It can produce about 50 L hot water of 50-60 °C utilizing the low altitude position of sun during winter and thus having energy gain both from top and front windows. The device can also be used for drying fruit and vegetables for use in off season. This solar device costs US $ 120 and makes the whole practice very economical.

Solar power generation

Solar energy can also be used to generate high temperatures through series of tracking concentrators, which convert flowing water to steam for running turbine to produce electricity. A feasibility report for 30 MWe Solar Thermal Power Station at Mathania, Jodhpur was prepared by CAZRI. On the basis of that a 140 MWe hybrid solar thermal power station will be established there. In this plant, it is proposed to produce 35 MWe by solar energy and 105 MWe by other sources like Naptha or Gas. The generated electricity would be fed to electric grid for supplementing the requirement of power in the region.

On the other hand small and medium size photovoltaic (PV) systems are used for generation of electricity directly at the place of utility without the need of long net work of electric grid thus saving transmission and distribution losses. The PV systems are quite useful to provide electricity for lighting of isolated cluster of houses, known as *Dhanis*. Solar PV lantern and solar home lighting system with two compact fluorescent lamps, storage battery and PV panel are provided by the state nodal agency on subsidized rates to rural people. About 6,000 home lighting systems are in operation around Jodhpur. Small PV plants of 10 KW capacities have been installed in some villages of arid region to provide electricity for lighting and pumping. Solar PV systems, developed at CAZRI for different agricultural purposes are described below.

Solar PV pump based drip system for orchards: Solar PV pump operated drip irrigation system, comprising 900 Wp PV array with 800 W dc motor-pump mono-block and OLPC drippers, is suitable for orchards in arid region as it economizes the use of water and eliminates practically all the problems that are associated with flood irrigation. The system is based on water requirement of horticultural plants, energy need and compensation of varying pressure due to change in solar radiation ensuring uniform application of water to fruit trees (Pande et al., 2003). The system can command 4-5 ha pomegranate orchard with a benefit-cost ratio of more than 2 and may prove to be a boon in farms where water and land are available but the area is devoid of electrical power.

The PV system for irrigation has now been converted to a generator with sub- components like DC-DC converter, storage batteries and compatible inverter so that it could be used for running small machines to carry out post harvest operations in addition to its utility as a pump.

Solar PV duster: Solar PV duster is a novel device suitable for dusting insecticide and pesticide powder on crop. It comprises a PV panel carrier, storage battery and especially designed compatible dusting unit. The PV panel is carried over the head with the help of a lightweight PV panel carrier that provides shade to the worker and simultaneously charges battery to run duster. The average field capacity of PV duster is about 0.75 ha/hr. The same system can run ultra-low volume sprayer also. In addition, it could be used to illuminate a compact fluorescent lamp for lighting. The device, costing about US $ 70, can be used for lighting the house through out the year and for operating as a duster/sprayer as and when required.

PV winnower cum dryer: The solar PV winnower is a convenient device for winnowing grains, spices and other agricultural produce during the season after the harvest when there is lull in the natural wind and also for dehydrating fruits and vegetables. The system comprises PV modules, especially designed compatible winnower and drying cabinet. As a winnower, it can separate grain at the rate of 50 kg per hour from threshed materials. Using it as a solar PV dryer, 40-50 kg fruit and vegetables (e.g. water melon flakes, *kachara* - local cucumber slices, grated carrot, jujube, coriander leaves, chillies etc.) can be dehydrated in less than half of the time required for open sun drying while fully retaining their color and aroma. The quality of the dehydrated product is excellent because of the ability to maintain the desired cabinet temperature by auto-regulated PV run fan. The system can be used for charging a battery for illumination of house. Thus, it becomes a multipurpose device for domestic lighting, winnowing and cleaning of grain, and dehydrating fruit and vegetables.

Wind power

Wind energy is emerging as a highly competitive option for power generation in many areas in the country (MNES, 2004). A few locations in Rajasthan have been identified for wind power generation. The data collected in Barli and Phalodi in Jodhpur district, Pachapadara, Bhadka and Derasar in Barmer district, and Khodal and Jaisalmer in Jaisalmer district indicate an annual mean wind speed (kmph) and average annual energy density (kWh/m^2/day) as 10.4 and 1.4 in Jodhpur, 14.9 and 2.8 in Barmer and 14.0 and 2.4 in Jaisalmer, respectively.

Considering a potential of using wind power in certain pockets, efforts have been made to explore this renewable source of energy. Wind power can effectively be utilised by erecting wind machines to generate electricity in locations where wind blows above critical speed of 10 km/h. Series of aero-generators (wind farms) are installed to generate electricity and then successfully feed to electric grid through proper inter-phasing. Such wind farms of 2.25 MW and 25 MW capacities were installed at Jaisalmer and of 2.1 MW at Phalodi by the State agency. A few private enterprises are now in the arena to generate electricity from wind power and selling it to the State. With their efforts, about 260 MW power is generated through aero-generators at Jaisalmer and it is being fed to national electric grid. The installed capacity in the country is about 3,000 MW ranking fifth in the world. At CAZRI, Jodhpur, modest efforts were also made in this direction in early eighties and a small sail wing type wind mill was developed for pumping water. This is a virgin field for harnessing renewable energy in arid areas where critical wind velocity is available.

Bio-gas

Biogas is an alternative source of fuel derived from organic wastes available abundantly in various forms mainly from dung by using bio-gas plants, which can be used by individual farmers as well in cow shelters (gaushalas) for generating electricity for lighting and providing fuel for cooking and for running small mechanical systems. At the same time, the system yields better quality organic manure. Considering the high population of cattle in the arid region, it is estimated that there is a potential of generation of 5.3 million m^3 biogas/day if collection efficiency of dung is 70 %. The generated bio-gas is equivalent to yearly saving of 4,526 million kg firewood. In addition, manure having 1,055 million kg nitrogen is ensured every year. Standard models of biogas plants suitable for individual households as well as for institutions or communities are available. Ensuring availability of water and temperature regulation to increase output in winter can make biogas a valuable source of renewable energy.

Biomass

Prolific growth of *Prosopis juliflora* in Indian Thar desert offers vast scope of renewable energy from its biomass (Pasiecznik et al., 2001). It is estimated that in arid region of western Rajasthan there is 668 million tonnes standing biomass (400 million tonnes dry wood) of *P juliflora*. Considering 4,500 kCal kg^{-1} calorific value of this species, there is 2.8 x 10^{15} kCal standing bio energy. Harvesting about 1/3 of biomass per annum (22.9 million tonnes wood) would provide 0.93 x 10^{15} kCal energy annually on sustainable basis. The species is suitable for charcoal making as well. Thus about 30 million tonnes of charcoal can be produced annually by utilizing one third of standing biomass. Alternatively, wood can be utilized for generation of electricity through gasification. The operation should however ensure good tree regeneration strategies for protecting the environment and to achieve sustainability.

Epilogue

The scope for the use of different gadgets operating with non-conventional energy is enormous to meet the shortage of energy from conventional fuels. There is a great need to harness and integrate different renewable systems and to disseminate these environment friendly technologies to rural hinterland. Involvement and active participation of different sections of the society and international cooperation in augmenting the R & D activities are needed for providing higher impetus to this initiative. Exploring and utilization of renewable sources of energy would make societies of drylands more self dependent on energy. The farmers can utilize their spare time for gainful employment in agro- based industries when this energy is available. They can also accrue benefits by way of value addition to their products improving their livelihood and quality of life.

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Theme: Indigenous and Traditional Knowledge

The role of indigenous knowledge in sustainable development of natural resources

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Abstract

The ultimate goal of the development is the well being of the people. To achieve a sustainable development, team work is a necessity and to achieve this, it is necessary that all the individuals participate in development programs and acknowledge its importance. The concept of sustainable development in general, and that applied to the natural resources in particular, has been dealt with in this article. The factors affecting and the methods to measure the sustainable development have been discussed.

Introduction

Conserving the natural resources is one of the most important challenges facing humanity today. The negative consequences of the damage to natural resources on human life necessitate that more attention is paid to protect these resources particularly for the next generations (Mircangar, 2005). After World War II, economical development was the main goal of countries involved. This caused some intensive damage to natural resources, particularly in Europe and North America (Avaft, 2002). The Convention of International Environment Conference in 1972 laid much emphasis on more conservative utilization of natural resources, reduction of pollution and extension of environment education. These decisions were further developed in the subsequent international conferences and organizations like UNDEP and UNCCD promoted them (Zaresalmasi, 1995).

During the last three decades, emerging environmental problems have attracted the attention of the economists and environmental scientists towards the fact that the economical and social development should occur hand in hand with the conservation of the natural resources (Choogli, 2005). Development and "growth" were considered synonyms in the past. However, there are major differences between them. In general, "growth" is a quantitative increase in an organism, while "development" is considered as a quantitative as well as qualitative change towards well being for an organism (Tangestani, 1993). Development is a process which is directed by man to provide with better living conditions for all human beings (Nayebabbasi, 2000).

Sustainable development

Sustainable development has been defined as an economic and social growth while the natural capitals do not reduce and the ecosystem is conserved all through the time (Zaresalmasi, 1995). Within the frame work of sustainability, UNESCO prescribes that "all generations should leave water, soil and air resources unpolluted for the next generations" (Avaft, 2002). This is important to acknowledge that sustainable development can be achieved only when all sections of the society including women, men, youth and even children contribute to it. Team working is a necessity in all aspects of economical, social and ecological development.

The sustainable development includes three aspects: economy, society and environment. Labor force, natural resources and technology are the three main elements for economic development. In social development the social organizations, both governmental and nongovernmental, along with demographic structure, social relations, beliefs and interactions are considered as the main elements (Khatoonabdi, 2002). However, the last are the elements of natural resources which include kind and per capita energy consumption, plant and animal diversity, and soil, water and mineral resources. The sustainable development will be achieved only if the human activities will not damage the stability of natural resources and the energy consumption is scientifically managed.

Evaluation of sustainable development

To evaluate the sustainable development, especial attention is paid to natural capitals because destruction of Ozone layer, water, soil, forest and other natural resources could not be substituted by any other resources. The following formula is used to evaluate development sustainability:

$$\Delta\ NRV = VI - RD$$

where ΔNRV= variation in natural resources value; VI= Increment of natural resource value; RD= decrement in natural resources value. Positive and negative ΔNRV values will represent sustainable and unsustainable development of natural resources, respectively.

To have a successful program to achieve a sustainable development in natural resources three principles should be taken in to consideration. Firstly, indices of development should be carefully defined; secondly, the function criteria in any section should be defined based on law; and thirdly the research based results should be used to solve problems.

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Traditional Syrian water management

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Abstract

The hydraulic 'noria' has been one of the most significant examples of Syrian ecological systems employed for supplying and carrying water for irrigation. It is an installation which, using the power of the river, raises water to irrigate fields that are usually at a higher level than the level of the water. The system is composed of two main parts, the wheel and the aqueduct. The wooden wheel has the base submerged in the river and turns because of the current. Water is transported through compartments or pots placed on the periphery of the rim of the wheel, and is carried into the channel on the top of the aqueduct, and is directed to irrigate fields and gardens. The Orontes valley, in West Syria, has been the ideal place for the development of numerous hydraulic norias. They were employed for irrigation until the 1960s when they were replaced by modern pumps. This system has significant environmental advantages. It is an economical and clean technology. It allows irrigation requiring no petrol or oil, but exploiting the power of the river. The installations are also well integrated into the landscape, using materials easily available in the area. The paper analyses this device focusing on its architectural, technological, ecological and environmental aspects. Due to its simplicity, efficiency, low operation and maintenance costs and its aesthetic qualities, this type of water-architecture deserves further attention and consideration in order to be renovated as a device which, in some cases, could be fully employed for its original purpose.

Introduction

The irrigation of the Orontes valley, in western Syria, has always had a fundamental role in the development of agriculture, one of the main economical resources in that area. The old systems of irrigation used in the past have been substituted by modern hydraulic works, due to the introduction of new technologies based on oil or electricity. Some types of ancient water management systems have characterised Syria over time. They were used to provide surface or underground water for domestic purposes and irrigation, exploiting the morphological characteristics of the river or ground. The most representative ancient system which draws water directly from the river is the hydraulic 'noria', also known by it's Arab name 'na'ura', i.e. a water-wheel powered by the flow of the river. The system raises water to irrigate fields which are at a level considerably higher than the level of the river.

Hydraulic naurias on different rivers in Syria

The Orontes, which flows in a contrary direction to most other rivers, originates from karst sources in the mountains of Lebanon. It enters Syria, crosses Homs, Hama, the Apamea lake and arrives in Turkey where it flows into the Mediterranean Sea. It has a permanent and regular regime, and, as it flows through Syria, its volume is increased by several tributaries. The river valley has been the ideal place for the development of numerous hydraulic norias. In fact the construction and use of the hydraulic norias is allowed by the ideal speed of the river, a gradual slope of the ground and the absence of major flooding. Hydraulic norias were mainly concentrated in the sections of the river characterized by high banks, in particular between Rastan and 'Asharina. Some systems also existed in the Homs area, South of Rastan, and near the Turkish border on the North section of the river (Fig. 1).

Hydraulic norias with different characteristics than the Orontes type also existed in the Aleppo area, on the Qwaiq river, and on the banks of the Khabur and Euphrates rivers where only a few remains of the masonry structures have survived. On the low Khabur river they were numerous, due to its constant speed and flow of water and the fact that its banks are high enough to contain the slight floods. Unlike the Orontes and Khabur, the Euphrates has never had a large number of hydraulic norias because the period of maximum water supply does not correspond to the period of maximum demand. In fact in summer, when water is vital, the river is at its lowest, while in late winter, when the water is not needed, the river is at its highest. In addition, the Euphrates is delimited by its high embankments which are prone to land slides. Another reason for the scarcity of hydraulic norias on the Euphrates is the fact that the water contains silt, and so it is not ideal for irrigation.

Hydraulic norias are not employed for their original purposes any longer, but the best preserved examples are kept in working order as historical heritage and for eco-tourism. Existing records show that they were in use in Syria in Roman times, in the 3rd century A.D. Most structures that exist now are the result of several repairs and restorations over time or are recent constructions built in the first half of the 20th century.

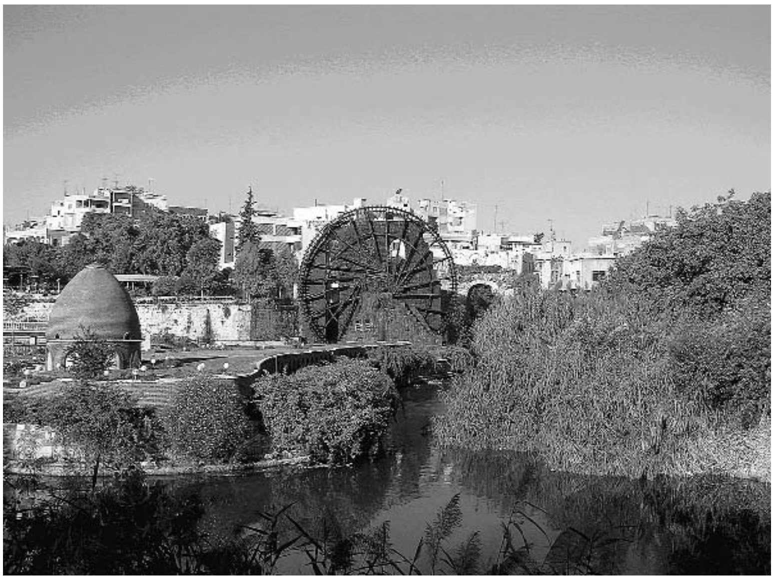

Fig. 1. A na'ura in the city of Hama.

Fig. 2. A nawa'ir in the city of Hama.

Structure of nauria

The fundamental parts of the system are one or two wheels made of wood, and an aqueduct made of stone. The wheel is located between the aqueduct and a triangular wall. The supporting horizontal axis lies on top of the triangular wall and on the sill of the window which characterises the front of the aqueduct. The base of the wheel is submerged in the river. The power of water presses on the paddles on the periphery of the wheel, causing the wheel to rotate and containers attached to the periphery of the wheel to get filled with water. The containers lift the water up and discharge it into the aqueduct channel and water is then directed to irrigate fields and gardens in the vicinity (Fig. 2).

The quantity of water raised depends on the size of the structure. When the wheels were in use, the average water raised by this system was 45 litres per second and allowed an irrigation of 25 ha (Weulersse, 1940).

The size of the structures depends on the height of the banks. The smallest are about 7 meters high, while the biggest can exceed 20 meters. The aqueduct, whose height is slightly lower than the height of the wheel to allow the pouring of water into the aqueduct channel, has a length which can reach hundreds of meters (Fig. 3).

The channel into which the wheel is inserted is particularly narrow (about one meter) in order to increase the flow of water under the wheel. This channel can be dammed when it is necessary to access the channel for maintenance. One channel, parallel to the main channel, contributes, when necessary, to evacuate the redundant quantity of water. When it needs to increase the water towards the main channel, a sluice gate allows the flow to be regulated.

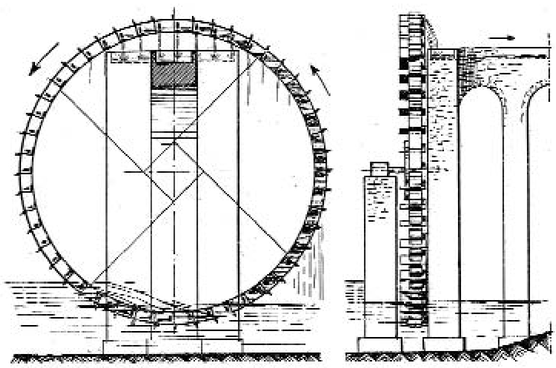

Fig. 3. Representation of a na'ura (Weuleresse, 1940).

In many cases a dike, also made of stone, bars the river. Along the length of the dike there are some passages for water to regulate its level during periods of flood or scarcity (Figuers 4 and 5). For better control of the water level, the passages may have internal sluice gates. The river is usually slightly barred obliquely before the location of the wheel, to direct maximum power to the wheel and provide maximum speed.

It is possible that, when the river is low, the system cannot work properly because water kept by the barrage - although directed to the main channel - is not strong enough to move the paddles of the wheel. Consequently the water accumulates behind the paddle which enters the water. When the water accumulated is enough to move the paddles, the wheel re-starts doing a few turns, although the movement is erratic.

When it is necessary to supply a large amount of water and to raise it to different levels, the structures are arranged in groups. There is the typology of a single installation with one aqueduct and tower, and one wheel. There is also an installation which includes two wheels with the same diameter, placed on either side of one tower. Another kind of installation is composed of two wheels with different diameters, which supply two aqueducts to allow irrigation at different levels. Most hydraulic norias are placed at both ends of the same dike to fully exploit its function and reducing the number of dams crossing the river.

Sometimes a mill for grinding grains was associated with a hydraulic noria in order to exploit the advantages provided by the dike. Today, where there are still dikes in a good state of preservation, providing a large quantity of water, modern hydraulic pumps are installed to raise water for irrigation. For the same reason some modern aqueducts (now in disuse) were built near the remains of old structures. In other cases, well preserved aqueduct channels are still used for carrying the water raised by the pumps to the fields (Fig. 6).

Fig. 4. Example of a dike with the passages of water.

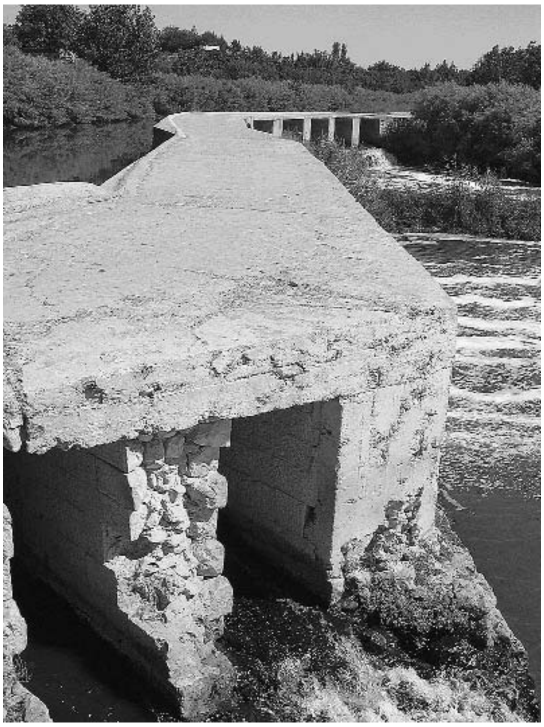

Fig. 5. Example of a dike with the passages.

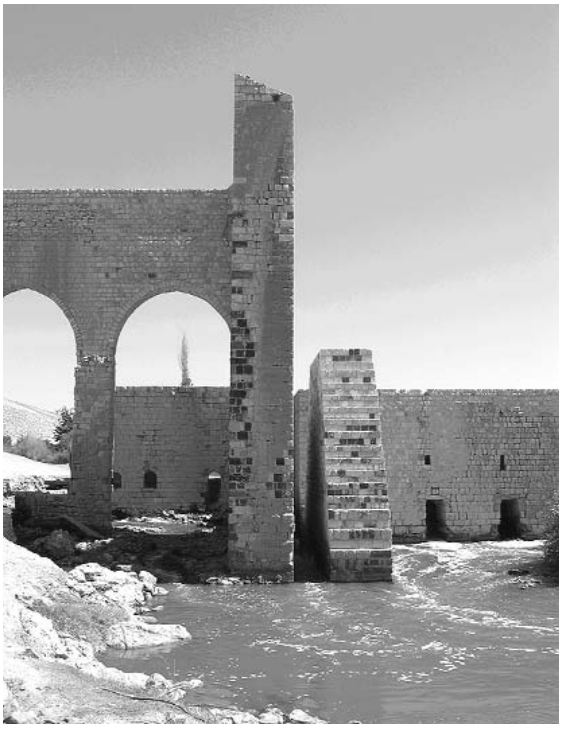

Fig. 6. Detail of aqueduct, triangle and of water mill (background).

The efficiency of the system is guaranteed not only by the masonry works, but also by the particular structure of the wooden wheel. The assembly and disposition of the spokes make it strong and more resistant to the force of the current and enables a better distribution of the internal forces involved. The simple mechanism and assembly of the wheels make them easy to maintain, repair and reconstruct. Wooden wheels are not lubricated. The use of oil could provoke an excessive speed of the wheel which could cause parts to break or disconnect.

In spite of the simplicity of the masonry structure, different patterns of towers and aqueducts show a variety of shapes. By contrast the wheels are built on the same model, and change only in the number of spokes and rims.

Advantages of nauria system

One of the main advantages provided by the system is that it allows irrigation requiring no fossil fuel, but fully exploiting the power of the river. In addition, the wood and natural stone, found locally, provide not only ideal easily available building materials, but allow the hydraulic norias to appear part of the natural landscape. Even the permeable limestone, which may not seem ideal, is waterproofed over time by deposits left by the calcium-rich water of the Orontes. In addition, the wheel has a simple assembly, is efficient and has low operational and maintenance costs.

In the second half of the 20th century they gradually stopped working, as water was raised by electrical pumps and distributed via a network of surface channels. However, some structures were still used for irrigation until the early 1980s. In the Orontes area in 1985 approximately 5,532 ha were irrigated using this hydraulic system (Soumi and Abdel Aal, 2004). When many hydraulic norias stopped working, most of them were abandoned until the 1970s when the government started a program of restoration in order to keep these installations in working order as Syrian historical heritage.

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The role of indigenous knowledge in the livelihood activities of rural communities in Sudan

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Abstract

Rural people in Sudan have inherited indigenous knowledge on many aspects of their surroundings and their daily lives and it constitutes a valuable resource for development. The knowledge covers a wide range of subjects. Although the potential of this knowledge for development has been realized by professionals, it has remained neglected for quite some time by formal institutions. Gender consideration with respect to the indigenous knowledge is also important. Tapping the valuable knowledge of both women and men can help in the sustainability of development efforts. Indigenous knowledge in Sudan has been inherited by the people from their ancestors who developed skills to adapt with their surrounding environments by adopting compatible coping systems. Studies have indicated that the indigenous knowledge transferred traditionally from generation to generation is in harmony with biodiversity conservation and livelihood support strategies and is enabling the local communities to participate in the process of development. Therefore, integration of indigenous knowledge with scientific research can facilitate sustainable natural resource management. Recent developmental projects have adopted extension system for raising awareness and knowledge transfer among rural people. Comparison between different categories of target groups based on questionnaires indicated significant differences among people with regards to source of knowledge (inherited or acquired from extension), with insignificant differences between peoples' attitudes towards practices acquired through indigenous sources while the difference between them about the externally acquired knowledge were large.

Introduction

Rural people have an intimate knowledge of many aspects of their surroundings and their daily lives. Over centuries, people have learned how to grow food and to survive in a difficult environments. They know what varieties of crops to plant, when to sow and when to weed. They can identify plants that are poisonous and those that can be used for medicine. They know how the diseases can be cured using indigenous formulations based on the native plants. In summary, they have evolved methods to ensure that they live in harmony with their environment and maintain equilibrium.

The indigenous knowledge covers a wide range of subjects:

- Agriculture and livestock rearing
- Food preparation
- Education and knowledge transfer
- Institutional management
- Natural resource management
- Health care, etc.

Background to indigenous knowledge

Indigenous knowledge in most parts of Sudan has developed through time by indigenous people who had to cope with their surrounding environments particularly in areas prone to drought and desertification. It is a valuable resource for development at the household and community levels. Under certain circumstances it can be as important and useful as the know-how introduced through extension agents based on applied research. Development efforts should therefore consider indigenous knowledge and use it to the best advantage. Although professionals and scientists have come to realize the potential of indigenous knowledge, it has remained for long a neglected resource at the government level. A key reason for this is the lack of guidelines for recording, applying and improving indigenous knowledge.

In recent years greater attention has been directed towards the documentation of local knowledge in Sudan. This was reflected in scientific efforts made by researchers. Socio-economic studies indicated that the historically acquired indigenous knowledge can be considered in harmony with the biodiversity conservation and food security strategies and can enable the local communities to participate in the development plans (Abusin and Elsamani, 1986). Indigenous knowledge integration with the scientific research can facilitate sustainable management of natural resource. According to Wiersum (1984), choosing a resource management intervention should start with an analysis of the local resource management practices.

Linking indigenous knowledge with new innovations in resource management has been given consideration in several studies (Malla, 2000; Hunt and Haider, 2001; Oba, 2001; Adhikari, 2002). These studies may help formal institutions to adopt a balanced management approach that considers local community needs and enlists their participation. The formal management of the resources is no longer the only option; local informal governance, based on indigenous knowledge, is another mechanism for effective management of these resources (Ibrahim, 2000). Positive changes in attitudes of formal institutions towards indigenous practices have necessitated directing more attention towards indigenous knowledge. This has been reflected in policies contained in the Comprehensive National Strategy (CNS, 1992) plan of Sudan. The development plan has called for:

- Giving due considerations to local knowledge, customs and traditions.
- Involvement of local societies in the planning process for developing the rural areas, as means for sustainable development and self-reliance.
- Giving special consideration to the role of local knowledge on adaptation mechanisms in Sudan and taking it in consideration when planning for national foodsecurity and conservation and development of natural resources (biodiversity and important ecosystems).
- Promotion of environmental awareness at different levels to enable a broad-spectrum of participation including local communities, NGOs and decision-makers.
- Rural development and poverty alleviation as twin pillars.
- Securing community rights with respect to land, water and other natural resources for their well being.

Diversity of indigenous knowledge in Sudan

Sudan, as a vast country extending from the high rainfall wood land Savannah in the south to the semi-desert and desert in the north, accommodates diverse environmental conditions. This underpins the fact that the local people in different parts have specific adaptation mechanisms related to agricultural practices and pastoral systems that have evolved through time and primed into indigenous knowledge. Examples can be drawn from different parts of Sudan. In the northern parts, where dry desert conditions prevail, the people have developed a rich local knowledge with regard to agriculture. They have developed mechanisms to conserve the meager available natural resources of land, water, forests and animals (AIACC, 2005). Examples include the use of solar energy in drying and conserving their agricultural crops, salting fish for preservation and storage for food, use of tree fruits for food during famine, use of animal wastes and agricultural residues as manure for fertilizing the soil, and use of leaves of Neem *(Azadirachta indica)* tree as a pesticide.

Indigenous knowledge survived and developed in western Sudan over time with growing community needs and under extreme weather conditions. Community leaders, who can be described as indigenous knowledge pools, play the role of local institutions for the promotion and transfer of knowledge and culture with regard to natural resource conservation and management (Elsiddig, 2004). The role of village chiefs extends beyond the general administration of the village affairs to cover interventions in aspects related to land use and social events such as:

- Mobilization of communities during disasters or abnormal conditions.
- Conflict resolution and development of traditional

conventions and agreements, e.g. between nomads and farmers or between different neighboring tribes.
- Organization of team work (called *nafir*) at the time of harvest, fire outbreak or emergency situations.
- Facilitation of implementation of customary laws.
- Supervision of land allocation and natural resource management.

People in western Sudan depend mainly on rainfall for water supply to meet the agriculture and domestic needs. As rainfall is very variable and unpredictable, people have developed adaptation measures based on their knowledge to detect occurrence of seasonal draught and water scarcity events. This can be considered as a system for early warning, which is the first step in the adaptation mechanism. They have shown ability to forecast a good rainy season or a dry period by observing certain changes in the environment. The production of large quantities of seeds by a certain tree species is considered to be a sign of drought in the following season while the presence of certain migratory birds is assumed as a sign of good rains in the coming season. Based on these local indicators food security plans are usually built.

Local people adopt strategies to cope with seasonal variability and to adapt themselves to hard conditions. Examples of such adaptations include:

- Cultivation of draught resistant crops permitting early harvest.
- Adoption of water conservation and traditional storage systems.
- Rationalization in using of available resources.
- Temporal movement.
- Preservation of agricultural crops and animal meat (salting, drying, grinding and storage).
- Fermentation of foods (canning, and storage).

The traditional agricultural systems in most of the dry lands of Sudan have been influenced by the circumstances created by drought, land degradation and decline in land productivity. People developed various adaptation mechanisms to cope with the changing environmental conditions and food crisis. Cultivation of drought resistant crops and expansion in cultivated area to compensate for the decline in grain production are common in almost whole of the dry areas of Sudan (Ibrahim, 1984). The adoption of water melon cultivation provides an example of adaptation to drought conditions. Water melon is not much affected by drought and, in addition, it provides benefits to farmers particularly under drought conditions, as a source of food, water, fodder and income.

Mohamed (1994) described a range of mechanical, biological and agronomic measures in various combinations taken by farmers along Wadi Elku in Jebel Marra area in western Sudan to enhance resource conservation and agricultural production. The indigenous techniques adopted by the Fur farmers along Wadi Elku involve the protection of the Wadi flood plain by allowing trees to grow according to the local regulations passed by native administration that also prohibits tree cutting.

Various water harvesting techniques are traditional developments at the village level. The terracing and embankment systems in west Darfur is an example of innovations of the Fur farmers developed spontaneously as a part of on-going system of resource and risk management (Elasha, 2005). The *trus* is an embankment constructed across the bottom of the Wadi to raise the flood water level resulting in water spreading on agricultural lands. Farmers also developed other techniques for water harvesting, defined as *teras*, which is a kind of spate irrigation (Mohamed, 1994). The *teras* system is composed of a base embankment across the contour along the boundary of a farmland and two arm embankments at right angles at both ends to the base embankment. The arm embankments act as convergence system for the flowing water. The upper end of the farmland is left without embankment to allow the flow of rain water down the slope into the farm. A system of gates is developed to allow over-flow of water to neighboring farms (Mohamed, 2004). The *trus* and *teras* water harvesting technology was a community-driven adaptation measure to face the scarcity of rainfall.

Water conservation adaptation strategies are well known in different parts of the Sudan (Elsiddig, 2005). Water storage in cement containers and in reservoirs constructed underground, locally known as *hafir*, is based on public participation (ILO, 1984). In some areas, where underground water is lacking, water used for domestic purposes is stored in the hollow trunks of the giant tree *Adansonia digitata*, called *tabaldi* in Sudan and as *baobab* in some other countries. Rain water is harvested and stored in these local devices developed by the local people. The clay pots used for water storage at home is a water cooler constructed by specialized traditional 'engineers'.

The above water harvesting and conservation systems indicate the contribution of indigenous knowledge and relevance of the traditional practices in the solution of present day environmental and food security problems in drought-stricken areas.

Gender consideration

Gender and indigenous knowledge are linked in many ways. Women and men often possess different skills and different knowledge of local conditions and everyday life and have different roles and tasks in their societies. They are linked to the resources differentially with regards to access, possession and control; and they have different understanding of the value of the resource base to the community. Gender assessment studies indicate that consideration of the knowledge, experience and capacities of both men and women can have positive impacts on planning of natural resource management (Elsiddig, 2004). Women and men have cultivated ecologically sound and effective techniques in resource management, individually and jointly. They often complete different jobs for the household, earn income in different ways, allocate time differently, have different legal and traditional rights, and frequently have different priorities and goals. Tapping the valuable knowledge of both women and men can facilitate the sustainability of development efforts (Elasha, 1996; Elsiddig, 2004).

Donor-funded development projects have introduced gender issues that necessitate provision of opportunities for both women and men to participate in development and sustainable management and to benefit from the resources (FINNIDA, 1997). Women contribute much to the labor and day-to-day decision-making that goes into crop production, animal husbandry and forest products management. The result of a gender analysis conducted in Darfur State, western Sudan indicated that more than 85% of total forestry laborers were women (Elasha, 1996). They grow subsistence crops, vegetables and trees in their backyards. Climate change and drought conditions have created new challenges faced by innovative adaptations such as integrated growing of home trees with crops in home gardens locally called *Jubraka*.

In many parts of Sudan the role of rural women compliments the responsibilities of men. Women collect and transport fuel for domestic needs, gather wild fruits, herbs and seeds, fetch fodder for livestock and take care of farms (Elsiddig, 2004). Collection and selling of forest products, developing handicrafts from forest raw material and participation in community woodlots development are some of the examples of women's contribution in income generation activities. Various studies have showed that where there is pronounced out migration of males in search of out of farm work or for other reasons, many Sudanese women have adopted additional functions which were traditionally performed by men, such as plowing fields, cultivating, harvesting, and even marketing the farm produce. Therefore, there is need to pay special attention to women in any project aiming at conservation and management of natural resources.

Cottage industry

In most of the rural areas in Sudan, cottage industry is an important contributor to the family income. The cottage industry depends mainly on trees for the raw material. Thatch and fibers from different palm tree species like Dom tree (*Hyphene thebaica*) are among the main domestic products. The fibers are also used for production of baskets, ropes and mats for sale. The Fur people in western Sudan are known for making high quality products in the home industry, usually for export to the big towns in Sudan. The methods used are those inherited by them from their ancestors, and the tradition is passed on to the nest generation.

Use of medicinal plants

Rural communities use a wide range of indigenous species as a source of medicines. The people know many indigenous plant and tree species that have medicinal value in addition to other uses identified in most of the rural areas of Sudan (Elasha, 2005). These plants provide medicinal material for curing anemia, malaria, cough, urinary infection and dysentery and other stomach troubles.

People participation in natural resource management

Natural resources in the rural areas of the Sudan were historically managed in a traditional management system based on local sets of norms controlled by tribal leadership and with local people's participation. The system was organized within tribal territories and customary regulations dictating use rights and resource distribution among sedentary agro-pastoralists, mobile nomadic pastoralists, and other resource users. The system, based on collaboration between native administration and formal governments, continued during the colonial era and in the subsequent period of national governments. The execution of the traditional system was driven by indigenous knowledge. The traditional leadership was well recognized, understood and respected by the local groups in the rural areas (Elsiddig, 2004). The system was sustainable and was supported by equity of use-rights and customs that controlled the use of the common resources. Knowledge transfer and activity supervision depended on family participation, elders and traditional leadership.

The system of native administration and traditional participation within the rural communities continued until the middle of the twentieth century. However, government attempts to control the management and use of the resources resulted in issuance of new legislations and acts that aimed at abandonment of native administration. The 1970 unregistered-land act, which had put all common resources and registered government reserves (forests and national parks) under government ownership, resulted in isolation of the local communities and prevented them from access to resources owned by the government. However, driven by their needs, people entered illegally inside government reserves in spite of the punitive measures. Conflicting attitudes of communities and formal institutes created a state of mismanagement that resulted in resource degradation.

The management systems introduced in the development strategies of new donor-funded projects that started operating since the beginning of the 1980s brought in the concept of participatory approaches based on the recognition of the role of traditional leadership and the importance of indigenous knowledge and traditional practices (Abdelmagid and Elsiddig, 2003). Project strategies were concerned with raising awareness of the people based on extension programs, building on the indigenous knowledge and introducing new concepts and knowledge transfer among local communities. Most of the project interventions started by a strategy concerned with reforestation campaigns, vegetation cover improvement, and development of livelihood support systems based on local community participation. The positive results of project strategies resulted in a change in the attitude of the formal institutions towards the role of the local community in the development. As a result, in the past two decades, local communities have played an important role in natural resource development projects in Sudan, both as participants and as beneficiaries.

Because of its positive results, the community-forestry approach gathered momentum (Elasha, 2005). It provided a conceptual framework for target groups to be recognized and for issues to arise and responded to. Recognizing the importance of the role that traditional knowledge and practices played in land use practices in the past (e.g. in Gum Arabic production), these were incorporated in the implementation strategies for community forestry. In Kordofan, for instance, inclusion of traditional leaders in the field as agents in the second phase of the restocking of the Gum Arabica belt project proved very successful. The '*Acacia senegal* bush-fallow system' is a traditional land-use practice providing adaptation to the degrading condition of the soil. The system is composed of twenty years of a bush cycle of *Acacia senegal* gum gardens followed by a 4 - 5 years cycle of crop cultivation. The bush-fallow cycle improves the soil fertility and provides income to the farmers through the sale of Gum Arabic (Ballal et al., 2005). The Gum Arabica belt rehabilitation project 1984 - 1994 approached improvement of the gum production system by introducing new technologies of seedling cultivation to improve the stocking densities and gum yield of the traditional gum gardens (Elsiddig et al., 2005).

Combating desertification was based on various approaches involving reforestation programs and local energy conservation. The latter concentrated on improving fuel use efficiency in the house hold mainly by introducing improved stoves technologies aimed at women as primary users of fuel wood and charcoal.

In most of the activities directed to natural resource management involving communities, experience indicated that there are two sources of knowledge acquired by people. One source included transfer of cultural values and indigenous knowledge inherited through time as traditional practices. The second was that provided by extension system (Alyousfy, 2001; Glover, 2005).

The response of community members with regards to their perceptions about environmental problems, their attitudes towards collaboration with formal institutions, and willingness towards participation in management systems was studied through formal survey. The results indicated some similarities as well as differences between different target groups. These can be classified into two major groups, according to the knowledge source (traditional or acquired through external agents). Statistical analysis using chi-square test indicated the differences between the different target groups within each class (Table 1 and 2).

High level of similarity was observed between the groups when the knowledge acquired was traditional and indigenous as indicated by low value of chi square showing no significant differences between the respondents (Table 1). There was high level of difference between the members of the community when the experience was based not on indigenous knowledge but was acquired through external agencies connected with extension (Table 2).

The relation of communities with resource management and knowledge transfer is based on the role played by community leadership. Table 3 shows the results of a survey conducted by Abusin and Elsammani (1986) on a sample of 186 target groups composed of thirteen categories of the local communities. They were all land users including

Table 1. Number and percentage of people within different categories of farmers having knowledge about trees and tree uses.

Category of farmers	Frequency	Know trees	Trees for wood	Trees for protection	Trees for multipurpose	Total
Highlands areas	Number	57	30	11	23	70
	% within category	81.4	51.4	15.7	32.9	100
Semi-desert areas	Number	60	55	11	25	92
	% within category	65.2	59.8	12.9	27.3	100
Central clay plain areas	Number	30	23	7	8	38
	% within category	78.9	71.0	18.4	21.0	100
Total	Number	147	114	29	56	200
	% within category	73.5	57.0	14.5	28.0	100

Source: Modified from Alyousfi (2003); N = 200; x^2 *=4.65.*

Table 2. Frequency (%) of farmers in different categories having perception of different indicators of soil degradation.

Farmers' category	Frequency (%)	Indicators of soil degradation areas						
		F	SE	F &SE pests	SE & & pests	RSF, SE	D	T
Mechanized scheme farmers	within	3.5	0.0	21.1	22.8	52.6	0.0	100
	between the category	4.3	0.0	70.6	100	75.0	0.0	35.2
Smallholder farmers	within	53.3	26.7	6.7	0.0	13.3	0.0	100
	between the category	85.1	100	29.4	0.0	25.0	0.0	46.3
Collaborative reserves farmers	within	16.7	0.0	0.0	0.0	0.0	83.3	100
	between the category	10.6	0.0	0.0	0.0	0.0	100	18.5
Total	within	29.0	12.3	10.5	8.0	24.7	15.4	100
	between the category	100	100	100	100	100	100	100

Source: Glover (2005). N = 162; x^2 *=226.39; p < 001; F=reduced soil fertility; SE=soil erosion; D=drought; T=total* sedentary agropastoralists, nomadic pastoralists, mechanized scheme farmers, forest products collectors and landless laborers. It appears that the majority of people support the acceptance of the native administration as responsible organization for the collaboration in the management of the resources. Reason mentioned was that the native administration system was based on experience, knowledge and reliability. People trust the native administration leaders and think that the leaders are known to the government. However, the range of other community-based organizations accepted by the local communities is an indication of the respect of democracy among local communities.

Control over natural resources and land ownership

Most of the tenure rights for land, trees and pasture in Sudan came from customary laws and indigenous traditions usually based on tribal structure. The land, the forests, the range and water within the village and the tribe territories were common resources managed according to the local regulations and allocated according to simple principles. Land-use planning was the responsibility of the village leader, called *Sheikh*. Conflicts between people within the tribe or between tribes were resolved by the traditional leaders and elders based on local conventions and experience (Elsiddig, 2005).

The sedentary and nomadic pastoralists under tribal systems in Sudan, developed tenure and usufructs rights to trees and other critical resources, as water and dry-season grazing resources, within their territories under the tribal management. This minimized opportunities for over-use and degradation. Trees, in particular, gained special interest as they provided fodder and other edible products in the dry season when seasonal vegetation was finished. In addition, trees constituted a source of energy, shade and income generation particularly for the nomads during their long movement in the dry season. Experience shows that trees constitute an important source of income to meet contingencies of the rural poor (Chamber and Leach, 1987).

Recommendations

There is a need for identification of effective means that would make indigenous knowledge and adaptation practices sustainable. Experience has shown that people adapt to changes in climate. Government is required to help the development of adaptation mechanisms by developing enabling policies such as tenure rights and technical support built on traditional practices. Because of the importance of improving the experience and practices among local communities, it is recommended that communication systems between communities and formal institutions should become a two-way system in order to enhance the knowledge transfer. There is a need for improvement of the rural infrastructure to facilitate development and improvement of traditional and intermediate technologies to improve the productivity of land-use systems. Efforts are needed to train more women in forestry and natural resource activities in order to enhance their participation at all levels. The most important element is the improvement of women’s participation in environmental rehabilitation and to increase their income in order to improve their living standards. The positive response and acceptance of some communities to the extension messages compatible with their traditional practices may encourage projects to continue the development programs based on integration of indigenous knowledge and scientific results.

Table 3. Perception of local communities towards the collaborative management of natural resources

Form of management	Number of respondents	%
Native administration and traditional leaders	56	30.1
Village council and community-based organizations	28	15.1
Farmers and herders unions	26	13.9
Religious leaders	10	5.4
Newly formed council of elders	10	5.4
Newly formed council of elites	46	24.7
Collaboration between all stakeholders	10	5.4
Total	186	100.0

Source: Abusin and Elsammani (1986).

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Theme: Sustainable Development and Socioeconomic Studies

Twenty-five years experience of research in dryland areas of Morocco

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Abstract

Dryland agriculture in Morocco covers about 68% of arable land and contributes to over 50% of total crop production in the country. Producing major staple food crops and livestock, it sustains a substantial proportion of the population. It consists of mixed farming where crops and livestock are highly integrated. Diversity is the primary characteristic of these systems. Improving productivity and welfare of the people of these areas is an important goal for political, economic and humanitarian reasons. Sustainable dryland farming development is possible if farmers are provided with technologies geared towards conservation, management and development of the natural resources for them, and maintaining adequate level of productivity of the ecosystem through optimum utilization of available resources. Drought is of common occurrence and it affects all the components of the farming system of the dryland farmers. It is now widely recognized that efforts to mitigate drought must take human, economic and political consequences into account. Dryland agricultural production could increase substantially if there is a sustained research together with favorable economic policies and a supportive policy framework. In the early 1980s, the Government of Morocco through INRA and USAID developed an applied agronomic program for dryland farming in the 200-400 mm rainfall zone of Morocco to produce technical basis, and applied research capability, for increasing agricultural development in the drier parts of the rainfed areas of Morocco. The major outputs of this program are the agro-ecological characterization and development of cereal and food legume varieties resistant to biotic and abiotic stresses, improved cultural practices, improved techniques for crop livestock integration, adapted machinery, alternative crops for marginal lands, and rapid rural appraisal and community approaches

Introduction

Rainfed agriculture in arid and semi-arid zones of Morocco covers 90% of agricultural land and is an essential source of cereals, food legumes and forage crops. These areas provide almost 45% of national cereal production and play an important role in the sustainability of small farms through the integration of animal and crop production. The main constraint to agricultural production in these zones is the occurrence of drought of variable intensity.

The agro-ecological characterization of these zones has shown that they are characterized by frequent drought of different nature. In fact, there are three types of drought conditions encountered in these areas: the drought that occurs at the beginning of cropping season; that occurring at the middle of the cropping season (February-March); and that occurring at the end of the cropping season (May-June).

The population pressure on the land has lead to continuous cropping and the use of marginal land and overgrazing of range land. Thus, there is an over use of natural resources which has resulted in a diminution of the land productivity and the degradation of soil, vegetation and water resources.

Aridoculture

The aridoculture is a package of technologies and knowledge for the improvement of the productivity of agriculture in the arid and semi-arid zones. These technologies aim at increasing and sustaining at high level the vegetal and animal production while conserving the natural resources of land water and agro-biodiversity. The aridoculture integrates biological, agro-meteorological, socio-economical and communication sciences.

Yield-gap analysis

There is substantial potential for increasing agricultural productivity in these zones as shown by the yield–gap analysis (Fig. 1). Obviously, there is a need for agricultural research and the development of new approaches for technology transfer to solve problems of arid and semi-arid zones and attain a sustainable agriculture in order to feed the future generations.

Research achievement in last twenty-five years

Since the early eighties, the aridoculture center in collaboration with national and international institutions has developed knowledge and adapted technologies in order to alleviate constraints of fragile production systems and improve natural resource management. Important research results have been obtained concerning water conservation and use efficiency, decision-making tools, improved cereal and food legume varieties, cultural practices, introduction and adaptation of underutilized crops, improved techniques for crop livestock integration, development of participatory approaches for technology transfer and impact assessment, and development of infrastructure for plant genetic resources conservation.

Environment characterization

The inter- and intra-annual variability of precipitation and the occurrence of extreme temperatures make agricultural production in the arid and semiarid zones highly uncertain affecting economy at the farm as well as at the national level. In addition, there is a large spatial diversity in climatic conditions, soils and other resources. This local diversity is associated with contrast in land use, cultural practices and economic potential of farmers, which is in most cases very low.

Agro-climatic studies conducted on data base of the region have proposed a new typology of annual drought. This typology is based on the seasonal rainfall. In fact, water deficit will not have the same impact on yield if it occurred at the beginning of the cropping season or during the active growth period. In order to define season for cereal crop, the growth period was subdivided into three key phases; crop establishment (October – December), vegetative growth (January-February) and grain-filling period (March – May). A season or a phase is considered water deficit if the cumulative rainfall for that period is less than the critical level. Critical levels of cumulative rainfall calculated for the Settat region are 119 mm for the first phase, 90 mm for the second phase and 86 mm for the third phase.

Studies on rainfall pattern for last several decades have shown that the mean annual precipitation is declining (Fig. 2) and the growing period for crops is becoming shorter (Fig. 3). This implies that the current cropping system needs to be reviewed and crops that have a shorter growth period have to be incorporated.

This ambiguity makes the planning, the interpretation of research results, and the transfer of technological recommendations that optimize the use of natural resources more difficult. Therefore, the

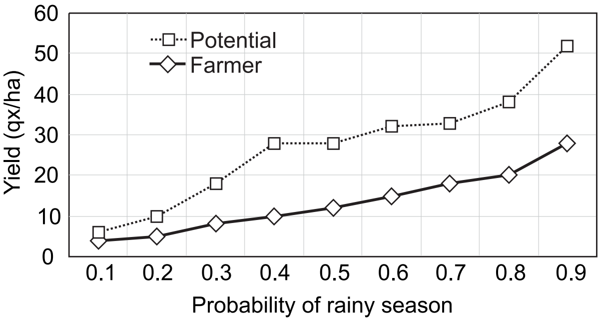

Fig. 1. Difference between potential and realized yield in Settat area in relation to the rainfall probability.

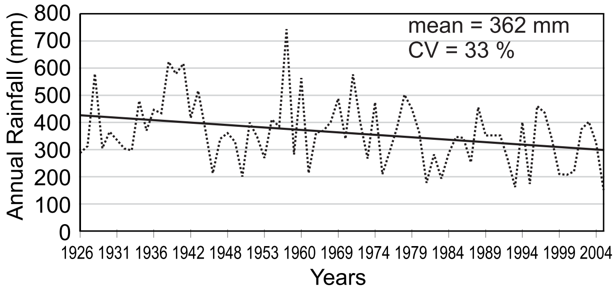

Fig. 2. Mean annual rainfall trend for the Settat area in Morocco from 1926 to 2004.

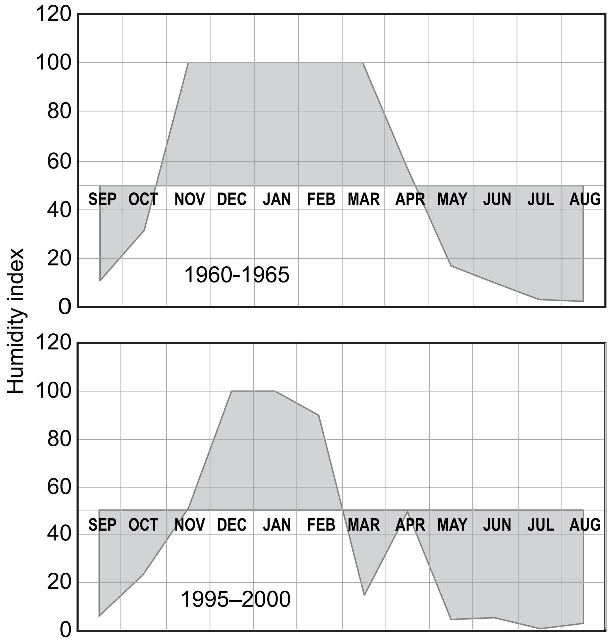

Fig. 3. The change in the length of the growing period, from 1960-65 to 1995-2000 in the Khouribga region as dictated by the humidity index in different months of the year.

new technologies need to be tested under different environments and over several years in order to be sure of their adaptability.

We have used simulation methods to quantify and model the climatic variability, spatially and over time, and its effect on plant growth and yield. In addition, experimental data could be compared with simulated data. The use of simulation methods permits the determination of zones with similar yield potential and crop production constraints. Also, it permits to rapidly identify the target areas for the technology transfer.

Genetic improvement of cereal and food legume crops

Small grain cereals are the most widely grown crops in the arid and semi-arid regions of Morocco. They are cultivated over more than 5 million hectares annually. Food legumes are the other major food crops in the country. These two groups of crops occupy over 70% of the cropped land and contribute to more than 55% of the national production. They constitute the major source of food and feed in the country. However, the production potential of these crops is influenced by inter- and intra-annual variability in weather conditions (precipitations and temperature), by edaphic factors (soil structure and fertility), and by cultural practices used by different farmers. In addition, these crops are subjected each year to a wide range of biotic stresses (insects, diseases and weeds) that limit their production potential and depreciate their yield and quality. For example, Hessian fly infestation in wheat could result in almost 100% loss of the crop yield.

Taking all these factors in consideration, the breeding program undertook crop improvement research and as a result was able to put into the national and the regional markets five new durum wheat varieties resistant to Hessian fly and several chickpea and lentil cultivars that could be grown in winter and thus have higher water use efficiency than the traditional spring sown cultivars. Several improved lines of wheat are in the pipe line that combine resistance to Hessian fly and rust. The program has surveyed the cereal diseases and insects pests of the region and has undertaken intensive disease and insect resistance screening program to identify sources of resistance to the major pests and pathogens. Besides, a large number of options for integrated pest management (IPM) in cereals and food legumes have been developed. Identification of a biological control agents such as *Bacillus subtilis* efficient against net blotch and powdery mildew and the development of a warning system for barley net blotch management and yield-loss modeling are essential components of the IPM.

Conservation of plant genetic resources

Morocco has a unique array of agro-ecosystems. Forty distinct ecosystems have been identified in continental Morocco. A large portion of these comprise of forests, woodlands, and grasslands. Bio-climatically, the following natural regions are found in Morocco: Sahara and hot and dry regions in the south of the country with ephemeral vegetation, hyper-humid and humid (cold and moist) regions in the mountainous areas and sub-humid and semi-arid regions in the plateaus and plains.

Morocco is an important center of diversity for a number of species including those under the crop mandate of the International Center for Agricultural Research in the Dry Areas (ICARDA). The collaboration between Morocco and ICARDA in areas related to genetic resource conservation and utilization started in the early 1980s with the acquisition of a large number of cereal, forage and food legume germplasm accessions for testing and use in the crop improvement program in Morocco and in the region. ICARDA has participated in ten collection missions in Morocco, which resulted in more than 2,900 new accessions that are currently conserved at the gene bank in ICARDA's Genetic Resources Unit. Some of this germplasm is already used by the crop improvement and rangeland projects at ICARDA.

Morocco is rich in diversity of species of importance to dryland ecosystems. This diversity, which is still found in a few marginal areas (mountains and oases), needs to be preserved. Following the signing of the FAO Plant Genetic Resources Undertaking by Morocco and the adoption of the Global Plan of Action on Plant Genetic Resources (PGR), INRA-Morocco has recently developed appropriate facilities at the Settat Regional Research Center with a medium and long-term storage capacity of more than 60,000 accessions. This facility serves as a national center for conservation and utilization of plant genetic resources in Morocco.

Cultural practices

Most cultural practices used by farmers in arid and semi-arid zones of Morocco are still of traditional nature. Therefore, dryland agricultural research has developed and improved a number of techniques for enhancing water- and fertilizer-use efficiency. Among these techniques are methods of seed-bed preparation that improve germination rate and water use efficiency and fertilizer recommendations for different crops based on soil test and plant requirement. In fact, the use of the latter has reduced the fertilizer input by 25%. Also, early weeding using herbicides is another way of improving water and fertilizer use efficiency.

Alternative or underutilized crops

The development of alternative crops, such as medicinal and aromatic plants (MAPs) is essential for product diversification in dry areas. In fact, MAPs offer some additional crop production opportunities in dry areas and enhance and stabilize farmer's income. INRA, through CRRA Settat, has started the research program on alternative crops in the last 4 years and achieved some interesting results on cultivation and adaptation of coriander, cumin and black cumin, fenugreek and other MAP species in farm conditions for biodiversity conservation and for improving farmers' income.

Improved techniques for crop livestock integration

Livestock production is a key component of the farming system in the arid and semi-arid areas of Morocco. Livestock is considered as farmer's bank and it is the only way to add value to the biomass from crop production at the farm. Crop livestock integration is a strategy for small- and medium-size farms in areas where climatic and soil conditions are harsh. The agricultural research in dryland areas of Morocco has given special attention to this production system in order to improve and diversify feed resources. Several technologies have been developed and introduced such as dual purpose barley, triticale, oat, forage legumes and techniques that improve the utilization and quality of agricultural and agro-industrial by-products in livestock feeding.

Also, the introduction of an alley-cropping system with shrubs and annual crops and the appropriate sheep feeding systems based on shrubs and cactus have been very successful in diversifying feed resources for livestock.

Partnership

The Aridoculture Center, since the time of its creation in early 1980s, has established fruitful collaboration with national and international institutions. The Center currently has collaboration with ICARDA on:

- Variety improvement concerning durum wheat, barley and food legumes;
- Selection of germplasm for Hessian fly, barley stem gall midge wheat stem sawfly and leaf rust resistance, and the initiation of Hessian fly biotype determination;
- Integrated pest management;
- Integrated natural resources management;
- Genetic resources conservation and gene bank development;
- Sustainable management of agro-pastoral resources;

- Management of scarce water resources; and
- Improving the livelihoods of rural communities and natural resource management in the mountainous areas.

Collaboration has been established with the International Development Research Center (IDRC), Canada on social and agricultural economic issues in order to elaborate a data base on farming systems in rainfed areas and assess the impact on ecosystem and health of the use of sewage water in agriculture. There is collaboration with NGOs, ministry of agriculture and local communities on approaches of technology transfer, organization of framers in a cooperatives, the improvement of the technical and economical efficiencies of the cropping/animal production systems and the diversification of farmers activities that generate year round income and prevent the farming community from migrating towards cities.

Numerical simulation of critical scale of oasis maintenance and development in the arid areas of north-west China

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Abstract

Oasis is a special geographic landscape among vast desert (Gobi) in north-west China (NWC). The surface sensitive heat flux and latent heat flux at Zhangye oasis during August 1 - 11, 1991 were simulated using NCAR nonhydrostatic mesoscale model MM5 Version 3. The horizontal grid resolution was set as 1 km. By comparing the simulation results with Heihe River Field Experiment (HEIFE) observation, it is proved that the model can be used to simulate the surface energy and water mass exchange of arid and semiarid regions in NWC. Based on the above results, the influence of different oasis scales on the local atmospheric field near ground surface, and the critical scale of oasis maintenance in NWC were studied dynamically. The conclusion obtained was that the local thermal circulation between the oasis and the desert would be formed in the oasis downstream, if the oasis scale was larger than 4 km. This local thermal circulation between oasis and desert adjacent to oasis helps conserving water vapor over oasis. At the same time, it transfers abundant water vapor from the oasis into the desert close by to supply relatively plentiful water vapor for the growth of desert crops on the fringe of the oasis. So, it is advantageous for oasis extension. If the scale of oasis were smaller than 4 km, the occurrence of local thermal circulation between the oasis and the desert is unlikely. This study provides a new standpoint for oasis maintenance and development.

Introduction

The oases cover only 5% area in arid/semiarid regions of north-west China, but this area plays an important role in feeding above 95% population. The oasis is a special ecosystem in contrast to the dry environment in arid regions (Zhang and Hu, 2001). The size of each oasis is different, some are large and other small. Their location and surrounding natural environment are also dissimilar. Their own characteristics are also very different. The processes associated with their development and evolution very much differ from one oasis to the other. So, each oasis has its own evolution history.

There is hardly any rainfall in the oases because they are located in the arid areas. Getting sufficient water becomes the basic necessity for oasis existence and extension. The scale (the size) of oasis plays an important role in its functioning and development. During the summer, the environment is scorching and extremely arid, and it lasts for a long time. The desert in north-west China is generally cloudless or only partly cloudy. A strong turbulence develops over the desert in the daytime because the stratification is extremely unstable. But, at the same time, the turbulence causes stable inverse stratification over the cold island in the oasis, where a stable cool and humid microclimate gets formed. It has a clear boundary and there is no mass exchange between the inside and the outside. A series of phenomena illustrates that the cold island has stable conservation. It is conducive to vegetative growth, because the cool and moist environment and weaker turbulence restrict transpiration and soil evaporation, and help preserving the limited water resources for vegetation growth in the arid regions (Su et al., 1987b). On the other hand, the oasis cold island could exchange the energy and the mass with the surroundings through the turbulence and the advection of local circulation. The reverse action could diffuse cool humid air into the surroundings and improve the microclimate of oasis fringes (Zhang and Hu, 2001), which would be of benefit for oasis maintenance and development.

A series of the microclimate characteristics, displayed by the "oasis effect," play a very important role in oasis ecosystem maintenance and development. It is not only because the superior light and heat resources benefit the land ecology and crop growth, but also, and more importantly, because the special microclimate reduces the water vapor loss and sustains oasis self-maintenance (Zhang and Hu, 2001). How could oasis, surrounded by the vast dry and hot desert, exist for so long time and not get engulfed by the desert closed by, is explained by meteorological theory (Hu, 1989; Hu and Wang, 1989).

The research on “oasis effect” in arid and semiarid regions is necessary as it is not only of theoretical significance but also of great practical value.

Review of related literature

The temperature, humidity and wind speed at the Gansu Institute of Agricultural Science (IAS), located to the west of the Zhangye City, in Gansu province, and at Nandatan, located to the south of Zhangye City, were studied from June 18 to July 22, 1984. The microclimate characteristics over the oasis in the Hexi region were studied by observing the gradients of meteorological elements. An oasis cold island effect was discovered (Su et al., 1987a; Su and Hu, 1988). The oasis in the desert under the condition of cloudless or partly cloudy weather during summer in the Hexi region is cold as compared to the surroundings. The oasis “cold island” affects the construction of planetary boundary layer, which adjusts itself and varies according to the conditions in the oasis. It is a special meteorological phenomenon within the planetary boundary layer, as illustrated in the Heihe River Field Experiments (HEIFE). Inverse sensitive heat flux in the daytime has been discovered over oasis adjacent to desert (Hu and Wang, 1989; Hu et al., 1994).

A two-dimensional model coupling land-surface processes and atmospheric planetary layer motion was developed, and the local climate resulting from on oasis surrounded by desert was simulated with the model (Ji and Miao, 1994). Zhang and Sang (2000) simulated the atmospheric boundary layer over a surface of desert-grassland area using a three-dimensional mesoscale numerical model combined with SIB. The mesoscale flux was compared with the turbulent flux in order to confirm the importance of the mesoscale movement, which is usually ignored in the surface parameterization scheme in GCM models. The results indicated that the mesoscale flux, especially the heat flux should not be ignored over the inhomogeneous underlying surface. The Pielke model was coupled with a combined land surface processes model, which included a simplified canopy model and a simplified desert soil model. Using this coupled model, the numerical simulations were carried out on the typical heterogeneous land surface with the oasis and desert distributed in the HEIFE experiment area (Niu et al., 1997). The local climate effect of heterogeneous underlying surface was simulated using the mesoscale model MM5. The influence of distribution of oasis on regional climate was also studied. The ground energy budget and the influence on the characteristics of the boundary layer were analyzed. This provided some insights into the mechanisms governing the desertification (Gao and Lu, 2001a,b).

The oases exist in their own scale. Zhang and Yu (2001) modeled the oasis-induced atmospheric mesoscale flow using a two-dimensional mesoscale atmospheric numerical model taking into account the condition of a simple land surface process. The sensitivities of the atmospheric mesoscale flow to oasis horizontal spatial scale, thermal and dynamical difference between oasis and the nearby desert, large-scale horizontal wind speed, and large-scale surface sensitive heat flux were studied. It was found that the oasis-induced atmospheric mesoscale flow became strong with an increase in the thermal and dynamic difference between the oasis and the near by desert. It became weak with the increase of large-scale horizontal wind speed and large-scale surface sensible heat flux, but intensity change of the mesoscale motion with horizontal spatial scale of oasis was not an isolated function. The atmospheric mesoscale motion was the strongest when horizontal spatial scale of oasis reached about 20 km and became weak when the oasis horizontal scale was less or larger. That means the best scale of oasis was 20 km.

The characteristics of oasis-desert interaction were studied by Xue and Hu (2001) dynamically and thermodynamically, based on a simplified dynamic model and the entropy budget equation, which describes the energy and moisture exchange between the oasis and the desert. The clear dependence of the oasis evaporation rate on the size of the oasis was revealed. Negative entropy occurs when the oasis scale is less than about 6 km. Hu (1987) developed a two-dimensional and steady-state numerical model of the planetary boundary layer to analyze the structure of "cold island".

The work reported above also indicated that there are many insufficiencies in our understanding of the oasis effect. Further theoretical and practical researches are, therefore, necessary. The critical size of oasis is just one of these research areas. The desert area faces conditions of drought and intense heat and is in the unstable stratification under the summer sunshine. A small plot of grass or trees planted in the arid Gobi does not last long, because that small oasis will be destroyed under intense arid environment before the cold island effect is formed. That means as long as the oasis in the arid desert is large enough to form a cold island it would have microclimate favorable for vegetation growth. Of course, this information on critical size of an oasis would be helpful in planting grass and trees and developing agriculture in the arid region in north-west China. Therefore, determination of the critical size of oasis needs further study.

Methods and material

Brief description of the model

The model used here is NCAR non-hydrostatic mesoscale model MM5. The horizontal grid is Arakawa-lamb B-staggering of the velocity variables with respect to the scalars. The vertical coordinate follows terrain that the lower grid levels follow until the upper surface is flat (Grell et al., 1995; Dudhia et al., 2001). There are many physical-process options for every parameterization scheme. Each scheme was selected as the following: The cumulus parameterization (ICUPA) was the Grell et al. (1995) scheme. The simple ice option (Dudhia et al., 2001) was adapted as the explicit moisture scheme (IMPHYS). The radiation scheme (IFRAD) selected was the cloud-radiation scheme. The planetary boundary layer scheme (IBLTYS) was selected as MRF PBL option. Modified Oregon State University Land-Surface Model (OSULSM) was chosen. Here is the brief description of MRF PBL scheme and OSU land surface model.

NCAR non-hydrostatic atmospheric mesoscale model MM5 has been developed to version 3.5 in which the Oregon State University/NCEP Eta Land-Surface Model (LSM) was coupled (Chen and Dudhia, 2001). Chen et al. (1996) extended the Oregon State University LSM (OSULSM), which was originally developed by Pan and Mahrt (1987). This LSM is based on the coupling of the diurnally dependent Penman's potential evaporation approach of Mahrt and Ek (1984), the multiplayer soil model of Mahrt and Pan (1984), and the primitive canopy model of Pan and Mahrt (1987). It has been extended to include the modestly complex canopy resistance approach of Noihan and Planton (1989) and Jacquemin and Noihan (1990). It has one canopy layer and four soil layers. The thickness of each layer from the ground surface to the bottom is 0.1, 0.3, 0.6, and 1.0 m, respectively. The total soil depth is 2 m, with the root zone in the upper 1 m of soil. Thus, the lower 1 m soil layer acts likely a reservoir with the gravity drainage at the bottom.

PBL scheme and the surface layer parameterization: The turbulent diffusion equation of diagnosed variations such as u, v, θ, q in MRF PBL is

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right)\right],$$

in which Kc is the diffusion coefficient, γ_c is adjusting factor of temperature and humidity gradient in mixing boundary layer, and it affects the calculation of the momentum, the heat capacity and the water vapor fluxes with large scale diffusion. The momentum diffusion coefficient in mixing boundary layer is expressed as

$$K_{zm} = kw_s z(1 - \frac{z}{h})^p.$$

Here, p is the index of profile, k is the Kàrman constant, z is the height above ground surface, h is the PBL height. In free atmosphere layer, K theory was used. The vertical diffusion coefficients of momentum (m : u , v) and mass (t : θ , q) are expressed as

$$K_{m,t} = l^2 f_{m,t}(Rig)\left|\frac{\partial U}{\partial z}\right|,$$

in which l is the mixing length, $f_{m,t}(Rig)$ is the stability function being related to the vertical wind shear $\partial U/\partial z$.

The LSM is coupled to the MM5 model through the lowest atmospheric level, which is also referred to the surface layer. A surface layer parameterization should provide the bulk exchange coefficients for the momentum, the heat, and the water vapor used to determine the flux of these quantities between the land surface and the atmosphere. The surface layer parameterization base is its surface flux calculation based on similarity theory, using the stability function and the roughness length to determine the surface exchange coefficient for the heat and the moisture. This LSM scheme through the PBL is component of the exchange coefficient together with the surface radiation forcing terms and the precipitation rate. The routine LSM with the PBL scheme calculate the boundary layer flux convergence, which contributes to the atmospheric temperature and moisture tendency, using the surface heat and moisture fluxes. Currently, the surface exchange coefficient for the heat and the moisture is formulated in MM5 as

$$C_h = \frac{k^2 V_a}{\left[\ln\left(\frac{z_a}{z_{0m}}\right) - \psi_m\right]\left[\ln\left(\frac{z_a}{z_{0t}}\right) - \psi_h\right]},$$

in which the variable z_a is the height, where is the lowest computation level in the model, above ground; k is the Kàrman constant; and V_a is the wind speed at the lowest layer. The quantities Z_{0m} and Z_{0t} are the roughness lengths for the momentum and the heat, respectively. Z_{0t} is defined as

$$z_{0t} = \frac{1}{\left(\frac{ku_*}{K_a} + \frac{1}{z_l}\right)},$$

in which Ka is the molecular diffusivity and u^* is the friction velocity.

LSM thermodynamics:
The surface skin temperature is determined applying a single linearized surface energy budget equation representing the combined soil-vegetation surface (Mahrt and Ek, 1984). The surface heat flux is controlled by the usual diffusion equation for soil temperature (T):

$$C(\Theta)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left[K_t(\Theta)\frac{\partial T}{\partial z}\right].$$

The volumetric heat capacity, C(J m^{-3} K^{-1}), and the thermal conductivity, Kt (W m^{-1} K^{-1}) are formulated as the functions of volumetric soil water content,

$$C = \Theta C_{water} + (1-\Theta)C_{soil} + (\Theta_s - \Theta)C_{air},$$

$$K_t(\Theta) = \begin{cases} 420\exp[-(2.7+P_f)], P_f \le 5.1 \\ 0.1744, P_f > 5.1 < 0 \end{cases}$$, and

$$P_f = \log\left[\psi_s\left(\Theta_s/\Theta\right)^b\right],$$

The volumetric heat capacities are C_{water}=4.2*106J m^{-3} K^{-1}, C_{soil}=1.26*106J m^{-3} K^{-1}, and C_{air}=1004 J m^{-3} K^{-1}. Here $\grave{E}_s$ and Ψ_s are maximum soil moisture (porosity) and saturated soil potential(suction), respectively, and both depend on the soil texture.

LSM hydrology:
In the hydrology model, the prognostic equation for the volumetric soil moisture content ($\grave{E}$) is

$$\frac{\partial\Theta}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\partial\Theta}{\partial z}\right) + \frac{\partial K}{\partial z} + F_\Theta,$$

where both the soil water diffusivity D and the hydraulic conductivity K are the functions of $\grave{E}$. And that $F_{\grave{E}}$ represents sources and sinks (i.e. precipitation, evaporation, and runoff) for soil water. The soil water diffusivity D is given by

$$D = K(\Theta)(\partial\psi/\partial\Theta),$$

wherein Ψ is the soil water tension function. K and Ψ are computed by

$$K(\Theta) = K_s(\Theta/\Theta_s)^{2b+3}$$ and

$$\psi(\Theta) = \psi_s/(\Theta/\Theta_s)^b,$$

where b is a curve-fitting parameter; K_s, Ψ_s, and b depend on soil type.

The surface runoff model in the Simple Water Balance (SWB) model was selected to calculate the surface runoff R. The surface runoff R is defined as the excess of precipitation infiltrated not into the soil (R=P_d-I_{max}). The maximum infiltration, I_{max}, is formulated as

$$I_{max} = P_d\frac{D_x[1-\exp(-kdt\delta_i)]}{P_d + D_x[1-\exp(-kdt\delta_i)]},$$

$$D_x = \sum_{i=1}^{4}\Delta Z_i(\Theta_s - \Theta_i)$$, and kdt=kdt$_{ref}$ (K_s/K_{ref}),

in which δ_i is the conversion of current model time step, δt (in terms of seconds) into daily values; K_s is the saturated hydraulic conductivity, which depends on the soil texture.

The total evaporation E is the sum of 1) the direct evaporation from the top shallow soil layer E_{dir}; 2) evaporation of precipitation intercepted by the canopy E_c; and 3) transpiration via canopy and roots E_t. That is $E=E_{dir}+E_c+E_t$.

A simple linear method was adapted for computing the direct evaporation from the ground surface:

$$E_{dir}=\left(1-\sigma_f\right)\beta E_p,\ \beta=\frac{\Theta_1-\Theta_w}{\Theta_{ref}-\Theta_w},$$

where E_p is the potential evaporation, which is calculated by a Penman-based energy balance approach that included a stability-dependent aerodynamic resistance, Θ_{ref}, and Θ_w are the field capacity and wilting point, and δ_f is the green vegetation fraction, which is critical for the partitioning of total evaporation between the bare soil direct evaporation and the canopy transpiration.

The wet canopy evaporation was determined by

$$E_c=\sigma_f E_p\left(\frac{W_c}{S}\right)^n,$$

where W_c is the intercepted canopy water content, S is the maximum canopy capacity. The budget for intercepted canopy water is

$$\frac{\partial W_c}{\partial t}=\sigma_f P-D-E_c,$$

wherein P is the input total precipitation. If W_c exceeds S, the excess precipitation or drip (D) reaches the ground.

The canopy evapotranspiration is determined by

$$E_t=\sigma_f E_p B_c\left[1-\left(\frac{W_c}{S}\right)^n\right],$$

where B_c is a function of canopy resistance and is formulated as:

$$B_c=\frac{1+\dfrac{\Delta}{R_r}}{1+R_c C_h+\dfrac{\Delta}{R_r}},$$

where C_h is the surface exchange coefficient for heat and moisture; Δ depends on the slope of the saturation specific humidity curve; R_r is a function of surface air temperature, surface pressure, and C_h; R_c is the canopy resistance.

Data collection in the project

Differences underlying surface physical characteristic between the oasis and the desert are obvious. The oasis grows very luxuriantly and hardly any desertification occurs in rainy season, but in the dry season the extreme drought and the arid environment could easily destroy the oasis because of weak self-maintenance ability. Hence the summer in a dry year was selected as the simulation period.

At first, a control experiment was designed and the simulation results were compared with observations of HEIFE. Then, a series of sensitive experiments were conducted to study the environmental influence caused by different sizes of oasis. NCEP reanalyzed data was adapted for large scale background fields. In order to compare with HEIFE observation data, August 1991 was selected. The starting condition was as of 20:00 hrs on August 1, 1991. The vertical coordinate followed the terrain. It was divided into 23 layers. The pressure at the top was 100hpa. The central longitude and latitude in the control experiment was 100.43°E and 38.93°N respectively. The horizontal grid distance was 1 km. The grid numbers in north-south direction and in east-west direction were 37 and 41, respectively. The time step of iteration was 3 s and the simulation period was ten days.

In order to avoid the influence of a special weather condition and to analyze the self-development of oasis, a series of sensitive experiments was designed. The central longitude and latitude in sensitive experiments were 101E and 40N respectively. The grid numbers were 45 in the east-west direction and 43 in the north-south direction. The horizontal resolution and the iterative time step were the same as in the control experiment. 1°×1° NCEP reanalyzed data was adapted also as the large scale background field. The ground surface fields and all the weather variable fields were assigned flat. The surface fields such as the elevation field, the soil depth, the soil temperature field, and the soil moisture were set same as the value of the center point where the desert originally was. The center point of oasis was 23, 22. The land use in the simulation region was set to be desert and there were oases of different sizes in the center of desert. The surface albedo was respectively 0.18 and 0.25 in oasis and desert; the roughness length was 15 cm and 1cm, and the moisture available was 0.5 and 0.02 $m^3\ m^{-3}$. The soil moisture of oasis was 0.3 $m^3\ m^{-3}$ higher than other points. The specific humidity at the lowest σ layers was 0.3g

kg^{-1} higher than desert. *U*, *V* wind field, and air temperature field were set to be uniform at the beginning. The simulation period was 7 days. The simulation results of the different oasis between 1 to 9 km, and 0 km oasis were analyzed to investigate the influences of different sizes of the oasis on the surroundings.

Data analysis and results

First, the energy and mass exchange on oasis ground surface was tested using MM5 in simulation to compare the simulation results with observations in IOP of HEIFE field experiment. Then the critical size of oasis was studied.

Comparison of the simulation and the observation

The data used were the records at Zhangye station in the HEIFE database. As the observations were not recorded on 1- 4, 10, and 11 August, the comparison period selected was from 08:00 hrs on 5th August to 20:00 hrs on 9th August 1991.The simulated and observed sensitive heat flux and the latent heat flux in the comparison period agreed well. The observed sensitive and latent heat fluxes were calculated with combination method using the observed data (Hu and Qi, 1993).

Comparison of the sensitive heat flux: The simulation matched well with the observation at Zhangye station. The coefficient of correlation between the simulated ground sensitive heat flux and the observed sensitive heat flux was very high with the coefficient of determination r^2=0.94. The average sensitive heat flux observed was about 35 W m^{-2} while the mean of simulation results was about 49W m^{-2} , the difference being only 14W m^{-2}. This illustrates that the simulated sensitive heat flux could stand for the real condition over Zhangye's oasis.

Comparison of the latent heat flux: The agreement of simulated latent heat flux with the observed one was better than the surface sensitive heat flux. The average of observed latent heat flux was about 75W m^{-2} and the mean of the simulated results was about 78W m^{-2}, the difference being only 3W m^{-2}. This indicated that the simulation could stand for the real condition over Zhangye oasis in this period. The coefficient of correlation between the simulation and the observation was very high with a coefficient of determination r^2=0.936. These results proved that MM5 could be used to simulate the energy and water vapor exchange over the oasis in NWC arid regions.

Influence of the oasis scale on the atmospheric fields over oasis

The oasis affects the local atmospheric field by forming firstly a thermal inner boundary layer in which the energy and the moisture are exchanged between oasis and desert. Then, the exchange of large scale energy and water vapor occurs between the ground surface and the atmosphere in the arid regions. The degree of influence of the oasis on the boundary layer is related greatly with its size.

Horizontal distribution of the temperature and specific humidity near the surface layer: The great mass of net downward energy absorbed by the desert is used to heat local soil and is transferred to atmosphere through the turbulence, while in the oasis about 80% of the absorbed net energy is used for plant transpiration leaving little energy to heat the soil and to be eventually transferred to the atmosphere. The transpiration transfers a large amount of moisture to the local atmosphere. It makes a cold and humid atmosphere in the oasis even though it is surrounded by the drought environment. A cool and wet microclimate is favorable to plant growth (Su et al., 1987b). The ground temperature of oasis is lower than surroundings and the difference is therefore negative. But the amplitude of variation is different. The ground temperature difference between oasis center point and desert is very small in the daytime in the oases of the size of 1 km, 2 km and 3 km; and it is zero nearly at 14:00 hrs. The temperature in oasis is obviously lower than desert, as the oasis size becomes larger than 3 km. The variation in the ground temperature difference between the oasis center with 4 km size and the surrounding desert is unstable. Sometimes, it is positive and sometimes negative. It is 0.1° lower at oasis center than desert surroundings at 14:00 hrs. At the same time, the ground temperature difference between the oasis with 5 km to 9 km scale and the surrounding is 0.5°,0.6°, 1.1°, 1.6° and 1.5°, respectively. That means, the oasis is colder in contrast to the surrounding desert if the oasis scale is larger than 3 km (3 km is not included).

Simulated specific humidity over oasis was larger than the desert. But the variation amplitude of different scale oasis is not the same. The specific humidity of the lowest σ layer over oasis is nearly the same as desert as the oasis scale is 1 km and 2 km, also the difference between them is nearly zero. The specific humidity differences of 4 to 9 km oases were positive. The difference increased with the increase in the scale of the oasis. The difference between 3 km oasis and the surrounding desert was 2 mg kg^{-1}. The differences between the specific humidity of 4 to 9 km oasis and the surrounding desert were 5mg kg^{-1}, 13 mg kg^{-1}, 15 mg kg^{-1}, 16 mg kg^{-1}, 17 mg kg^{-1} and 22 mg kg^{-1}, respectively, indicating clearly that oasis was a wet island in the desert surroundings if its scale was larger than 4 km.

From the above analysis it is clear that an oasis scale of 3 km is a key scale. The cold and wet environment occurs if the oasis size is larger than this value. It should however be noted that even though an oasis of 4 km size has lower temperature and higher humidity than the surrounding, it sometimes may be unstable and may not last for long time.

Analysis of the mesoscale circulation

As a result of great difference in surface thermal characteristics between the oasis and the desert surroundings, there is strong horizontal gradient in the horizontal temperature field at the intersection in the inner boundary layer of oasis and desert. The dry and hot air blocks are transferred to adjacent oasis through the advection and the turbulent diffusion at daytime. The sensitive heat flux is transferred downwards over the oasis. Likewise, the water vapor moves into near desert margins from the oasis. All these constitute the integral image of oasis-desert interaction. So the oasis-desert local thermal circulation is induced by underlying horizontal thermal difference.

The influence on local horizontal wind over 1 km oasis is too week to be shown in the circulation, while, the influence on u, v velocity vector over 9 km oasis cover is strong. In the daytime, horizontal u, v wind field near surface over 9 km oasis is different due to the cooler surface temperature than surroundings, and converse is true at night. While the horizontal wind field background near surface is not affected much in the 1 km oasis even in the daytime.

It is well-know that if the horizontal velocity flow at lower layer is convergent, the vertical wind will be upward; when the lower layer wind flow is divergent the vertical wind is downward. So the vertical wind over the oasis center and the desert located to oasis downstream was examined. The vertical wind speed was positive over the desert adjacent to oasis. That is to say, the vertical air over desert moves upward. The turbulence diffusion is very strong here. There are little differences among very sensitive experiments. It is not so over the oasis. Obviously, vertical wind speeds over 1 to 3 km size oases are almost positive. Local air parcel moves upwards. The turbulence over such oases is also strong. The cold and wet air will be transferred soon into the arid surroundings by the turbulence exchange in the inner boundary layer. The dry and hot air parcels over desert will transport into the oasis soon from its lateral boundary because of mass conservation principle. The cool and humid microclimate over oasis will be destroyed. So, the mechanics of maintaining and developing a stable and conserved oasis is blasted. Such oasis will not keep for a long time, even though development is undertaken. If the scale of oasis reaches 4 km, vertical movement is not steady. It is upwards mostly and downwards sometimes. This construction is also not favorable for oasis maintenance. When the oasis scale is larger than 4 km, the vertical wind movement of the cool and wet air over oasis is almost downward and it forms the local thermal circulation with the upward movement of hot and dry air over adjacent desert. It is helpful to keep the environment ecosystem microclimate over oasis to be moister and cooler than surrounding, which is favorable for maintaining and developing the oasis.

It could be concluded from the above that if the oasis is larger than 4 km, it forms easily the oasis-desert thermal local circulation. That is advantageous for the cool and moist construction over oasis and contributes to maintain stability of oasis.

Profile of the temperature and the humidity

The oasis-desert circulation will affect high layer atmospheric elemental field distribution. An examination of the profile of the temperature and the humidity would therefore be interesting. The air temperature decreases progressively with the height if the oasis scale is smaller than 2 km. The moist air will be carried upward by the turbulence transportation, and then the dry and hot air will compensate from the surroundings. The hot and dry air will ruin the cool and moist microclimate over oasis. The temperatures are constant and do not change with height up to 200 m if the oasis scale is 2 km and 3 km. And, the air temperature decreases progressively with height above 200 m. If the oasis is larger than 4 km, there is a high temperature center at about 200 m to form an "inverse-temperature" layer. The "inverse-temperature" layer forms a stable upper cover over oasis. It could keep the oasis protected because the hot and dry air trespasses into it, to make oasis relatively an isolated independent ecosystem. This could keep the "cold island" intact. Simultaneously, the "inverse-temperature" layer would restrain the development of the turbulence and reduce the evapotranpiration. That is advantageous for the crops growth inside oasis.

The specific humidity over desert decreases gradually with height when the oasis is 1 to 3 km in size. The maximum humidity is at the lowest vertical layer. When the scale of oasis is larger than 4 km, the specific humidity does not decrease gradually with height. Under 200 m height, the humidity decreases gradually, while it increases with height from 200 m to 700 m, and then decreases again above 700 m. The maximum humidity is found at 700 m above the ground surface. So, an "inverse humidity" layer is formed. Because the "inverse-temperature" layer restricts evapotranspiration, the water vapor can not be transferred to higher levels. So, the water vapor is conveyed towards downstream desert just through horizontal flow of the oasis-desert circulation near the surface.

A part of the water vapor reaching the desert could be re-used by sandy vegetation ecosystem in the oasis-desert transition zone. It would benefit the drought tolerant plants growing between oasis and desert located downstream to oasis and favor extension of the oasis. The water vapor re-cycling mechanism not only makes oasis lose less moisture, but also permits the lost water of oasis to be re-utilized by desert system adjacent to oasis. This would ensure higher use efficiency for limited water resources in the oasis, and overcome in some measure the water shortage in NWC. This is one of the main elements for oasis self-maintenance and development (Zhang and Hu, 2001).

Synthesizing the analysis of horizontal and vertical temperature, humidity distribution and mesoscale circulation, it can be concluded that 4 km is a key size for oasis self-maintenance and development.

Statistics of oasis size distribution in NWC

A statistical survey of the oases in NWC indicates that their size mostly ranges between 8 to 46 km. The number of oases smaller than 8 km is zero. This would indicate that oasis of the size of 8 km or below could not exist in the nature. These statistics indirectly support our above conclusion.

Summary and conclusions

Using NCAR nonhydrostatic mesoscale model MM5, the ground surface sensitive and latent heat flux were simulated at Zhangye city from 1 to 11 August 1991. A comparison of simulated data with HEIFE field experiment observations revealed that this model can be used to simulate the surface energy and water vapor cycles on Zhangye oasis. The degree of influence of oasis on the atmospheric fields differed with the size of oasis. The simulation and dynamic analysis of the influence of oasis on atmospheric fields revealed that the oasis-desert thermal circulation is formed only when the oasis scale is larger than 4 km. This oasis-desert thermal circulation would help to maintain the cool and moist microclimate over oasis. Because of the local thermal circulation, the "inverse-temperature" and "inverse-humidity" layers are formed. The evapotranspiration is restrained and it guarantees the stability and conservation of the oasis. These all are advantageous not only for keeping the moisture over the oasis but also for the development of drought tolerant crop species on the fringe of oasis, which would provide possibility for oasis maintenance and development. So, 4 km size is a critical scale of oasis.

There are however some deficiencies in this research. For example, ecological process scheme is not included in this model. The ecological effect can not be embodied. The critical size of oasis is a synthetical index, which is based on geometric, thermal, dynamic, and similar factors. A more powerful proof will be deduced if the ecological processes are also included. It should also be recognized that a long time simulation was not conducted because of the limitation of the computing time. A better quantitative description of oasis would need further research on oasis in arid and semiarid regions of NWC.

Acknowledgements

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Empowering rural communities for better management of desert collective rangelands - from concept to implementation

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Abstract

Sustainable development of pastoral and agro-pastoral systems, dominated by collective and/or tribal ownership of rangelands, is a key issue for the WANA region. These two systems are located in arid areas and are increasingly threatened by desertification process. The policy responses to tackle this complexity have been sectorial and fragmented, 'top-down' type, putting forward technical solutions and neglecting the social context. In response to the frequent failures, methods of 'participatory development'" emerged during the 1970s within international development arena. Adoption of participatory approaches by national governments appears not only partial, but also particularly slow. Recent experiences suggest that integrated and participatory approaches may lead to more efficient resources management and to more effective poverty reduction policies. Local development is the most recent approach to face these challenges. It aims at organizing people on a decentralized basis and at promoting participatory programming which could lead to an effective responsibility sharing by the local people. Donors and governments have not, so far, given a fair chance to decentralization to fulfil its promises of efficient, equitable and sustainable development. In addition, it has often been observed that responsibilities were transferred to local population without the means to carry them out. The collaborative research conducted by ICARDA and IFAD in Southern Tunisia has led to the development of tools and methods adapted to the development of collective desert rangelands based on empowerment of local rural poor communities and using participatory methods. The pilot action showed that participatory natural resources management in such areas can be instrumental in institutionalizing participatory approaches. In both democratic and non-democratic settings, these approaches foster inclusiveness, transparency and accountability of public services and policy-making processes. The tools developed play an essential educational role in changing mindsets of bureaucrats and people and communication patterns.

Introduction

During the past several decades, many development projects have been conducted in the dry environments to reduce poverty, prevent the natural resources from further degradation, and generate local development. Most of the policy responses to the sustainable development challenge of arid and semi-areas, and to rangelands problems in particular, were sectorial and of top-down type. The measures included the following:

- Urgency measures during and after drought to reconstitute flocks, beneficial to large herders (subsidies or credits/head). This policy of crisis management has negative impact on natural resources, favoring overgrazing and land degradation.
- Improving watering facilities. It is a typical example of governments' fragmentary understanding of pastoralist. Watering facilities used to be managed according to customary rules and arrangements between tribes. Government watering facilities are now public and open to all users and thus contribute to open access of rangelands.
- Increasing livestock and natural pastures productivity through techniques developed for

favorable areas (genetic improvement of livestock, disease control, mass vaccination, etc.)
- Improving services and cooperative arrangements

In the 1980s an ambitious program was launched in Algeria and Syria aimed at organizing herders into production cooperatives. In spite of heavy investment and use of a large number of technical procedures, this centrally planned development did not work. However, the lessons learned from these efforts were that in the low rainfall areas (LRA) prevailing land use patterns were not sustainable and the resources base was vanishing rapidly. Both facts threaten the very fragile livelihood of the rural poor. The sustainability of pastoral and agro-pastoral systems is threatened because of the dramatic effects of desertification.

Recent experiences suggest that integrated and participatory approaches may lead to more efficient resource management and to more effective poverty reduction policies. Enhancing local development is the most recent approach to face these challenges. It aims at organizing people on a decentralized basis and to promote participatory programming to make them more responsible for the development of their community. The expertise accumulated over centuries by local population is crucial in defining the strategies to cope with desertification. New technologies integrated with the traditional local knowledge, require careful assessment of their impacts, limits of their application, and possible damage they may cause. In this respect, local communities play a key role. Also combating desertification is a local and site specific issue. Only the local people are in a position to know what can be done that is socially and economically acceptable to them and that will be continued after projects end. Usually, people are more interested in short-term benefits than in saving for the future.

The international community has recognized since a long time that desertification is a major threat for human being. But it is only in 1992 (United Nations Conference on Environment and Development/ UNCED, Rio de Janeiro) that a new, integrated approach, emphasizing action to promote sustainable development at the community level has been supported. In 1996, the Convention to Combat Desertification (CCD) put emphasis on partnership and participation, which became the first international, legally binding instrument that explicitly requires application of the principles of partnership and participation. It urges the parties to ensure that all relevant actors – the population affected by desertification and their associations, NGOs, national governments, donor organizations and research institutions – work together, establish joint priorities, and devise and implement long-term programs. The concepts of participation and community approach need to be defined. Abundant literature has been published on the subject. We suggest the following:

(i) ***Participation***: Restitute to population the right of initiative and the decision making process to define, plan and implement activities and programs related to their future welfare and the management of the resources available in their territories. This definition implies that:
   - External agents and states recognize the population as development actors, as partners and not only as project targets.
   - The action program relies on a good knowledge of the environment that allows a concerted diagnosis taking into consideration the hope, the objectives and the constraints of all stakeholders. Action can be considered participatory only if it is resulting from explicit negotiated compromise between all stakeholders.

   Participatory approaches are often becoming a requirement of donors in recent development projects. Although the notion of participation is widely accepted and is officially included in most of project documents and in Government policies, it is often not successfully implemented.

(ii) ***Community approach***: Many references describe at length the advantages of the community approach. Ngaido et al. (2002) suggest the following principles and highlight the main advantages:
   - Efficiently and rapidly improving the living standards through the mobilization of unused human and material resources;
   - Providing the readiness of social actors, their spirit, their initiatives, their attitudes and their will, to partake in the program preparation and implementation; and
   - Integrating the populations in their country's social, political and economic life.

   The community approach deals with the whole community that is far from being a monolithic block. It is characterized by its flexible, dynamic dimension, adapted to local circumstances, which can be used as a catalyst of development. Moreover, the approach focuses on the initiation of comprehensive development schemes in singled-out communities or villages on the basis of what community members perceived to be their felt needs. These activities are initiated with the presence of specially trained staffs who, by living in the community and working with its members, gain the confidence of the community. They serve as facilitator of thinking and discussion processes and guide members to identify issues and translate into a community development plan. Community approach is mostly suitable and directly relevant in natural resource management projects. However, important principles for its success must be the following:

- Demand-driven, based on needs and priorities defined by the people themselves;
- Socially inclusive, ensuring that all community sub-groups have a voice and benefit from these actions; and
- Creating an enabling policy and institutional environment.

Participatory community approach: ICARDA and IFPRI experience

Problems faced by rural populations living in poor-resource areas cannot be solved by technology alone. They will likely worsen with increasing population demands unless significant policy and institutional changes occur. The Mashreq/Maghreb project, whose activities aimed at fostering crop-livestock production systems integration in low rainfall areas (Fig. 1), applied an innovative community development approach in the late 1990s, which evolved from on-farm demonstrations in the mid 1990s (Haddad and Eltom, 2002; Ngaido et al., 2002) to focus on:

- Fostering integration between different disciplines, actors, etc;
- Stimulating farmer and community participation in steering their own development process;
- Facilitating technology transfer through a participatory technology development;
- Promoting collective action on the basis of a shared consensus; and
- Using gained experiences in different regions to the benefit of target communities.

The M & M project followed integrative approach between natural, biological and social sciences to support the development strategy of the selected communities. This approach started stepwise during the 1st phase of the project (1995-1998) but gained momentum and reached its required level during its 2nd phase (1999-2002). During the latter phase, the project, with a wealth of technologies developed by the NARS during the 1st phase, adopted the community approach in order to foster integrative efforts of the national teams.

The concept of community approach in the Mashreq/Maghreb Project

Community based approaches for natural resource management have been introduced in many countries since the early 1980s. In the West Asian and North African (WANA) region, however, the use of the community approach to transfer technologies was an important institutional innovation that transformed the relationships between farming and herding communities, national agricultural researchers, and other stakeholders. The overall framework of the project is presented in Figure 1. A four-step process was used in all the countries to implement the approach in each of the selected communities (Thomas et al., 2003):
Step 1: Following initial surveys, each country team selected 2 communities that were considered representative of the main production systems and conducted participatory rural appraisal (PRA) or rapid rural appraisal (RRA) surveys to assess the opportunities and constraints of each community.
Step 2: Each team organized a workshop for each community to present the results of the surveys and identified options to address community problems. Technologies that could mitigate some of their production constraints were also presented and discussed. Some of the technologies were dropped during the meeting and never made it to the community negotiated plan because farmers had some prior knowledge of the proposed technologies or they did not fit in their production strategies. Technologies, which were retained for each production system, were included in the negotiated action plan (Fig. 2). The negotiated action plan outlined agreed upon activities and options to be tested at the community level and the responsibilities of each of the parties. This was the forum where other stakeholders, especially government officials, identified the activities that they could support.

Step 3: This step represented the implementation of the negotiated action plan. Each network of researchers worked in implementing their activities but teams met periodically to review the progress achieved. Research activities included 1) policy, institutional, and monitoring surveys; 2) adaptive research for evaluation of the technological options; 3) agro-ecological characterization; 4) community modeling and econometric analysis of the household and community surveys; and 5) adoption and impact studies. In addition to team meetings, networks met in different technical meetings that were also opened to other disciplines to refine their methodologies and share results. The final objective of this step was to identify "best-bet" institutional and policy options and "best-bet" technological options, and develop community land suitability maps. These different outputs served to develop packages of technological, and institutional and policy options that will be replicated in other barley-based or rangeland-based production systems.

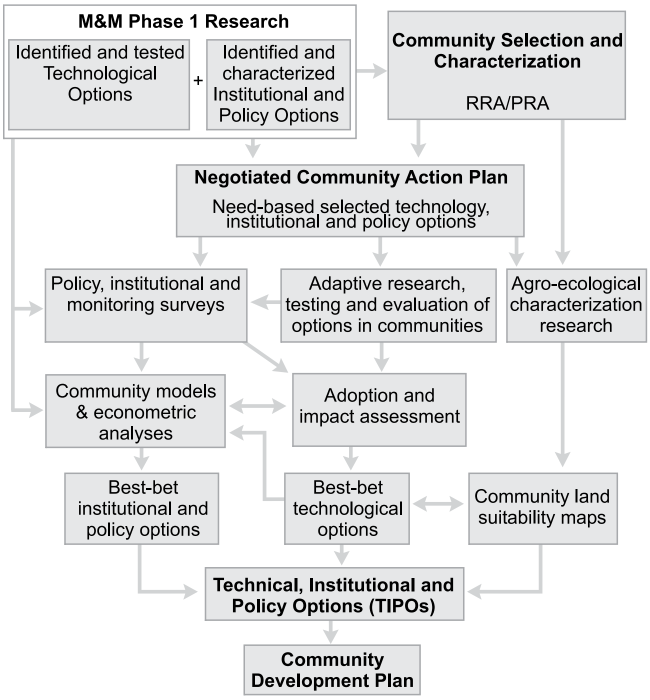

Fig. 1. The Mashreq and Maghreb (M&M) Project community approach.

Step 4: Development of the community development plan based on the results of analyses of all the constraints and opportunities that were identified at the beginning and during the implementation of project activities. The plan included the priorities (education, health, infrastructure, etc.) that were identified and the progress made in addressing these issues to help the communities mobilize funding outlined by the project. These plans would form the basic framework for any future intervention in the community.

Mechanisms for implementing the community approach

Principles considered in the application of the community development approach should not be seen as elements of a standardized recipe, given that communities as social organizations are not the same everywhere though they can present some similarities. In general, following actions were involved:

- Set-up a multi-disciplinary action-research-oriented team;
- Define clearly the community;
- Adopt participatory methods;
- Enroll facilitators instead of conventional extensionists;
- Get community members organized;
- Adopt a holistic approach for community constraints' analysis; and
- Facilitate elaboration of a community development plan.

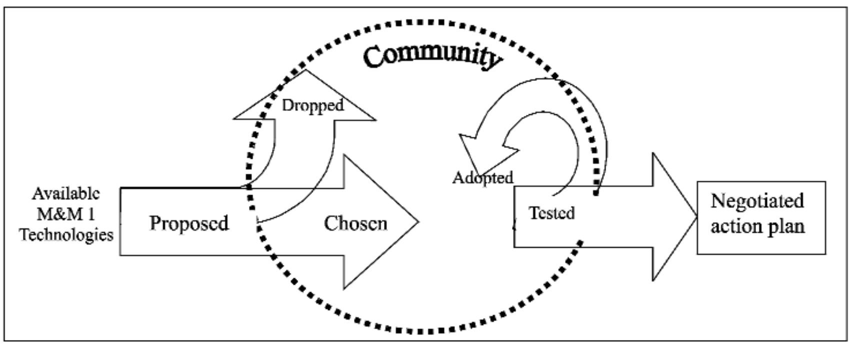

Fig. 2. Technology selection process.

Building multidisciplinary teams: Integrating all these different disciplines and creating multidisciplinary teams were essential requirements for working at the community level. The objective was to develop teams that would understand production niches as well as strategies in order to determine the best technological intervention options. To reach such understanding and to develop partnership among team members, teams convened numerous meetings to discuss the approach and the roles and expectation of each team member. The process was also expected to transform scientists' perceptions of their roles, which go beyond the traditional role of providing improved technological packages and practices to farmers to include community development priorities, the priorities that were identified by the communities but outside the scope of the project.

Defining and identifying communities: In the past, tribal-based organizations were the common feature in all communities of the dry areas of WANA. However, administrative reform policies have transformed traditional tribal systems and introduced new institutions. As a result, the notion of a community differed from country to country. But in the agro-pastoral areas, traditional local institutions have survived and the spirit of community is still there, even though the administrative divisions do not fit with community border. The Mashreq/Maghreb project adopted the following definition (Ngaido et al., 2002):

- Social organization composed of households that are organized into sub-structures;
- Settlement--its territory, and its pastures;
- Socially cohesive unit with its resources;
- A structure with a regulatory body and sets of agreed rules and practices;
- Users of a specific area (space).

Steps for implementing research at the community Level: Four steps were identified and used were problem identification, negotiation with communities, implementation of negotiated action plans, and development of community action plans. The success of these tasks depends on farmers' participation, not only in the testing and evaluation of new technologies, but also in problem identification and research planning. The project was aware of the numerous community priorities and issues that are outside the boundaries of the project and the need to involve all stakeholders, especially government officials and technicians, in those community priorities while facilitating future up-scaling and out-scaling of the approach.

Partner institutions: At the level of each community, each country team created a Community Steering Committee (CSC) composed of selected community members, agricultural/extension agents working in the area, and team members (Fig. 3). The role of the CSC was to facilitate the interaction between community members and researchers and monitor the implementation of the agreed research agenda with the community. The committees were directly involved in the drafting and implementation of the work plans and deliverables. In addition, each community selected a facilitator who was responsible for monitoring the implementation of the negotiated action plan, and organizing visits of team members and community workshops. The facilitator was an important interface between the national steering committee, the community steering committee, and the other stakeholders. The CSC convened meetings to discuss the objectives and implementation of project activities. The interaction and mutual involvement of all stakeholders to the decision-making was critical for gaining the support of local policymakers and administrative institutions.

Difficulties encountered: The approach and methodologies developed within the M&M program were not applied at the same level in all eight countries or in the 16 communities. Many difficulties and constraints slowed the whole process.

Fig. 3. Project informal institutions.

Following are some of the difficulties encountered:
- Centralized decision-making processes in some countries;
- Land tenure and secure ownership differ from countries mainly in the rangeland;
- Different stakeholders may have divergent interests: weakest versus strongest;
- Civil organizations are not yet developed in all countries and or in all regions of a country;
- Community approach is time-consuming (long-time span);
- National teams are not at the same level of progress (shortage of human capacity in some fields);
- In general weak extension services; and
- Low rainfall areas face high risk and uncertainty that make the generation and transfer of technology a very slow process.

From concepts to implementation

Where we stand today

Participation is clearly understood by governments, development agencies, donors, NGOs and population. Three decades ago, when a population was not against a development program, it was considered as its participation in the program. Since early 1970s the concept has evolved gradually to reach the status of self-governance (Fig. 4). But in most of the WANA countries, and except for a few pilot projects, participation is in mid way, between the level of the "population is contributing in kind" and "negotiation".

Adoption of participatory approaches by national governments and its translation into actual implementation is not only partial, but also particularly slow. The modesty of progress achieved in changing government agencies attitudes and practices towards participation over the last thirty years is manifest when contrasted with the impressive sequence of events that have changed the face of the world during the same period, including: the wave of liberal economic reforms of the eighties, the subsequent transition of former socialist countries to a market economy during the nineties, the unsustainable evolution of external debts, the repeated occurrence of major natural and man-made disasters (droughts, famines, epidemics and wars in Africa particularly), the information revolution, fast urbanization, the fall of numerous military and authoritarian regimes, the development of regional economic and political integrated blocks; all of these processes and phenomena culminating in the globalization phenomenon (El Harizi, 2003).

Stakeholders' readiness to implement participatory approach

Main stakeholders interacting with rural community development are international/national donors, NGOs, the population through its formal and informal local institutions, the central and regional government bodies including local and regional councils, political parties, and finally the administration, which is often the implementing agency for rural development programs (Fig.5). The strength and weaknesses of the stakeholders are given in Table 1.

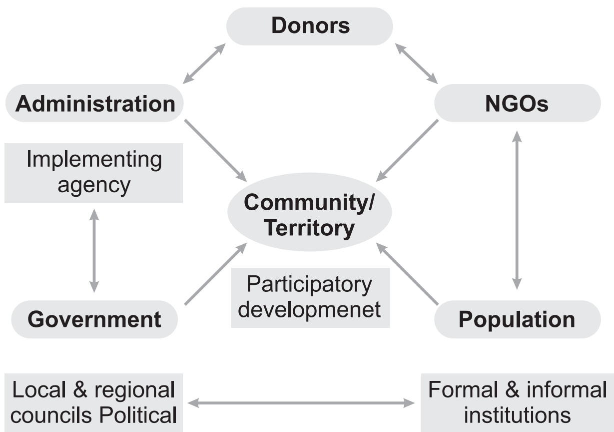

Fig. 5. Main stakeholders involved in rural community development.

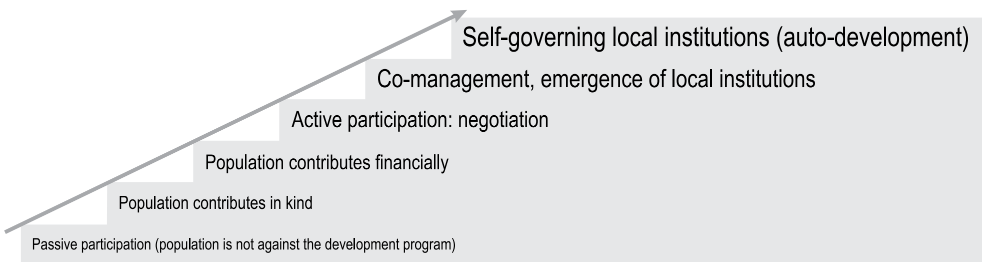

Fig. 4. Different levels of participation.

Table 1. Strength and weaknesses of main stakeholders involved in rural community development

Stakeholders	Strength	Weaknesses
Donors	- Participation is a pre-requisite to the loan agreement - Relatively good experience with participation	- Project duration (too short to fully implement PA) - Project formulation (too much details) - Poor backstopping (needed at the beginning)
NGOs	- Working at proximity of community - Relative autonomy in decision making and in fund management	- Isolated intervention (no strategy for wider dissemination) - Poor interaction with administration (substitute to the administration rather than taking over the administration)
Population	- Good know-how - Reliable partner if organized - Social solidarity	- Assistance "mentality" - Weakness of informal local institutions - Poverty
Government	- Presence and capability to mobilize actors - Capability to rise funds	- Tend to generalize - Centralized decision making - Relation with actors based on consultation and not on dialogue
Administration (development agencies)	- De-concentration - Cumulative technical experience	- Centralized decision making - Heavy and inappropriate procedures for participatory development - Staff not skilled in participatory development - Funds allocated to human capacity building and technical innovation are hardly used

From participation to empowerment: putting ICARDA experience in action with development projects

From participation to empowerment

In order to understand the current emergence of the concept of empowerment, it is useful to sketch out the emergence and adoption patterns of participation. During the seventies, the idea of "participatory development" emerged within international development arena in response to a perceived failure of earlier State-driven development policies to ensure sustainable and equitable distribution of benefits. Starting with very modest objectives of cost sharing between the State and the beneficiaries (financial participation), the idea and methods of participatory development diversified extensively in scope, theoretical foundations, and intensity in the last three decades, building very much on pilot initiatives of NGOs. In the process, new grounds such as policy-making and research were also broken. Today, participatory approaches form part of national development policies in a majority of developing countries.

Nevertheless, it would be an error to view participation as radically departing form previous state-driven approaches. Participatory approaches, in their diversity, have in common that the directly concerned people do not have the initiative and control of the development process. The people, typically designated as beneficiaries or target groups, are expected, urged or encouraged to participate in others' endeavors on the ground that participation gives them some influence on decisions that affect them while improving the overall effectiveness and sustainability of development interventions (El Harizi, 2003).

Participatory methods for NRM management: who is empowered?

Participatory methods for natural resource management (NRM) have often been presented as a solution to NRM issues. Several authors, such as Chambers (1997), note that participatory NRM can be instrumental in institutionalizing participatory approaches. In both democratic and non-democratic settings, these approaches foster inclusiveness, transparency and accountability of public services and policymaking processes. Through the introduction and generalization of participatory programmatic tools, participatory NRM plays an essential educational role in changing bureaucrats and people's mindsets and communication patterns. Experience also shows that higher participation sought through development projects in the absence of representative organizations often provides additional opportunities to rural elites to capture the bulk of NRM expected benefits. Devolution of NRM generally implies that a subset of stakeholders is given exclusive rights of use at the expense of other stakeholders without formal agreement or compensation. Partly because of the weak legal basis of such solutions, it is rarely the case that the really poor get their fair share from these arrangements. Devolution of NRM is carried out in the name of empowering the people through increased access to resources but the question is who is empowered in practice: the rural poor or the elites?

The challenge of equitable and sustainable use of natural resources is not primarily question of technical management, but a matter of governance. This is not to say that management considerations are irrelevant, but that appropriate managerial solutions and their related institutional arrangements must be identified and negotiated under the rules of an appropriate governance structure. A number of conditions should be part of any such governance structure, including:

- A demonstrated political commitment to democratic representation of the local population and to downward public accountability;
- The application of the principle of subsidiary in defining the distribution of discretionary powers between various government levels;
- Secure property rights; and
- A long-term financial support for the development of an adequate local administration capacity.

IFAD and ICARDA working together to empower agro-pastoral communities

Sustainable development of pastoral and agro-pastoral systems, dominated by collective or tribal ownership of rangelands, is a key issue for the WANA. These two systems are located in arid areas with low rainfall and are increasingly threatened by desertification process. Participation and local development concepts are perceived today by many people as promising tools for sustainable development. As defined by Johannesburg Summit (1992), sustainable development includes economic growth and equity, natural resources and environment protection, and social development.
In this environment, participation means the restitution to local population the right to fully and effectively participate in the decision-making process, and in planning and implementing research and development actions. Practically, the governments and “external actors” must recognize that:

- Farmers and pastoralists are partners and not a “target population” of a development project.
- The development action plan is based on a “concerted diagnosis” taking into account constraints, objectives and expectations of all stakeholders.

With the full support of the Tunisian Ministry of Agriculture, and based on former experiences, ICARDA (Mashreq/Maghreb project) and IFAD investigated the “Development of Tools and Methodologies for Collective Rangeland’s Participatory Management”, using new tools based on the concepts briefly described above (Nefzaoui et al., 2003). The IFAD-funded project entitled “Program of agro-pastoral development and promotion of local initiatives at southeast Tunisia” (PRODESUD) was used as a pilot study to develop and validate tools and methodologies at a practical scale. The project covers 4.7 million ha (about one-fifth of the total area of the country) where 10,000 households live and where 90 % of the country’s rangelands exist. The agroecology of the project area is hyper-arid with an average rainfall of 80 mm/year. The project budget was US $ 44 million for 7 year duration. The final expected output of this research is to develop guidelines to implement participatory approach for agro-pastoral areas and to train project staff in the methodologies and tools developed.

For the first time IFAD invested in developing methodologies and tools needed by the project prior to appraisal. On the request of IFAD, the Tunisian M&M team started working after the inception of the project, and the results were used for the appraisal and the formulation of the development project (Fig. 6).

The work consisted of (a) identifying and characterizing agro-pastoral communities of the project area; (b) developing and validating participatory methodology and tools using two pilot communities; (c) developing guidelines to implement participatory approach by the project team and by other IFAD projects; (d) training the project staff on the methodology; and (e) backstopping of the project in its starting phase.

Identification and characterizing agro-pastoral communities of the project area

In agreement with Tunisian authorities, the definition of project target communities was to be done according to the tribal map, which does not exist. Therefore, the first task was the development of the tribal map. For practical reasons, the term of "Social territorial unit (STU)" was used instead of tribe, but both of them have the same meaning. Thus, the research team implemented the following tasks: (a) inventory of agro-pastoral spaces and their users; (b) identification and mapping of Social Territorial Units (STUs/tribes or sub-tribes): 24 communities were identified; (c) survey of all households of the project area: 9000 households were surveyed; (d) typology of production systems in project area: 5 production systems were identified; and (e) selection of 'Pilot communities' to investigate and test and validate participatory tools and methodologies developed within M&M project: two pilot communities were selected, Ouled Chéhida as a representative of the steppe rangeland, and Guermessa as a representative of the mountainous rangeland areas.

Developing and validating participatory methodology and tools

Three paradigms were formulated: (1) Interdependence between productivity improvement and sustainable natural resources management. (2)The concerted management of a 'collective rangeland' is possible only when the space users are known and fully involved in decision making. (3) Modalities for use are not to be confounded with management responsibilities.

The methodology included 5 phases (Fig. 7): (1) Characterization of the community (knowledge/learning phase); (2) Participatory diagnosis and planning; (3) Participatory programming; (4) Organization of the population; and (5) Implementation of community development plan and monitoring and evaluation. Theses phases are closely related as shown in Figure 7. Compared to the methodology developed within M&M, the main innovations were: (1) The weight given to the characterization of the community, which serves to create a data base used both for the following phases (diagnosis, planning, programming), but also for implementation of the community development plan, including the monitoring and evaluation and the expected contracts (MOU) between the project management unit and the population represented by a 'body' established within the participatory process. (2) The team implementing the process is composed of project staff, multidisciplinary team from all departments, and professional facilitators.

Phase 1: This phase relates to the improved knowledge of the community and included the following tasks: meeting with population and mapping their space and its use, (ii) mapping of the Pilot STU using GPS, (iii) survey of all community households, (iv) physical and social mapping of the community, (v) elaboration of the 'community

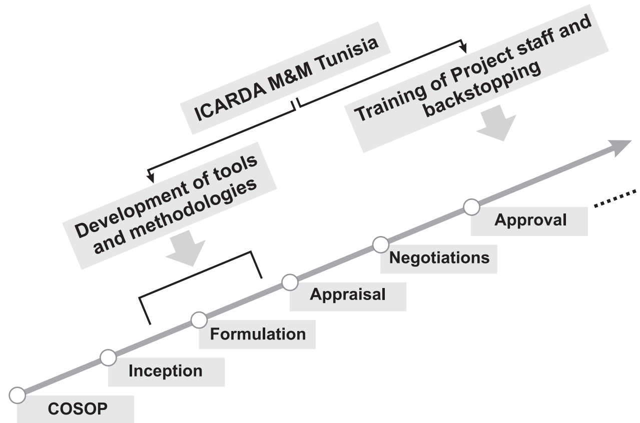

Fig. 6. IFAD procedures for formulation of development projects and Mashreq/Maghreb Project involvement for development of tools and methodologies and backstopping.

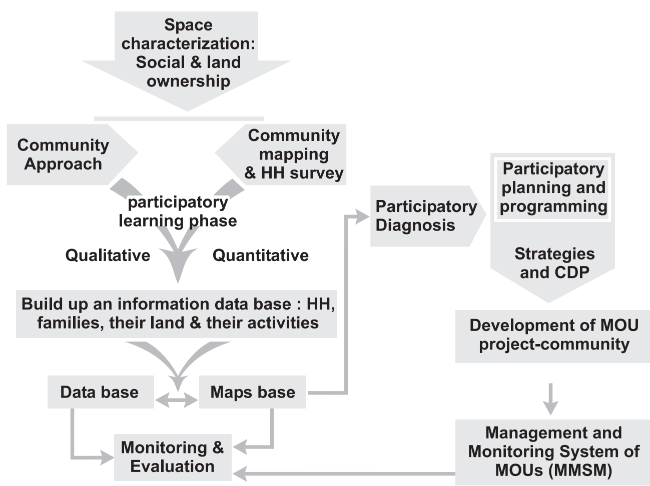

Fig. 7. Design of the community participatory approach applied in PRODESUD, Tunisia.

knowledge book', and (vi) restitution and validation of 'community knowledge book' by the population (Fig. 8).

The lessons learned from this phase are: (1) for natural resources management and participatory development, identification of interlocutors/ representatives having the right of use and decision power on the territory, is an important step; (2) the concept of socio-territorial unit fits with these criteria; (3) the participatory knowledge/ learning phase are important to establish cooperation and trust with the population, to learn about the environment and the problems prior to the diagnosis exercise; and (4) the development of learning tools is a good investment for the future because these tools are used for diagnosis, planning, and monitoring and evaluation.

Phase 2: The process concerns "Participatory Diagnosis and Planning". Participatory diagnosis and planning followed the following sequence: spontaneous diagnosis, problem classification, restitution/validation of problems, introduction of 'local institution' issue; alternative solutions analysis, solutions priority setting, restitution and validation, development of 'long term vision' map, and selection of local institution type. These sequences are inter-related, with a logical evolutionary process. It is a team work requiring patience and permanent adaptation of tools, for which skills and long experience are needed and where facilitators and multidisciplinary teams are acting together (Fig. 8).

The lessons learned from the implementation of the second phase are: (1) restitution of knowledge acquired is an important step prior to the diagnosis; (2) resource persons play an important role in analyzing problems and searching solutions; (2) importance of ' long term vision' of space management: appropriation by the users (population) of a long term plan; (3) the exercise (test at pilot level) raises the problem of scale: from pilot scale to the total project area; (4) planning process is time consuming, but difficult to avoid (necessary maturation of sequences); and (5) development plan is different from the plan of action: development plan is to develop a strategy for more or less long period while the plan of action (annual, pluriannual) is a precise tool to mobilize finances and implementation facilities (means). Another lesson learned was that one should not underestimate the ability of populations to identify appropriate technical solutions, to emerge with good agreements identified internally (issue of property rights and land use issues), to negotiate grazing arrangements with neighbours, and to promote income generating activities for women and young for whom rangelands are not perceived as important.

Phase 3: The primary community development plan includes all "the dreams" of the community. Some of these activities are not realistic, and need to be discussed by the multidisciplinary team to assess their technical and economic feasibility. Following the feasibility studies, and the negotiation with the community, some activities are

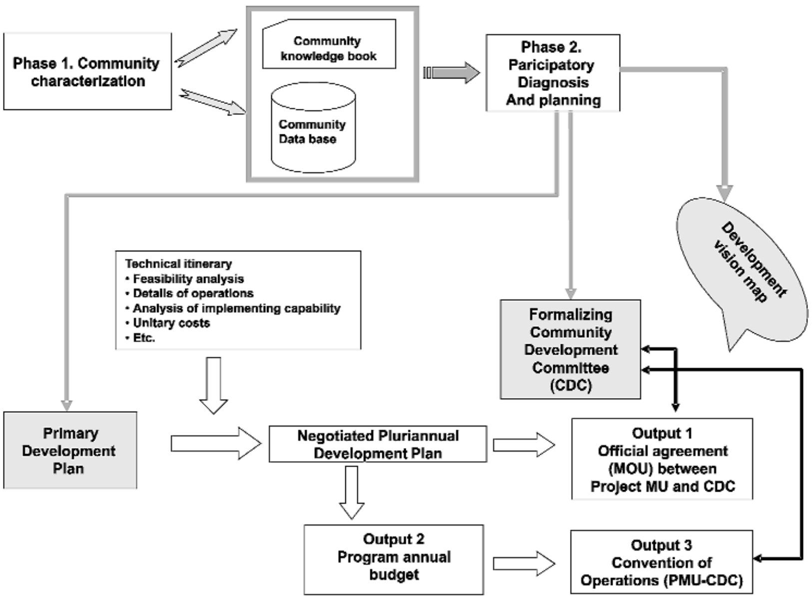

Fig. 8. Main phases of the community participatory approach applied in PRODESUD, Tunisia.

dropped and the remaining ones constitute the multiannual development plan of the community together with the development vision map drawn by the community members. The community pluri-annual plan is a set of tables indicating the activities to be implemented, their location, their costs, the source of funding, and the duties of the project and the population. It will represent the appendix of the MOU to be signed by the project management unit, the representatives of the community, and the Governor. This official document gives population the power to monitor the implementation and to become the executing agency when they are requested. The other important document produced out of the pluri-annual development plan is the program annual budget, which is officially signed by project management, the population representative and regional authorities.

Phase 4: This phase involves organization of the population and promotion of local institutions. There is no precise moment to introduce and discuss with the population the issue of local institution that will represent the population, because opportunities and conditions change from a community to another, and especially on the social composition of the community. The exercise starts always by screening current institutions acting at the community level, their mandates and attributes to end up by identifying the need to establish democratically elected committee that will be the representative of the community. As soon as the population agrees on the type of institution to be build up and its members, an official request is submitted to the Governorate by the population to have clearance for a ‘development association’, named GDA (Groupement de Développement Agricole). Immediately after the association is officially recognized, it can start working with development project and to raise funds for the benefit of the community from other sources.

Examples of the impact of the approach in PRODESUD pilot experience

Budget allocation: The project total budget was allocated in two main components. The first (55 % of the total) was dedicated to general infrastructure and capacity building of the whole region, and the second (45 %) to the local development of the communities. Concerning the first component, the activities to be implemented were negotiated with decision makers (Governor, delegates, *Omdas*) and technical departments, while the budget of the second component was determined through community development plan and was under the control of the elected body, and indirectly the end users, representative of the community. This is obviously innovative, because the population through the participatory process will determine the activities to be implemented, the amount to be spent, the location, the beneficiaries, and the executing agent. It would also be monitoring and endorse the work implemented. The power given to the community is a part of the MOU signed between the community and the Project management unit. Besides, small businesses are currently emerging from the community, since they have the priority to implement some of the activities (soil and water conservation, planting, nurseries, etc.) within their community. The president of the *Groupement de Développement Agricole* (GDA) is acting equal to the project director, and approves and co-signs with him any deal/bargain related to their community.

Local institutions: In the three years since the project started, the community development plans of 17 communities out of a total of 24 have been developed, and their local institutions formalized. The type of local institution chosen, in accordance with the existing laws, is the *Groupement de Développement Agricole/GDA* (agricultural development council). The GDA is composed of 3 or 6 members elected during the annual general assembly by the population. Each year the third of the council is replaced, in order to renew all the members within 3 years. The GDA is in-charge of all matters related to the community. The GDAs have their office and access to modern communication technologies, and some of them, as those in Guermessa and Ouled Chéhida, are developing linkage with several other stakeholders, NGOs and other donors. Four GDAs have already earned US $ 50,000 grants from GEF/UNDP for their capacity building and to implement some activities related to environment conservation and conserving rangelands. Guermassa is already linked to Karianet and is in process of developing its own website.

Conclusions

The community approach is bringing hope for achieving sustainable development as it empowers communities, provides tools for addressing household and community livelihood strategies, and promotes the coordination of investment efforts by different stakeholders. A substantial amount of knowledge has been accumulated from different communities in the region that will assist in guiding future research and development efforts. The coordinated regional approach of the Mashreq/Maghreb project has facilitated exchange of knowledge and experiences between national teams. Individual countries have taken the lead in the development of specific methodologies, technologies or institutional options that have then been rapidly transferred to the other national teams in the project.

The impacts of the project and ICARDA collaboration with IFPRI and IFAD have been outstanding particularly in the areas mentioned below:

1. Institutionalizing this type of research at the national agricultural research system (NARS) level (up-scaling and out-scaling): the project has contributed in expansion of this type of research among NARS. Some of the countries have initiated a pilot phase for institutionalizing the community approach. For example, Algeria is using the approach as the framework within its land reclamation program and in its National Program for Agricultural Development (PNDA); in Jordan, the community approach is being integrated into the government agricultural strategies for the dry areas; in Tunisia, the community approach is being used for the development of the IFAD rangeland project in southern Tunisia; and in Morocco, the process of decentralization and the recognition of communities' rights over their resources provide opportunities for mainstreaming the approach in the dry areas.
2. Contributing in developing integrated development framework for the development of the dry areas: the community approach and its different components contributed in changing the paradigm of research and development in the dry areas.
3. Getting policy makers at the local and national level to realize that policy, technical, and institutional options are not and cannot be dissociated from each other if successful rural development is to be achieved.
4. Networking and regional integration: The project served as a bridge between communities, government services and NGOs to promote the development of the selected communities. National teams worked with their communities to develop proposals and get funding for priority actions. The linkages with new partners provided an important social capital that facilitated the implementation of the negotiated action plans and the elaboration of community development plans.

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The role of urban and rural women in sustainable energy development in Iran

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Abstract

Sustainable social development is achieved only when all the society members, male and female, actively participate in development programs. Iranian women, both urban and rural, play a significant role in their own communities. The results of this investigation show that in urban communities the women are involved with all the activities of raising children, house keeping, food production and food processing. In rural communities their duties are even more; they are involved in agricultural activities as well as the making handicraft products. Despite the lack of statistics, it is clear that the role of women in social development in Iran can not be ignored. Therefore, to achieve a sustainable social development for the coming generations a fundamental investment in the well being of women in Iran is highly recommended.

Introduction

Countries involved in World War II put an excessive pressure on their natural resources to achieve a quick economic development after the War was over. This resulted in faster destruction of environmental resources than ever before. Having realized this, more attention is now being paid to environmental conservation in the development programs in both developed and developing countries. It is believed that the sustainability of natural resources is the basis of sustainable human development.

Sustainable development is defined as "providing the requirements and well being of the society without damaging the environmental resources". The conventional energy resources are finite and it is not quite known how long the fossil fuel – the most available and cheapest source of energy– will last. On the other hand over consumption of fossil energy has caused numerous world-wide environmental problems. The best way to conserve fossil energy resources is to limit its consumption and make the most efficient use of currently consumed amount.

Women play a key role in reducing losses of energy resources in both urban and rural areas. The following are some of the ways to save energy by women:

Urban women

1. Saving energy in heating homes through better insulation.
2. More efficient use of cooking energy by using proper ovens.
3. Using sun energy directly and by indirect methods such as solar batteries.

Rural women

One the most environmental friendly fuel sources in rural communities is biogas which is produced from most agricultural wastes through fermentation process. This source of energy could be used for cooking, light and for operating engines. The other energy source in rural communities is animal residues which are used for cooking and warming the houses during winter.

Nomad women

Firewood and bushes are the main energy source among migrating nomads in Iran. *Astragalus* bushes, forest and oak trees are most popular source of firewood. These sources are mainly used for cooking, making dairy products, warming the tents and for light. If there is not enough firewood available, animal residues are used for above purposes. In some cases, bushes and firewood are burnt to frighten wild animals (Fig 1).

Fig. 1. The role of nomad women in housekeeping.

Kinds of fuel used by rural women

Low income people in rural areas and nomad communities mostly use animal residues as fuel energy source. These residues are gathered by women and children. In most of the cases this type of fuel has been substituted by fossil fuels in Iran. However, it is expensive and difficult to carry especially by nomads. The low income villagers and nomads mostly use Kerosene as the main source of fuel, which produces a lot of air pollution. It is important to think about the new sources of energy to substitute for Kerosene. If the government could help to produce biogas from animal and crop residues, there will be better quality manure returned to agricultural lands and less number of bushes will be destroyed by the ranchers.

Because of high prices for crude oil, most of the countries in the world are exploring other sources of energy. Fortunately the Iranian government has invested enough money to develop the new sources of energy like atomic, sun and geothermal, biogas and hydraulic energy. There is a need to make use of the international knowledge and experience in more efficient use of energy from both traditional and new energy sources. Investment should be made in research.

Enhancing energy conservation practices of women

The women's role in conserving the energy of any type both in house hold and economical activities is very important. There is a need to study and better understand women's needs in rural and urban communities. There are different ways to involve the women in energy conservation and development projects more efficiently. These include establishing technical information sites to provide with information and educational programs both in rural and urban areas and educate people (especially women) to use the available energy more efficiently. Use of multimedia is effective in educating people and giving them enough information about the significance of healthy environment for a healthy life.

Enhancing the role of women in conservation of natural resources

The Iranian women in both rural and urban areas play a significant role in social and economical development of the country. Their education level and social activities as well as household duties make their role even more significant in energy development projects. So their well-being must be in the agenda of government policies.

Government should establish an information data bank about their problems and needs, invest in upgrading the level of their education, provide for their basic living requirements to save natural resources (especially in rural areas), investigate and understand their indigenous knowledge in range management and energy conservation, promote rural cooperatives and enable more women leaders to contribute in them, provide economical resources for women activities, provide equal job opportunities for women in development programs at country levels and finally develop infrastructures to promote all aspects of their social and cultural life.

The role of indigenous range-user organizations in range improvement activities in arid and semi-arid rangelands of Iran

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Abstract

Within the last decades hundreds of range improvement projects have been developed in Iran solely based on technical principles. However, the evidence shows that there has been no co-operation between the range users and governmental organizations on range conservation, improvement and utilization. The goal of this study was to evaluate the indigenous range utilization cooperatives, their role and capability in range improvement programs, and the possibility of getting them involved in the range improvement projects. To achieve these goals a socio-economic study was carried out. Two separate questionnaires were designed, one for the ranchers and the other for the government agents. A few old and experienced ranchers were interviewed to explain why they did not actively participate in range improvement projects sponsored by the government. The possibility of combining modern techniques with the traditional techniques to improve rangelands was assessed.

Introduction

Rangelands play an important role in Iran's economy because of their influence on soil conservation, water cycle in the nature, and forage production for livestock and wild life. The economic life of a significant section of society, comprising of nomads and ranchers, depends on rangelands (Moshiri, 1995). But these people have been utilizing this resource in their own conventional systems, while the range experts are trying to promote new methods of rangeland utilization based or the latest scientific techniques developed in Iran and abroad (Ansari, 2000). Because of a lack of systematic relationship between range users and the governmental organizations, the range improvement projects in Iran have not been fully successful. Existing evidence and past experience suggest that an integrated approach, considering all aspects of social, economic and technical issues, is necessary in successful implementation of range improvement projects.

Materials and methods

To investigate the role of indigenous range utilization systems, this experiment was conducted in the semi-arid upland ranges of Changlova in Kohkilouyeh province of Iran (Nourmohammadi, 1991). There are about 150 ranchers living in this site; of these 130 are nomads. After preliminary study about the social and cultural characteristics of ranchers, special questionnaires were designed and sample groups were interviewed to fill out the questionnaires. All the qualitative data collected during the survey were converted to quantitative form and the frequency and percentage for each item were computed. The correlation of livestock number owned by ranchers and the level of their cooperation with responsible government organizations in range management and improvement projects was determined. The number of livestock was also correlated with other attributes.

Results and discussions

The number of ranchers utilizing the upland rangelands of Changlova in Kohkilouyeh province in last several years is presented in Table 1. Majority of the ranchers were utilizing this range from the period before the land reform occurred. One-third of the total surveyed ranchers started range utilization during Islamic revolution and a small proportion (13%) started the use after Islamic revolution.

Table 1. The period and number of the ranchers utilizing Changlova rangelands

Period when range utilization started	Frequency (no. of ranchers)	Percent
Before land reform (1963)	80	61.5
During Islamic revolution (1963-1979)	33	25.4
After Islamic revolution (1979)	17	13.1

The land ownership is public in this site and all the members of the tribe or organization use the land equally. The data regarding the duration for which the rangeland had been utilized and the size of the dryland holding of the ranchers is presented in Table 2. Of the total 130 ranchers surveyed, more than half had been using the land for more than 36 years while the rest used it for less than 36 years. The size holding of these two classes of ranchers was compared by χ^2 test. The number of ranchers with 4 ha or less land area was statistically not different between the old and new users category. So was the case for land holdings of 10 to 15 ha. However, the number of ranchers having 5 to 9 ha land holding was significantly higher in the old user category than the new user category (Table 2).

Table 2. The relationship between the period of range utilization and the size of dryland holding of the ranchers used for grazing in Changlova rangelands

	Period of utilization of rangeland (years)			
Size of dryland holding of ranchers	**More than**	**Less than**	**Total**	χ^2
(ha)	**36**	**36**		
0-4	42	32	74	ns
5-9	30	15	45	10.58
10-15	8	3	11	ns
Total	80	50	130	

Table 3. The relationship between livestock number and the size of dryland holding owned by the ranchers

	Number of livestock			
Area of dryland (ha)	**0-100**	**more than 100**	**Total**	χ^2
0-4	68	4	74	18.5
5-9	43	3	46	ns
10-15	6	6	12	ns
Total	117	13	130	

The data on the number of ranchers having different numbers of livestock heads and land holdings of different sizes are shown in Table 3. The majority (90%) of the ranchers had 100 or less number of animals. The number of ranchers having less than 4 ha land and less than 100 heads of livestock was significantly higher than the number of ranchers with same land area but more than 100 heads of livestock. There was no significant difference in the number of ranchers having less or more than 100 livestock heads when their land holding was 10 to 15 ha.

The governmental organizations involved in rangeland utilization and improvement have the responsibility to develop range improvement projects and supervise the ranchers in applying the recommended techniques while utilizing the range. On the other hand, the traditional range user organizations, comprising ranchers and nomads, follow their own techniques and regulations in rangeland utilization. Each one of these indigenous organizations is headed by a most experienced rancher who decides how and when the range site should be used for grazing.

In response to the question "did you co-operate with governmental organizations in what they have done for rangelands" nearly one-third (38%) answered in negative. In response to the question "why you did not co-operate” again nearly one-third (32.7%) said that they were not asked as to what they did. Some 38.7% said that they did not believe in the activities promoted by the government for rangeland use. The result of the survey, therefore, indicates that the projects proposed by government can not be successful, unless the ranches have enough confidence in what is being proposed and they are involved in the project right from the beginning. There was a negative correlation between the years of range utilization and the co-operation with government organizations. This means that

Table 4. Ranchers' conditions for co-operation with government projects in rangeland improvement

Conditions	Frequency	Percent
Leave the management of the rangelands totally to ranchers	34	36
Government should provide financial support to ranchers	57	44
Government should give long-term and low interest loans	37	28
The borders of range site should be clear	59	45
The range site should be fully protected against other ranchers and nomads	41	31
The old conventional rangeland utilization systems should be applied again	9	7

more experienced ranchers have never been consulted when a range improvement project is prepared by government organizations.

In another question ranchers were asked to state their conditions under which they could cooperate with the government-sponsored projects. The result is presented in Table 4. The data in Table 4 indicate that the rangelands are freely utilized by the ranchers and they expect that the government should do all the investment for any range improvement. The conditions by ranchers for their co-operation with government could be classified in two categories. First the financial requirements (loans and free financial helps) and second the social ones (clear boarder lines of the range site and its security). The government authorities always blame the ranchers for any rangeland destruction because of their over grazing and utilization of bushes as fire wood.

One the most important reasons for lack of success of the government projects is that social and cultural characteristics of ranchers are not taken into account while developing the projects. The other reason is that their experience and indigenous knowledge is not paid enough attention. In response to the question as to 'how the rangeland conditions could be improved' nearly 70% respondent said it could be done by making "rancher's cooperatives".

The results of this study shows that ranchers are not interested in getting directly involved with range management and utilization in the government-sponsored project. Their participation can however be enlisted by getting them involved in the project right from planning stage and by paying due attention to their valuable experience while deciding on the improved methods to be implemented in the range management projects. This combination of indigenous knowledge and new scientific methods should be widely promoted among the youngsters through an over all educational program.

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The quantitative relationship between urbanization and water resources utilization in the Hexi Corridor

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Abstract

Based on the statistical data from the year 1985 to 2003, we analyzed the quantitative relationship between urbanization and total water utilization, water utilization benefits, and per capita water utilization in 5 districts and 3 inland river basins in the Hexi Corridor. A relationship model between them was constructed. The relationship between urbanization and total water utilization in the Hexi Corridor was logarithmic. If this condition continues, rapid urbanization in the Hexi Corridor will face higher water stress. So the development mode of water resources and urbanization should be adjusted, and the fresh water withdrawal should gradually be decreased. The relationship between urbanization and water utilization benefits was linear and positive. So the Hexi Corridor should accelerate the process of urbanization and industrialization to obtain higher water utilization benefits. The relationship between urbanization and per capita water utilization is complex, but it obviously is related to the total quantity of water resources available. Water resource scarcity obviously restricted the process of urbanization in the Hexi Corridor; the water resource constraint was more intensive in the eastern part, where resources are the scarcest. The process of urbanization is faster in the middle region than in the eastern part. However, the middle region consumed much more water resources. The western region had the highest urbanization level and water utilization benefits, but its per capita water utilization was also the highest. Therefore, Hexi Corridor should construct an intensive water resource utilization system to lessen the water resource constraint on the process of urbanization. This is crucial for implementing the strategy of urbanization and achieving the 'great development' in west China.

Introduction

The Hexi Corridor lies in the northwest of Gansu Province and to the west of the Yellow River in China. It is a long corridor between Qilian and Aerjin Mountains in the south, Mazong, Heli and Longshou Mountains in the north, Wushaoling Mountain in the east, and Yumenguan in the west. Distance from north to south is 40-100 km and from east to west is about 1120 km. Badain Jaran Desert and Tengger Desert lie in its northeast. It has 5 districts (Wuwei, Jinchang, Zhangye, Jiayuguan, and Jiuquan cities) with a total area of 27.6×10^4 km^2, which is nearly 60.4% of the whole Gansu Province. It has 3 big river systems (Shiyanghe, Heihe, and Shulehe rivers) flowing from east to west. It is one of the key regions of the great development of west China, and is an important part of the Silk Road and the New Asia-European Railway.

The average annual total water resources in the area are about 93.99×10^8 m^3. The surface water resources are 87.57×10^8 m^3, groundwater 26.91×10^8 m^3 and the renewable water 28.32×10^8 m^3. The total available water resources are 80.31×10^8 m^3 (Fang et al., 2004). In 2003, the actual water utilization was 82.17×10^8 m^3; thus the utilization ratio of available water resources reached up to 102%. The utilization ratio of water resources in the Shiyanghe, Heihe and Shulehe river basins reached up to 154%, 112% and 76.4% respectively, much above the critical threshold of 40% (Xie, 2004). Therefore, a series of eco-environmental and socio-economic problems have been caused in the Hexi Corridor (Wang, 2002). As the strategies of urbanization and great development of west China are further carried out, the urbanization of the Hexi Corridor will accelerate (Fang and Li, 2004) and the water resource constraint on social and economic development will get accentuated (Chen and Hao, 2005). It is therefore important to analyze the relationship between urbanization and water resources utilization, so as to accelerate the process of urbanization and industrialization in harmony with the well-being of the society in the Hexi Corridor.

Using data from ‘Gansu Water Resources Communique and Water Conservancy Annals’ in the five cities in the past years, and the socio-economic data from 1985 to 2003 from the statistical yearbooks of each city, we investigated the relationship between water resources use and urbanization. For the ease in data collection we took the 5 cities as the basic study unit. Jingchang and Wuwei cities lie in the east of the Hexi Corridor and 90.4% of the area of these two cities belongs to the Shiyanghe River basin and the rest to the Yellow River basin. The Shiyanghe River basin has an area of 3.87×10^4 km^2 , essentially all in the Jingchang and Wuwei cities, and its total water resources are 17.35×10^8 m^3 (82.3% of the two cities). Therefore, these two cities were selected to reflect the situations of the Shiyanghe River basin and the eastern part of the Hexi Corridor. Zhangye city lies in the middle of the Hexi Corridor and is the main part of the Heihe River basin. The development and utilization intensity of water and land resources in Zhangye city is the biggest in the whole river basin (Zhang et al., 2004). Water utilization for crop production and domestic use in this city accounts for more than 88% of the total water resources of the Heihe River basin (Bao, 2004). Therefore, we took Zhangye city to reflect the situations of the Heihe River basin and the middle part of the Hexi Corridor. Jiayuguan and Jiuquan cities lie in the west of the Hexi Corridor and most of their area (88.9%) falls within the Shulehe River basin, which has a total area of 16.998×10^4 km^2. Therefore, we took these two cities to reflect the situations of the Shulehe River basin and the western part of the Hexi Corridor.

Quantitative relationship between urbanization level and total water utilization

Changes in urbanization and total water use in the five cities:

The total population in the Hexi Corridor in 2003 was 479.79×10^4. It was 1.26 times that of the population in 1985 and the annual average growth rate was 12.9‰. The total population in Wuwei, Jinchang, Zhangye, Jiayuguan and Jiuquan cities was 193.02×10^4, 46.03×10^4, 126.81×10^4, 17.31×10^4 and 96.62×10^4, respectively, and the annual average growth rate was 12.5‰, 16.0‰, 10.6‰, 29.9‰ and 13.4‰.The urbanization level (nonagricultural population / total population) in the Hexi Corridor was 27.24%, which was 8.99% higher than that in 1985. The urbanization level in Wuwei, Jinchang, Zhangye, Jiayuguan and Jiuquan cities was 15.41%, 47.69%, 23.67%, 87.64% and 34.98%, respectively. With the rapid growth of population and urbanization, the total water utilization in the Hexi Corridor increased to 82.17×10^8 m^3 in 2003 from 66.47×10^8 m^3 in 1985. The annual average growth rate was 1.2%. The level of urbanization in all the five cities rose slowly except in Zhangye city after 2000. The water utilization curves in the 5 cities are similar (Fig. 1). Comparatively, total water utilization in Zhangye city increased faster, and total water utilization in Wuwei City increased fast at the beginning and then dropped off (Fig.1).

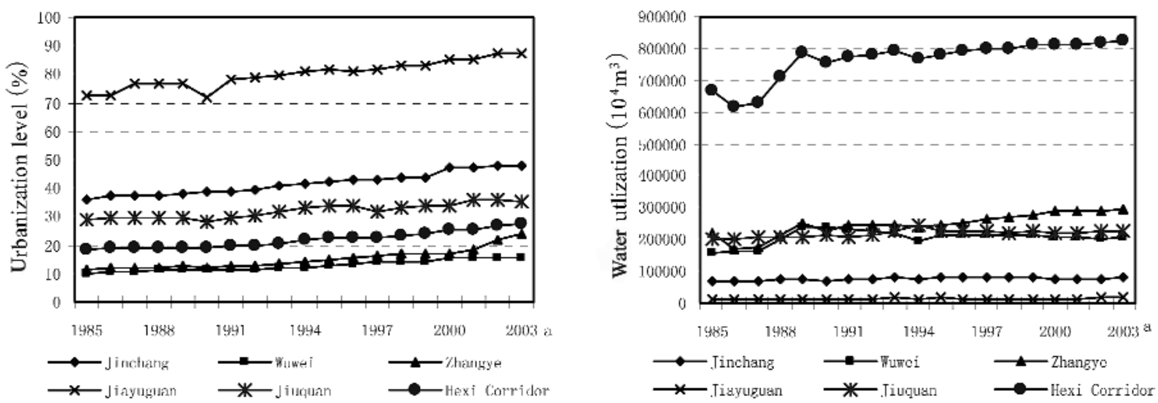

Fig. 1. Changes in urbanization and total water utilization from 1985 to 2003 in the Hexi Corridor.

Model describing relationship between urbanization level and total water utilization:

Many studies in China and aboard in the past shave investigated the relationship between urbanization level and economic development. The relationship between total water utilization and economic development has also been investigated. For example, by analyzing statistics of 157 counties and districts in the world in 1977, Zhou (1995) found that the relationship between urbanization and economic development could be best expressed by a logarithmic equation:

$$Y=c+d\ln Z \quad (1)$$

where Y is urbanization level (%); Z is per capital GDP (Yuan); and c and d are derived parameters of the regression equation.

Based on the historical data of GDP and water utilization in China, Song et al. (2004) found that the relationship between total water utilization and economic development could be expressed by a power function as follows:

$$X=gZf \quad (2)$$

where X is total water utilization (104 m3), Z is per capital GDP (Yuan), g and f are derived parameters of the regression equation.

From the above two equations, the economic variable (Z) can be removed to obtain a logarithmic relationship between urbanization level and total water utilization as expressed below:

$$Y=a+b\ln X \quad (3)$$

where Y is urbanization level (%); X is total water utilization (10^4 m^3); a and b are derived parameters of the regression equation.

Based on the above three models and historical data of urbanization level and total water utilization (Fig. 1) and per capita GDP (Fig. 2) in the 5 cities in the Hexi Corridor, the quantitative relationship between urbanization level and economic development (Table 1), between total water utilization and economic development (Table 2), and between urbanization level and total water utilization (Table 3) was obtained..

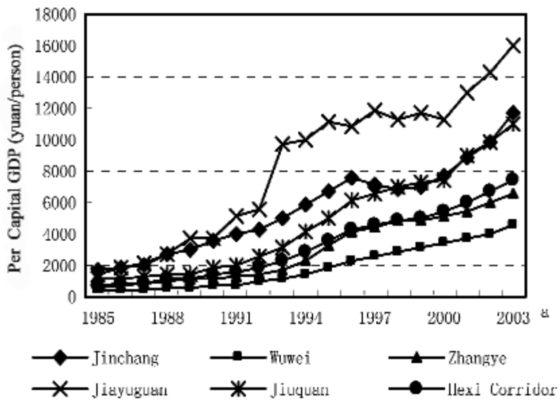

Fig. 2. Changes in per capita GDP in the Hexi Corridor.

The relationship between urbanization level and economic development:

There was strong correlation between urbanization level and economic development in the Hexi Corridor (Table 1). The correlation coefficients are all higher than 0.873. The relationship was logarithmic and statistically significant. Sequence of significance of relationship between urbanization level and economic development in the 5 cities and the whole Hexi Corridor was as follows: Wuwei > Hexi Corridor > Jiuquan > Jinchang > Jiayuguan > Zhangye. It indicates that with the economic development, urbanization level rises more in Wuwei city than in the other cities. The sequence of growth in urbanization level (seen from the slopes of the logarithmic equations in Table 1) in the 5 cities and the whole Hexi Corridor was as follows: Jiayuguan > Zhangye> Hexi Corridor >Jiuquan > Wuwei >Jinchang. It indicates that the economic development has the biggest influence on urbanization in Jiayuguan and the smallest in Jinchang city.

Table 1. The model showing relationship between urbanization level and economic development in the Hexi Corridor

Name	Relationship model	R	Sig.
Jinchang City	Y=0.6164 ln$X$- 10.664	0.936	0.000
Wuwei City	Y=2.122 ln$X$- 2.66	0.978	0.000
Zhangye City	Y=3.638 ln$X$- 13.02	0.873	0.000
Jiayuguan City	Y=5.650 ln$X$+ 30.29	0.905	0.000
Jiuquan City	Y=2.941 ln$X$+ 7.86	0.939	0.000
Hexi Corridor	Y=3.539 ln$X$- 5.91	0.951	0.000

The correlation between total water utilization and economic development in the Hexi Corridor was strong in all cities except Wuwei (Table 2). The correlation coefficients were all higher than 0.75 except in Wuwei city. Especially in Jiayuguan and Zhangye cities, the correlation coefficients were all higher than 0.8. The relationship model between total water utilization and economic development was a power function and all the regression equations were significant except for the Wuwei city.

Table 2. The model showing relationship between total water utilization and economic development in the Hexi Corridor

Name	Relationship model	R	Sig.
Jinchang City	Y=40416.8 $X^{0.0757}$	0.784	0.000
Wuwei City	Y=141917.3 $X^{0.0508}$	0.361	0.129
Zhangye City	Y=74533.2 $X^{0.1550}$	0.836	0.000
Jiayuguan City	Y=2361.4 $X^{0.2010}$	0.908	0.000
Jiuquan City	Y=151448.4 $X^{0.0651}$	0.751	0.000
Hexi Corridor	Y=371015.8 $X^{0.0917}$	0.820	0.000

The sequence of elasticity coefficient of water utilization (seen from the exponentials of the power functions) in the 5 cities was as follows: Jiayuguan> Zhangye> Hexi Corridor> Jinchang> Jiuquan> Wuwei. It is in accordance with the sequence of correlation between total water utilization and per capita GDP. It indicates that the result of economic growth in the past 18 years in the 5 cities in the Hexi Corridor is the rapid growth of water utilization, especially in Jiayuguan and Zhangye cities.

Jiayuguan is an industrial city. Its industrial structure has changed from 1985 to 2003 by an increase in the heavy industries, which are high water-consuming entities and are also major supporting industries. Therefore, water demand has increased fast in Jiayuguan city. Zhangye is a typical oasis city. Agriculture takes up the biggest proportion of water here as high water-consuming agriculture is the major industry. Therefore water demand has increased fast in this city. There are two reasons for small correlation between total water utilization and per capital GDP in Wuwei city. One is that Wuwei is a typical agricultural city. As it is very short of water resources, it had to cut down the irrigated area to reduce agricultural water utilization. The primary industry developed here slowly, but the city paid more attention to the development of the tertiary industry. The development of the tertiary industry resulted in relatively rapid growth of GDP. As the economy developed relatively fast but total water utilization dropped off, the correlation between total water utilization and per capita GDP became the smallest amongst the 5 cities in the Hexi Corridor. It indicates that water scarcity has the biggest constraint on economic development in Wuwei City.

The relationship between urbanization level and total water utilization:

The correlation coefficient between urbanization level and total water utilization in the Hexi Corridor is smaller than the correlation coefficient between urbanization level and per capita GDP and the correlation coefficient between total water utilization and per capita GDP (Table 3). However, the correlation between urbanization level and total water utilization in the Hexi Corridor is still strong except in Wuwei city. The model describing relationship between urbanization level and total water utilization can be expressed by a logarithmic equation and all the simulated logarithmic equations were significant except for Wuwei city. The sequence of significance between urbanization level and total water utilization in the 5 cities and Hexi Corridor on the whole was as follows: Jiayuguan> Zhangye> Jiuquan> Hexi Corridor> Jinchang> Wuwei. It follows the same sequence as the correlation between total water utilization and per capita GDP and it indicates that the relationship between urbanization level and water utilization mainly depends on the economic development.

Table 3. The model showing relationship between urbanization and total water utilization in the Hexi Corridor

Name	Relationship model	R	Sig.
Jinchang City	Y=40.851 ln$X$- 417.903	0.600	0.007
Wuwei City	Y=3.875 ln$X$- 34.7	0.251	0.299
Zhangye City	Y=16.904 ln$X$- 194.760	0.750	0.000
Jiayuguan City	Y=23.829 ln$X$- 147.149	0.844	0.000
Jiuquan City	Y=36.149 ln$X$- 412.605	0.693	0.001
Hexi Corridor	Y=22.918 ln$X$- 288.554	0.689	0.001

The logarithmic relationship permits calculation of total water utilization corresponding to a certain level of urbanization. Taking the whole Hexi Corridor as a case, when urbanization level increased from 10% (Y=10), to 20% (Y=20), and to 30% (Y=30), the corresponding total water utilization increased from 45.30×10^8 m^3; to 70.07×10^8 m^3; and to 108.40×10^8 m^3. As urbanization level and total water utilization was not perfectly related, there were some discrepancies between the real conditions and the results we obtained from the logarithmic relationship model. But the trend was clear; as urbanization level increased more water was required. If the total water utilization were to continue increasing at the logarithmic rate the urbanization level in the Hexi Corridor will hardly keep on increasing because the development and utilization of water resources have exceeded the safe limits of exploitation of natural water resources. Therefore, mode of urbanization and economic development should be adjusted so that the total water utilization would attain zero or negative growth. In conclusion, the Hexi Corridor should construct an intensive water resource utilization system to lessen the water resources constraint on the urbanization process.

Relationship between urbanization level and total water utilization in the three inland river basins:

Adopting the above mentioned approach, logarithmic relationship models were constructed between urbanization level and total water utilization in the three inland river basins in the Hexi Corridor (Table 4). The correlation between urbanization level and total water utilization in the Shiyanghe River basin was the weakest and its was statistically not significant. The correlations for the Heihe and Shulehe river basins were strong (0.750 and 0.718 respectively) and the relationship statistically significant. It indicates that water utilization would increase more in the Heihe River basin than Shulehe River basin for every unit increase in urbanization. This can be seen more clearly from Fig.3. As urbanization and industrialization levels are relatively low in the Heihe River basin (urbanization level and the proportion of the secondary industry to GDP were 11.34% and 22.38% respectively in 1985, and 23.67% and 33.08% respectively in 2003), the Heihe River basin is still in the period of rapid growth of water utilization. While urbanization and industrialization levels are relatively high in the Shulehe River basin (urbanization level and the proportion of the secondary industry to GDP were 33.98% and 48.84% respectively in 1985, and 42.98% and 50.62% respectively in 2003), the Shulehe River basin has stepped into the period of slow growth of water utilization (Fig. 3).

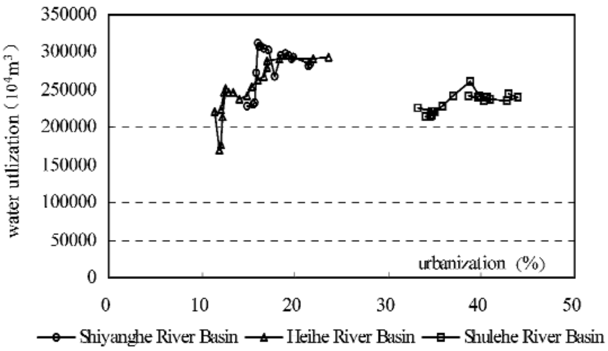

Fig. 3. The relationship between urbanization and total water utilization in the 3 river basins of Hexi Corridor.

The urbanization level and total water utilization are similar in the Shiyanghe River basin and the Heihe River basin (Fig. 3). However, the two river basins have important differences. In 1985, the urbanization level in the Shiyanghe River basin and Heihe River basin, respectively, was 14.91% and 11.34%, and total water utilization was 22.9028×108 m^3 and 22.1293×108 m^3. In 2003, the urbanization level in the Shiyanghe River basin and Heihe River basin, respectively, was 21.62% and 23.67%, and total water utilization 28.4224×10^8 m^3 and 29.3655×10^8 m^3. From 1985 to 2003, the urbanization level in the Shiyanghe River basin increased by 6.71%, and level in the Heihe River basin increased by 12.33%. The total water utilization in the Shiyanghe River basin increased by 5.5196×10^8 m^3 while in the Heihe River Basin it increased by 7.2362×10^8 m^3. Thus, the urbanization process in the Shiyanghe River basin was slower than in the Heihe River basin, and total water utilization also grew slower in the Shiyanghe River basin. The urbanization process in the Shiyanghe River basin and Heihe River basin was slow compared with the average level of China, but the urbanization process in the Shiyanghe River Basin was slower than in the Heihe River basin because the Shiyanghe River basin has greater water resource constraints.

Table 4. The model showing relationship between urbanization level and total water utilization in the 3 river basins of Hexi Corridor

Name	Relationship model	R	Sig.
Shiyanghe River Basin	Y=7.8541 ln$X$- 80.43	0.325	0.175
Heihe River Basin	Y=44.974 ln$X$- 517.82	0.718	0.001
Shulehe River Basin	Y=44.974 ln$X$- 517.82	0.718	0.001

As shown in Fig.3, total water utilization in the Shiyanghe River basin rose with the increase in urbanization level at the beginning, but fell afterwards. This was not because water demand in the Shiyanghe River basin rose at first and then got reduced, but because this river basin had to reduce water utilization when the development and utilization of water resources approached and exceeded the ecologically safe threshold of use of natural water resources. As water utilization was reduced, the development of high water-consuming agriculture and industry was restricted, and the urbanization process was also restricted.

Quantitative relationship between urbanization level and water utilization benefits

Changes in water utilization benefits in five cities:

Water utilization benefits can be reflected by water utilization per unit production value or by production value per unit of water utilization. The smaller the water utilization per unit production value or the bigger production value per unit water utilization, the higher are the water utilization benefits. Per *stere* (1 stere= 1cubic meter) water GDP values in the 5 cities in the Hexi Corridor in the past years are shown in Fig.4. The water utilization benefits in the 5 cities in the Hexi Corridor increased gradually from 1985 to 2003. The overall increase in per *stere* water GDP in the Hexi Corridor as a whole was 10.60 times, while city–wise increase in Jinchang, Wuwei, Zhangye, Jiayuguan and Jiuquan was 8.06, 12.01, 10.80, 10.72 and 11.25 times, respectively. On the other hand, the absolute water utilization benefits in the 5 cities followed a different sequence: Jiayuguan > Jinchang > Jiuquan > Wuwei > Zhangye. Where the urbanization level is higher, water utilization benefits are also higher. It indicates that urban system is a system giving higher water utilization benefits than rural system. The correlation between urbanization level and water utilization benefits was positive.

Relationship between urbanization level and water utilization benefits in the five cities:

To study the relationship between urbanization level and water utilization benefits, we drew scatter diagram of urbanization level and water utilization benefits in the 5 cities in the Hexi Corridor, from 1985 to 2003 (Fig. 5). The relationship between urbanization level and per *stere* water GDP was linear, and positive. The sequence of urbanization level in the 5 cities and Hexi Corridor over all was as follows: Jiayuguan> Jinchang> Jiuquan> Hexi Corridor> Zhangye> Wuwei. The sequence of water utilization benefits was as follows: Jiayuguan> Jinchang> Jiuquan> Hexi Corridor> Wuwei> Zhangye. Thus, in general, where urbanization level is higher, water utilization benefits are also higher. However, in Wuwei and Zhangye cities there is some abnormality. In Wuwei city, because of serious water scarcity, agriculture, which consumed most water resources, increased slowly and total water utilization tended to decrease. Because of the decrease of water utilization the benefits per unit increased. The sequence of growth rate of urbanization level in the 5 cities was as follows: Zhangye> Jiayuguan> Jinchang> Jiuquan > Wuwei. The sequence of growth rate of water utilization benefits in the 5 cities was as follows: Jiayuguan> Jinchang> Jiuquan> Wuwei> Zhangye. It indicates that water utilization benefits in Zhangye city were very low, and the effect of rapid growth of urbanization level in Zhangye City was the rapid growth of total water utilization. If this condition continues, rapid urbanization in Zhangye city will be highly restricted by water resources.

To describe quantitatively the relationship between urbanization level and water utilization benefits linear regression equations were developed for each city (Table 5). The correlation coefficients were all above 0.9. It is clear that with unit increase in the urbanization level the increase in water utilization benefits followed this sequence: Jiayuguan> Wuwei >Jiuquan >Jinchang>Hexi Corridor> Zhangye.

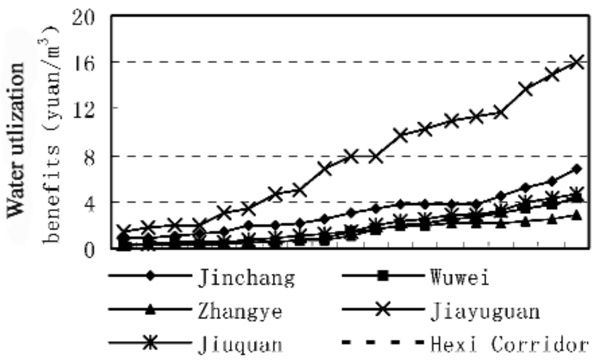

Fig. 4. Changes of per stere (m^3) water GDP in the Hexi Corridor.

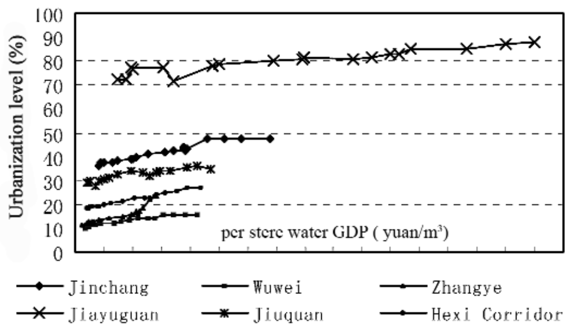

Fig. 5. Analysis of the relationship between urbanization and water utilization benefits in the Hexi Corridor.

Table 5. The model showing relationship between urbanization and water utilization benefits in the Hexi Corridor

Name	Relationship model	R	Sig.
Jinchang City	Y=35.039+2.170X	0.974	0.000
Wuwei City	Y=10.356+1.391X	0.978	0.000
Zhangye City	Y=10.058+3.639X	0.930	0.000
Jiayuguan City	Y=72.736+0.953X	0.945	0.000
Jiuquan City	Y=28.708+1.667X	0.927	0.000
Hexi Corridor	Y=17.601+2.249X	0.994	0.000

Relationship between urbanization level and water utilization benefits in the three inland river basins:

We drew the scatter diagram of urbanization level and water utilization benefits in the 3 inland river basins in the Hexi Corridor from 1985 to 2003 (Fig. 6). With the increase in urbanization level, water utilization benefits increased in all the three inland river basins. Urbanization level and water utilization benefits in the Shulehe River basin are biggest, and water utilization benefits have also increased the fastest. In the Heihe River basin the urbanization level rose the fastest while water utilization benefits rose the slowest, and the rapid growth of urbanization level was at the expense of extensive utilization of water resources. Urbanization level in the Shiyanghe River basin was bigger than that in the Heihe River basin while water utilization benefits were smaller before 2002. As the urbanization process and industries which have low water utilization benefits were restricted more seriously in the Shiyanghe River basin, urbanization level there was smaller while water utilization benefits were bigger than in the Heihe River basin after 2002. The regression equations (Table 6) were linear and coefficient of correlation highly significant. The relationship showed that with every unit increase in urbanization the water utilization benefits growth followed this sequence: Shiyanghe River asin> Shulehe River basin> Heihe River basin.

Table 6. The model showing relationship between urbanization and water utilization benefits in the 3 inland river basins

Name	Relationship model	R	Sig.
Shiyanghe River Basin	Y=14.857+1.602X	0.978	0.000
eihe River Basin	Y=10.058+3.639X	0.930	0.000
Shulehe River Basin	Y=33.453+1.994X	0.967	0.000

Quantitative relationship between urbanization level and per capita water utilization

Changes in urbanization level and per capita water utilization in the five cities:

Based on the statistics of water utilization and population from 1985 to 2003, per capita water utilization in the 5 cities in the Hexi Corridor was calculated (Fig.7). Before 1996, curves of per capita water utilization in the 5 cities showed high fluctuation. After 1996, the fluctuations were less. Per capita water utilization in Zhangye city increased continuously, while in other cities it showed decrease. As the urbanization level continued to rise but per capita water utilization fluctuated irregularly, the relationship between the two could not be described by a linear equation.

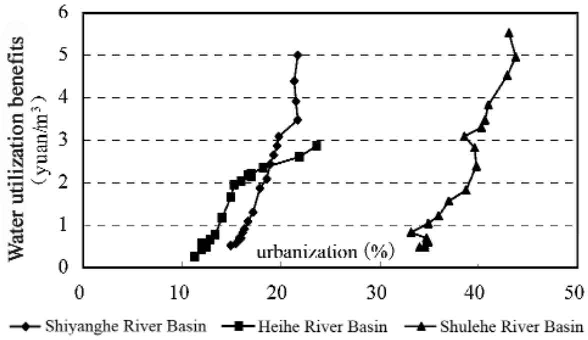

Fig. 6. The relationship between urbanization and water utilization benefits in the 3 river basins of Hexi Corridor.

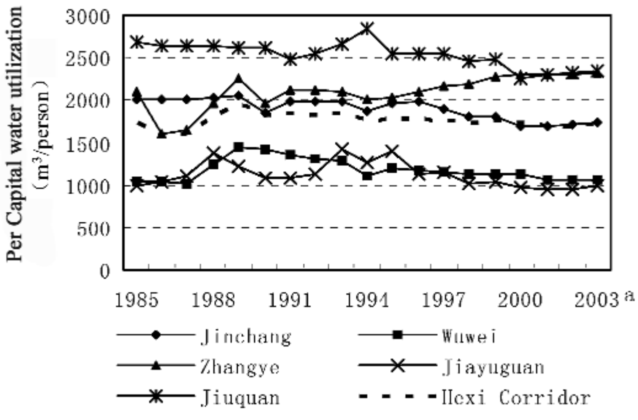

Fig. 7. Changes in per capita water utilization in the Hexi Corridor.

Relationship between urbanization level and per capita water utilization:

Based on the statistical data from 1985 to 2003, we drew the scatter diagram of urbanization level and per capita water utilization in the 5 cities in the Hexi Corridor (Fig. 8). The per capita water utilization tended to decrease with the increase in urbanization level except in Zhangye city. However, the relationship was not linear. It was also complex in spatial scale. For example, the urbanization level was the biggest in Jiayuguan city and the smallest in Wuwei city, while the per capita water utilization in Jiayuguan and Wuwei cities was similar. Urbanization level in Jiuquan city was in the middle of the 5 cities while per capita water utilization was the biggest. Thus, per capita water utilization appears to be influenced by many complex factors. These may be climate, geographical environment, water consumption habit, urban characters, industrial structures, and so on.

As the changes in per capita water utilization were relatively regular after 1996, we constructed the relationship models using the data from 1996 to 2003 (Table 7). The relationship in Zhanye city was positive. In the other cities and the whole Hexi Corridor it was negative. It indicates that with the increase in urbanization level, the extensive utilization mode of water resources in Zhangye city continued while in the other cities it was adjusted.

Table 7. The model showing relationship between urbanization and per capita water utilization in the Hexi Corridor

Name	Relationship model	R	Sig.
Jinchang City	Y=82.103-0.0205X	0.910	0.002
Wuwei City	Y=32.918-0.0165X	0.854	0.007
Zhangye City	Y=-37.393+0.0248X	0.688	0.059
Jiayuguan City	Y=112.449-0.0275X	0.832	0.010
Jiuquan City	Y=55.551-0.0887X	0.722	0.043
Hexi Corridor	Y=125.442-0.0581X	0.908	0.002

Relationship between urbanization level and per capita water utilization in the 3 inland river basins:

From the scatter diagram of urbanization level and per capita water utilization in the 3 inland river basins in the Hexi Corridor from 1985 to 2003 (Fig.9), we can see that both urbanization level and per capita water utilization in the Shulehe River basin were the highest, but per capita water utilization decreased gradually. The urbanization level in the Heihe River basin was the lowest in 1985. But it rose the fastest and was bigger than that in the Shiyanghe River basin after 2002. However, per capita water utilization in the Heihe River basin was always higher than that in the Shiyanghe River basin and it increased gradually with time. Even after 2000, per capita water utilization in the Heihe River basin was bigger than that in the Shulehe River basin. In the Shiyanghe River basin, the urbanization process was very slow and after 2002 it was lowest amongst the three basins. Per capita water utilization in the Shiyanghe River basin was also the smallest and it continued to drop with time. Therefore, the relationship between urbanization level and per capita water utilization in the 3 inland river basins was related to the total quantity of water resources. Where water resources were the scarcest, per capita water utilization was the smallest. It indicates that, scarce water resources obviously restricted the urbanization process in the Hexi Corridor.

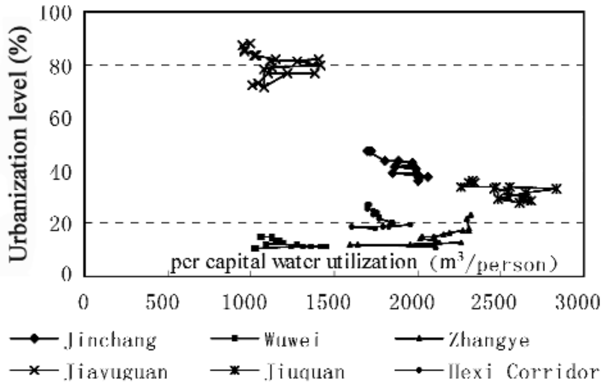

Fig. 8. Analysis on the relationship between urbanization and per capita water utilization in the Hexi Corridor.

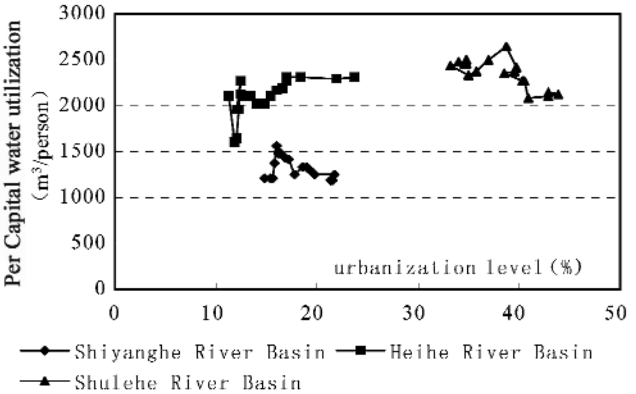

Fig. 9. Analysis on the relationship between urbanization and per capita water utilization in the 3 inland river basins.

Conclusions

Following conclusions can be drawn from this study:

(1) In the Hexi Corridor, the relationship between urbanization level and total water utilization can be simulated by a logarithmic curve. As urbanization increased, more water was required for every unit increase in urbanization level. The utilization ratio of water resources has exceeded 100%, surpassing the ecologically safe limit of exploitation of natural water resources. If this condition continues, rapid urbanization in the Hexi Corridor will lead to higher water stress, and create socio-economic and eco-environmental problems. Hence, the development mode of water resources and urbanization should be adjusted, and the fresh water withdrawal should gradually be reduced by achieving zero or negative rate of water utilization growth. Rational allocation and optimal management of water utilization for ecology-production-living system should be strengthened. Water utilization structure and industrial structure should be adjusted to save more water. A water-saving society should be constructed by popularization of water-saving technologies and concepts.

(2) The relationship between urbanization level and water utilization benefits was linear and positive. So the Hexi Corridor should accelerate the process of urbanization and industrialization to obtain higher water utilization benefits.

(3) The relationship between urbanization level and per capita water utilization was complex. However, per capita water utilization was related to the total quantity of water resources available.

(4) Scarce water resources obviously restricted the urbanization process. The constraint was highest in the eastern part, where water resources are the scarcest. The urbanization process is the fastest in the middle region. However, it consumed much more water resources than the eastern and western part. The western region has the highest urbanization level and water utilization benefits, but its per capita water utilization is also the highest. Therefore, the Hexi Corridor should construct an intensive water resources utilization system to lessen the water resource constraint on the urbanization process. This is essential for achieving the objective of promoting urbanization and development of west China.

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Optimizing environment laws to combat desertification: a case study of Gansu Province, China

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Abstract

This paper reviews the framework and practice of natural resource and environmental law in the People's Republic of China through a case study of Gansu Province, one of the poorest provinces most adversely affected by desertification. The effectiveness of environmental law in preventing desertification is examined through a case study of Shiyang River Basin Management in Gansu Province. It turns out that ongoing water use policy and inappropriate management has exacerbated ecosystem degradation, and further contributed to already serious desertification. Equity issue in sharing natural resources in the river basin is argued. The capacity of environmental law is analyzed by examining desertification issues in Gansu Province legal jurisdiction within the Desertification Prevention Control Law, Agriculture Law, Grassland Law, Water Law and Land Administrative Law. Specific suggestions to optimizing laws to combat desertification are proposed in respect of legal criteria for promoting natural resources and eco-system sustainability, administrative supervision over natural resource utilization, collectives' stewardship, water law enforcement and institutional coordination.

Introduction

Gansu ranks 28th in terms of economic well-being out of 30 provinces in the People's Republic of China (PRC). Enterprises and businesses are underdeveloped. Agriculture operates under difficult climatic conditions and is vulnerable to recurring drought. Agricultural productivity is low and off-farm employment opportunities in rural communities are limited. Desertification is a major environmental problem that impacts on the lives of approximately 15 million people. Water shortage, land degradation and poverty are intertwining factors, serving as both a cause and effect, thus reinforcing each other. At play are many intermediate factors, which form a complex web of cause and effect relationships. Any attempt to solve one problem without addressing the others is likely to fail.

Gansu's challenge in desertification control is to balance the diverse economic, cultural and social needs of dry-land inhabitants and users whilst also maintaining its land and water resources, which contain the biodiversity and cultural heritage of these landscapes. This dichotomy calls for the strengthening of the enabling institutional environment (legislation and its implementation) to balance natural resource use and ecological concerns.

The law regime to combat desertification

Legislation is an essential component to combating land degradation. The PRC has developed a range of natural resource and environmental laws relevant to land degradation. In Gansu Province, 4 categories of laws have been applied to prevent desertification.

Enactment of the People's Congresses is the primary category of law, and is issued at multiple levels (national, provincial and prefecture) of the People's Congresses. In ethnic autonomous regions, local enactments also extend to the county level. At the national level, the specialized enactment for combating desertification is the *Desertification Prevention and Control Law of the PRC* (DPCL), adopted at the 23rd meeting of the Standing Committee of the 9th National People's Congress on 31st August 2001. Other principal national laws relating to desertification control are: *Grassland Law 2002, Agriculture Law 2002, Water Law 2002,* *Forestry Law 1998, Land Administration Law 1998, Flood Prevention Law 1997, Energy Economization Law 1997, Mineral Resources Law 1996, Prevention and Control of Water Pollution Law 1996, Water and Soil Conservation Law 1991, Environment Protection Law 1989, and Wild Animal Conservation Law 1988.*

The Gansu Provincial People's Congress has since adopted a series of provincial laws to strengthen national law with emphasis on local issues. By taking these measures, local laws obtain more practical and binding force for local activities relating to natural resource utilization and management. At provincial level, the following laws have been developed: *Measures for Implementing Law of Desertification Control 2002, Regulations on Management of Natural Preservation Areas 1999, Measures for Implementing Forestry Law 1999, Measures for Implementing Water and Soil Conservation Law 1997, Measures for Implementing Water Law 1997, Measures for Implementing Environmental Protection Law 1997, Measures for Implementing Fishery Law 1997, Measures for Implementing Grassland Law 1997, Regulations on Basic Farmland Protection 1997, Regulations on Mineral Resources Management 1997, Measures for Implementing Wild Animal Conservation Law 1990, and Measures for Implementing Land Administrative Law 1990.*

Autonomous laws in the field of grassland management, forestry management and the management of natural protected areas play an important role in ethnic areas. There are more than 20 autonomous prefectures and counties within Gansu Province. Most are in dry and semi-dry grassland areas and are vulnerable to desertification. In this province, customary law, consisting of indigenous knowledge of inherited resource use, pasture manners, land and water use agreements, etc., has been respected by rural people and ethnic groups, and widely applied to their areas.

State Council's measures and regulations are mainly formulated to support laws of the National People's Congress. Measures and regulations issued by the State Council are usually regarded as the binding instruments equivalent to the laws issued by People's Congresses. Without specific measures and regulations, a law could be hardly implemented. Furthermore, measures and regulations of State Council and Provincial Government are usually supported by ministerial mandates or decrees. Mandates and decrees exist at the policy level and usually feature individual elements of law and legislation taken at the broadest sense. This method is regarded as the most feasible and quickest way to implement national/local laws and regulations. Within China's legislative regime, mandates and decrees of ministries and provincial governments are the principal elements of legislation. This situation was changed after the *Administrative Permission Law* came into force in 2003.

International conventions and agreements are important environmental instruments to guide domestic legislation and policy making to combat desertification. International instruments relevant to China include those rules which are binding and non-binding. Binding rules relevant to China are *The Convention to Combat Desertification 1994* (signed on 14 October 1994 and ratified on 30 December 1996), *The Convention on Wetlands of International Importance*, and *The Convention on Biological Diversity 1995* (acceded on 3 January 1992 and brought into force on 30 July 1992). The non-binding ones are *World Soils Policy*, *World Soil Charter*, *World Conservation Strategy*, *Stockholm Declaration of the Human Environment 1972*, *Nairobi Declaration 1982*, *World Charter for Nature 1982*, *Rio Declaration on Environment and Development 1992* and *Agenda 21.* These rules support and build awareness of sustainable development among citizens and government leaders at the state level. The publication of *Agenda 21 for China* and *The White Book of China on Population, Environment and Development in the 21st Century* in 1994, was evidence of the positive impact that international environmental strategies had upon domestic and local applications and implementation.

Of all the legal instruments the main one to combat desertification in Gansu Province is the DPCL and its provincial implementing measures. DPCL, as a specialized law for combating desertification, is an integrated law. Provisions in the DPCL can be grouped into sectoral and inter-sectoral measures. Sectoral measures are generally undertaken to prevent land desertification, including: (i) monitoring, statistics analyzing land desertification; early warning of droughts and dust storms (Article14); (ii) establishing sand breaks and windbreak shelter-belts or networks of perennial shrubs and grasses (Article 16); and (iii) establishing Enclosed Protection Areas of Desertified Lands, where no re-settlement will be allowed and all local residents shall be relocated outside of these areas (Article 22). Generally, these sectoral measures are led and conducted by the forestry bureaus in consultation with other governmental sectors.

DPCL's inter-sectoral measures against land desertification are a unique feature in later legislation, as it addresses cross sectoral issues on water, agriculture and livestock production within a single law. DPCL Article 17 is a complex provision related to vegetation protection and referring to *The Regulations on Wild Foliage Protection of State Council 1996* and *the Provisions on Agricultural Wild Foliage Conservation of Ministry of Agriculture 2002*. It requires county-level governments to formulate a vegetation management and protection system, in which special institutes for vegetation protection are to be planned for townships and villages. Vegetation wardens will observe and survey vegetation management on farm or grazing land. DPCL Article 18 relates to *Grassland Law*. It begins by re-affirming the principle that the maximum number of livestock shall be determined by grass-cover availability. It then puts specific focus on the responsibilities of the administrative body in charge of agriculture/animal husbandry as follows:(i) to guide and organize farmers and herders to establish the appropriate mix of livestock species;(ii) to promote stable livestock and grazing rotation; and (iii) to formulate standards and regulations for carrying capacity and organize its implementation. DPCL Article 19 has some provisions connected to *Water Law*. It stipulates that within desertified lands integrated water allocation and management should be based on the carrying capacity of the river basin or the watershed region. To avoid decreases in vegetation and land desertification the water utilization plan should take into account water needs in vegetation protection throughout the whole region. This is intended to reduce desertification caused by the excessive development and over-utilization of surface water and upstream water. Water-saving agriculture and other water-saving industries are strongly promoted. DPCL Article 20 draws on the *Agriculture Law*. No cultivation is allowed on woodlands or grasslands lying on the desert margin. Where the cultivation of land has a negative ecological impact, cultivated lands shall be converted to woodlands or grasslands.

DPCL also provides a legitimate basis for two essential policy tools. Under Chapter 2 of DPCL, the National Planning for Combating Desertification (NPCD) is the first basic strategic instrument for combating desertification. The purpose of the NPCD is to identify desertified lands where human activities will be regulated or prohibited within a specified time limit. The task of NPCD is to formulate Action Plans for Combating Desertification (APCDs) within specific schedules, steps and measures. APCDs are the main measures to ensure that targets of the NPCD are met; i.e. to reduce desertified land and halt desertification expansion. There are three levels of APCDs, national, provincial and city/county levels. Articles 10 to 11 of DPCL entitle NAPCD to provide an overall action plan for combating desertification.

The second policy instrument provided by Chapter 4 of DPCL is the desertified land restoration program. Restoration is targeted at desertified lands, which can be owned by the State or by collectives. There are two scenarios which determine whether a restorer holds a land-user right. When a restorer does not hold user rights or is not the owner of the land, he/she must first take the desertified land-user rights by signing a contract with landowners for the transfer of those rights. County-level governments will validate the transfer of rights by issuing a land-user's certificate. If the desertified land is owned by a collective, the transfer then must be strictly processed by procedures referred to in the *Country Land Contracting Law 2002*. All rights derived from the restoration of desertified lands such as new vegetation, woods, grasses, etc. and new earnings belong to the new land users under DPCL. In this regard, the DPCL was the first law before 2002 that enabled the collective owning the land to transfer land-user rights to a body that does not have membership of the collectives; this however, was only limited to the desertified land restoration programs. All restoration activities for desertified lands should follow specific administrative procedures including application and validation of projects, designing the intervention, financing arrangements and so on. The forestry administrative body has to set up vegetation restoration criteria for the final review of the project. To encourage restoration of desertified lands, the State provides preferential policies such as financial subsidies, tax discounts, reductions or exemptions to all groups involved in activities to combat desertification.

Measures for Implementing Law of Desertification Control of Gansu Province 2002 was promulgated by the Standing Committee of Gansu Provincial People's Congress in 2002, and took effect on March 1st 2003. The significance of this local law is to specify measures on the management of desertified land. All desertified land designed in combating desertification plans is divided into three categories, enclosed preserved land, prevented protected land, and restoring utilized land. Various measures of prevention, protection and restoration are formulated on each type of desertified land, as are the penalties (Article 9 to 12; Article 28).

Law performance: a case of Shiyang river basin

Gansu Province suffers from severe water scarcity. The Yellow River is the major supply of surface water, however its flow to the Province is decreasing; it decreased from 29.9 billion cubic meters in 1994 to 18 billion cubic meters in 1997 (Yanwen, 1999). Water consumption of the Yellow River for each province in the Yellow River Basin has been allocated by quota within the *National Water Allocation Plan of the Yellow River*. It was not surprising that Gansu Province overused its quota of the Yellow River, due to its shortage of other ample tributaries (Yanwen, 1999). The annual water consumption from the Yellow River in 1997 was 4.2 billion cubic meters, and its quota was 3 billion cubic meters. Shiyang, Sule and Hei rivers are three other major inland rivers originating in Gansu Province. Shiyang river basin has been suffering from a major water crisis and is affected most by land desertification. The Shiyang river basin is almost entirely located within Gansu Province containing Wuwei and Jingchang prefectures. Shiyang River originates in Tianzhu county and extends to the middle zone-Gulan county, Lianzhou district and Jingchang prefecture, then goes down to Minqin county and finally disappears into the northern desert.

Existing ground-water priorities

When water scarcity is a regional problem, priorities of water use are generated from practice and policy. In Shiyang river basin and throughout Gansu Province, the current principle of prioritized water use is to first allocate water to areas that produce the highest commercial value or fiscal revenue for the governments. The industrial sector as a major contributor of revenue has been the first prioritized user of water for a long time. In the agricultural sector, areas with irrigation facilities and better soil or climatic conditions also easily acquire prioritized water use. Water users in the middle reaches are given more focus than upper and down stream areas.

Industry: Industry and agriculture are in conflict due to intense water shortages. Jingchang city is globally renowned for its nickel production and has been the 'Nickel Capital of China' since 1958. Industrial development has blossomed in this area with population being attracted to mineral sites and factories. In 1982, this city emerged by uniting Yangchang county and Jingchuang district and became a provincial ranked city. In 2001, the GNP of Jingchang City was RMB 3.5 billion Yuan, industry and agriculture contributed RMB 2.6 and 0.93 billion Yuan (73.6% and 26.4%) respectively.

According to the *Water Resource Investigation and Evaluation and Hydraulic Plan of Jingchang City 1985* (still valid), the theoretical overall surface water resource of Jingchang city was 686 million cubic meters. In 2001, total water consumption reached about 800 million cubic meters; resulting in a shortage of 180 million cubic meters. This shortfall was met by using underground reserves. Some 23% of total water consumption was in industry. Almost 95% of water used in industry was guaranteed by the local government. In Gansu Province, 'guaranteed industrial water supply' is a typical policy of water allocation.

Prioritized industrial water use led to increased stress placed on the demand of agriculture and forestry for water. In Jingchang city the 180 million cubic meters shortage of water was nearly all at the expense of agricultural water; only 39.9% of total arable land was guaranteed for irrigation, and all grassland was rain-fed (Youhao et al., 1998). Farmers had little chance to use surface water and were forced to use underground water instead. By law, local governments usually demarcate Underground Water Conservation Territories where surface water is rich but prohibited from exploitation. Many disputes on underground water exploitation occurred between farmers and local governments. On the other hand, forestry and ecosystem maintenance constitute 5-8% of total water consumption, but it is without a guarantee endorsed by government policy.

The mid-stream zones: There is an old Chinese proverb, '*the pavilion closest to water wins the moon*'. However, this should not mean that the upper and mid-stream sections have prioritized stream use. People may be accustomed to defining water use priorities by physical location. However the water use principle practiced by local government was to prioritize the use of potential fiscal revenue contributors. From an agricultural perspective the factors of better soil, more cultivatable land and better invested hydraulic facilities have contributed to the mid-stream zone attaining the largest share of water use in agriculture.

Since the 1950s, 21 small and medium-sized reservoirs have been built within the mid-stream zone, together with a 10,000 km canal network system. The water control capacity of this hydraulic system is approximately 1.086 billion cubic meters. This is very close to the total water flow of the Shiyang river, which amounted to 1.555 billion cubic meters. When the Red Cliff Reservoir, a unique reservoir in the desert, was established in upper Minqin county, the ecosystem of the down stream zone below Red Cliff Reservoir mainly covering Minqin county almost became a man-controlled hydraulic system. As large volumes of water were taken out for industrial and agricultural use in the mid-stream, the volume of stream water reaching Minqin county decreased rapidly, from 500 million cubic meters in the 1950s to 150 million cubic meters in the 1990s21. If this situation is kept unchanged in the near future, the Shiyang River could dry up within the mid-stream zone. The adverse impacts on the ecosystem over the past 40 years demonstrates that down stream watersheds have been degenerated, and the river basin has been driven to desertification.

In 1998, 96.36% of total water resources in Minqin was consumed by agriculture, of which most was the underground water (Zongli, 1998). In practice, a village had a number of wells that were authorized for use by permit and given certain quantity of water to use. However the process of underground water extraction was beyond the reach of supervision. Village users took underground water free of charge and without compliance with quantitative provisions of permits. The only effective incentive for villagers to save underground water was the cost of electricity for extracting underground water rather than the cost of underground water.

Equity issues of sharing the stream

Tianzhu is a Tibetan autonomous county in the upper stream of Shiyang river basin. Forested land in Tianzhu account for 44% of the Qilian Mountains Forest Conservation Area (an area of global biodiversity significance). Tianzhu county was given serious responsibility to steward the headwaters for the sake of the whole river basin. In 1997, Qilian Mountain Forest Conservation Area became a national natural reserve zone, so the provincial law, *Regulations for Managing Qilian Mountain National Natural Conservation Area of Gansu Province* (Provincial People's Congress, 1997) was issued. This law prohibits tree cutting and other utilization activities in the Qilian Mountain. This certainly reduced Tianzhu county's fiscal revenue. On the other hand, the official government finance budget, for higher levels of natural conservation has remained unchanged since the 1980s and amounts to RMB 0.65 million Yuan. This is far below the estimated cost of RBM 4.75 million Yuan as revealed in a survey carried out with Zang (Tibetan) ethnic locals and officials in Tianzhu county in May 2002. Tianzhu county annually spent RMB 1.3 million Yuan from its county funds to meet these conservation targets.

To ensure equity in sharing the stream, the above provincial law on Qilian Mountain and *Gansu Province Government Mandate No.7 (1998) and No.93 (1999)* was promulgated, and it required the establishment of compensation mechanisms for the benefit of the headwaters stakeholders. Legislation demands that 3% of water resource revenues generated by the middle and down stream zones, 2-5% of revenues derived from supporting research programs and income from tourism, are used to compensate the upper stream. Fiscal transfer among local governments is arranged for this compensation. Mandates came into force in 1999 but have never been complied with by all counties, nor have compensation mechanisms actually been performed.

Driven by agricultural growth, for several years the Wuwei prefecture, located in the middle stream, had attempted to build a new reservoir in the upper skirt of Tianzhu county. As the reservoir would obviously not bring any substantial benefit to Tianzhu, except the risk of damaging its traditional herding land of Tibetan ethnic group, Tianzhu county objected to this proposal. Meanwhile in the down stream, farmers of Minqin county have only received irrigation surface water once a year. If the new reservoir was built, they could hardly expect any additional irrigation water to ever come (Qing, 2002; Hongxi and Zhao, 2002).

Analysis of the effectivity of law in desertification control

Legitimacy of water use policy:

It is probably a good and necessary measure to question whether the existing prioritized water use policy in Gansu Province was ever in accordance with the *Water Law 1988*. It never enshrined within it an order of priority between industrial and agricultural water use. In fact the governing principle of *Water Law 1988* indicates that water use considerations should first be for people's daily living, and that various stakeholders should then coordinate for its water use (Article 14). This principle was incorporated into the Gansu provincial law, *Measures for Implementing Water Law in Gansu Province 1997,* which required overall plans to take all factors into consideration and make reasonable water allocation among agriculture, industry and the ecosystem conservation. In areas of water shortage, it is reasonable to restrict the scale of urbanization and industrial growth to avoid the over consumption of water. In the *Water Law 2002,* it stipulates that the utilization of water resource should first meet the living needs of both urban and countryside people, and only then will attention be directed at the coordinated needs for agriculture, industry, navigational and ecological water use. It also specifies that in dry and semi-dry areas, water use should fully contemplate the water use needs of the ecological environment (Article 21).

Agriculture water use in most areas of the Shiyang river basin represents the daily cost of survival, as produce from grain-dominated agriculture may only provide farmers with just enough funds to survive on. Even in the mid-stream zone, agricultural production does not bring farmers much disposable income. For the sake of regional economic development, prioritizing industry's water use may be economically efficient, but the side effects of such policy are that the entire region is encountering water shortage and poverty. The fairness and legitimacy of this prioritized water use policy is in debate and challenged on equity principles.

Through the applications of policy in allocating water use rights in Shiyang river basin, a question arose as to whether policy conflicts with the law? In the Shiyang river basin, it is clear that policy challenges the law in practice for natural resource management in the following ways: (i) policy replaced the statutory law, e.g. almost free extraction of surface water in Minqin county; (ii) policy changed statutory law, e.g. water-use priorities practice in Jinchang city; and (iii) statutory law was ignored in operation, e.g. the failure in enforcing the compensation to upstream wardens in Tianzhu county. The examination of these issues from the legal perspective will help understand the enabling environment of desertification control.

Effectivity of law in desertification control

Water shortage, land degradation and poverty form a complex web of cause-effect relationships for desertification, and it is the aim of various laws and policies to devise solutions for these relationships. There is much evidence demonstrated through the water management of Shiyang river basin, which points to the ineffective role that environmental law is playing in devising solutions for desertification.

Legal criteria of natural resources sustainability:

It is known that in the area of pollution control, legal criteria are critical to effectively controlling pollution, and provide a basic defense system for protecting the environmental quality from pollution. The existing environmental law has not evolved to the extent of establishing an equivalent criterion for the protection of natural resource health, the preservation of carrying capacity for natural resources or ecosystem service. Legal criteria for natural resources' sustainability would have the same function as in pollution control, and act as a safeguard against natural resource exploitation. The absence of technical support to provide physical definition of sustainability of natural resources greatly weakens the law's capacity in controlling desertification.

DPCL in operation: Desertification Prevention Control Law (DPCL) is a milestone of China's legislative effort to address desertification. The provisions of DPCL have incorporated successful techniques in the practice of desertification control. However for the effective implementation of DPCL, detailed measures need to be adopted. This can be carried out at either the national or provincial level.

The first focus of supplementary regulations of DPCL is to develop a set of definitions and classifications of 'desertification' and 'desertified land', which are key terminologies for all legal instruments of DPCL. Technical resolution of issues about 'desertification' and 'desertified land' has to be examined to ensure compliance with sound natural resource utilization and management. Therefore, technical standards could be well-linked to human activities that impact on natural resources and affect the functioning of natural ecosystems. This link then provides clearer justification of responsibilities and liabilities to individuals or organizations to the 'desertified land' affected by those human activities. Socio-economic aspects of desertification deserve special consideration. This needs to be combined with a consideration of acute and chronic land degradation and a calculation of the economic cost of restoration (e.g. to identify desertified lands, and to define the enclosure boundaries of desertified lands, etc.). Once the terminology is agreed there is a need to design acceptable legal status or binding agreements. The local law *Measure for implementing Desertification Prevention and Control Law of Gansu Province 2002* solved part of this terminology issue by categorizing three types of desertified land as enclosed reserved land, prevented protected land, and restoring utilized land. But there is still a lack of technical measurement to justify each type of desertified land and its extent of desertification. Therefore, rational measures of prevention and conservation have not been identified.

Another focus of further provisions to DPCL is to provide clearer institutional responsibilities for forestry authority in the development of forests. Institutional co-ordination must be emphasized for inter-sectoral measures set out among DPCL, *Grassland Law*, *Water Law* and *Agriculture Law*. Implementing these inter-sectoral provisions will be reliant on whether all relevant agencies can practice their natural resource administration through an integrated approach

Land ownership and usage rights arrangement: Since China has the world's largest population, land has attained preeminent value to its citizens.. The *Land Administration Law 1998* defines two types of land ownership, state-ownership and collective-ownership. State-owned land includes urban lands, urban outskirts and some cultivatable farmland in the country, and collective-owned land mainly includes farmlands, grasslands, and other agricultural lands, which are predominantly county lands owned by village collectives (Article 8 and 9). Under the *Land Administration Law 1998* the practice of land use planning usually divides land into two categories, exploited land and non-exploited land (Article 39 and 40). Exploited land is further sub-grouped into construction use land and agriculture land use.

State-owned lands have been well regulated by a series of laws and regulations that include land use rights (usually for 50 years or 70 years), its transfer, its trading operations, and estate market regulation. Collective-owned lands, mostly referred to as 'responsibilities land', have been contracted to farmers and herders since the agricultural land reforms in the 1980s. Farmer's land tenure was effectively guaranteed across the country and it motivated farmers to increase agricultural production. However herder's land tenure had not been as widely applied as farmland. Land use rights of collectively-owned land were non-transferable and non-tradable until the enactment of DPCL 2001 and *Country Land Contracting Law 2002.*

Non-exploited land was initially owned by the State, and therefore could exist for any possible use. The State could transfer land ownership to collectives or give land-user rights to any civil entity. In 2001 and 2002, two countrywide situations arose for state-owned non-exploited lands to be transferred to collective-owned or company-owned (land use rights only) for the particular purpose of combating desertification. The State identified desertified lands in specific areas and invited civil entities to restore these lands. These entities had to prove their capacity for carrying out the work, and in return were endowed with the land-user's rights for a period no less than 50 years. As most non-exploited lands in Gansu are in areas where exploitation is difficult, such as the Gobi Desert, barren lands and rocky land, land rights arrangements can be one of the most effective incentives to encourage people to participate in land desertification control.

Grassland's privatization: Following the success of farmland tenure reforms, privatization of grassland tenure was an important socio-economic reform of the animal husbandry sector. Countrywide reform started in 1985 by endowing grassland tenure on individual herders on short-term (15 years at that time and 30 years nowadays) contracts. Gansu Province processed grassland tenure reform in 1996, ten years after the national program commenced. By 1999, 46.8% of pastoral land covering 9 pastoral counties was contracted to herders (Zhang et al., 1999).

The grassland contract system was originally designed to enhance livestock production and protect herders' benefit. In the 1980's people regarded the grassland as a resource rather than as a component of the ecological environment. The *Grassland Law 1985* stressed that forage supplies and the number of livestock within contractual grassland areas must be balanced; this is re-affirmed by the *Grassland Law 2002,* the *Agriculture Law 2002* and *Desertification Prevention Control Law 2001* (Article 14). However for decades this measure was not complied with. Large increases in the number of livestock caused rapid degradation on the remaining grassland.

In Gansu Province most grasslands were kept under free communal use without fenced enclosures, despite being under tenure contracts (communal grazing under free range).
Collective–owned grassland remained a communal property, shared generously by farmers and herders from neighboring collectives, villages or even counties. This behavior made the capping of livestock numbers based on forage production absolutely impossible.

Water law issues: From the point of view of the water management of Shiyang river basin, water issues in Gansu Province could be summarized as: (i) failed compliance with compensation to upper-stream catchment area; (ii) water pricing system excluding underground water us; (iii) no county-level water allocation within a river basin; (iv) water permission lacking quantity limitation; and (v) ineffective penalty system for violation of water use regulations.

Enabling law to combat desertification

In order to attain sustainable natural resource management and desertification control, legislative regime changes are required at both the provincial and local levels. Environmental legislation needs to reflect the functions of nature and its natural capacity. Greater emphasis should also be made of enforcing existing legislation. Without strict implementation and enforcement, the application of environmental law would never result in successfully controlling desertification. The following suggestions and recommendations are made to optimize the capacity of Chinese environmental legislation and its enforcement.

Develop legal criteria of natural resources and eco-system sustainability: There is ample evidence of this in Gansu Province, as natural resources and the ecosystem will be approaching over-use without regulations to control natural resource utilization. Legislative reform should further develop a series of legal criteria for natural resource utilization and protection in aspects of: (i) legal definition of desertified land; (ii) legal standards for the restoration of desertified lands; (iii) legal definition of natural resource productivity in line with output capacity grading; (iv) legal standards for land use closure of desertified land or degraded land (grassland/farmland/woodland); and (v) technical instructions for the selection of plants for vegetation regeneration, forestation for shelterbelt building, and crops for water-saving and value-adding agriculture. Such legal criteria could be delivered as technical instructions, guidelines and standards, and enforced with legal obligations to implement them.

Legal criteria will considerably enhance the implementation of environmental laws. First, the legal criteria should consider integrating with the administrative system for natural resources. They should be set as one of the targets for administrators' responsibilities, similar to those targets set for output and regional economic growth. This would motivate governments to adopt multi-objective development, encompassing socio-economic factors, rather than over-focusing on the single goal of economic growth. Secondly, the activities of natural resource users should be regulated by specific conditions to enhance sustainability. Privatization of farmland and grassland by granting short-term tenure provides an efficient way to tie incentives to farmer/herder production. By incorporating the status of short-term tenures with the legal criteria for land resource sustainability, administrators could tie conditions to ensure that land users comply. To enable a participatory approach to desertification control, legal criteria may provide the public with available guidelines to review, supervise and monitor the policy making and other activities of the natural resource users.

Enhance administrative supervision in natural resource utilization: There are many overlapping responsibilities of administrative supervisory bodies. The result is that either there is attempt to execute the same thing or none of them enforcing it. Some administrative responsibilities need to be clarified: (i) the Grassland Supervision Station (an organ under the Ministry of Agriculture, and in charge of monitoring grassland and designating grassland capacity) should be empowered to oversee the grazing activities; (ii) the Environmental Protection Agency should have more powers to oversee natural resource activities, which could possibly have adverse impacts on the environment, such as reclamation, mining, digging of medicinal plants etc.; and (iii) the land administrative agency and county-level people's governments should take direct responsibility for ensuring that the non-exploited open land is under proper control and administration. One of the approaches to overcome supervision overlap is to establish a multi-sector co-ordination panel, empowered to issue mandates or decrees to clarify conflicts.

Emphasize the collectives' stewardship on their own land or natural resources: To avoid a 'tragedy of the commons', establishing stewardship liability for rural collectives on their own land and natural resources should be emphasized. Provisions of this has been demonstrated in the *Country Land Contracting Law 2002* (Articles 13, 26, and 59), but needs to be enforced in the course of implementation. The enclosure of, or other similar actions of grasslands, needs to be ensured to allow for the proper control of grassland, and encourage and support stewardship. Penalties or incentives to correct natural resource abuse would also have a positive effect.

With regard to grassland conservation in Gansu Province, the land tenure system needs to be completed along with stewardship to be put into effect. Stewardship liability should address the enforcement of a policy to 'balance animal husbandry with grass production'.

Enhance water law enforcement: In the future, water management administrators should focus more on enforcing law established under the *Water Law 1988* and its revisions in 2002. The enforcement of water law needs: (i) to implement an integrated system of water allocation by county/river basin; (ii) to comply with a water pricing and trading/compensation system; (iii) to apply water permission by complying with strict quantity limitations; (iv) to regulate underground water extraction and utilization; (v) to provide the fixed proportion of water used for eco-system maintenance; and (v) to enforce penalties for violation.

Overcome institutional overlaps and improve coordination: Inter-agency and multi-sectoral co-ordination is essential because sustainable land management is multi-dimensional. This co-ordination role may be carried out by the appointment of an institutional panel. The panel should be independent and distinguish itself from other natural resource authorities. It should be: (i) responsible for natural resource sustainable management; (ii) directed by People's Governments; (iii) co-chaired by senior and comprehensive governmental authority such as the Development and Reform Commissions (DRCs) and Environmental Protection Agencies (EPAs); and (iv) have representation from sectoral natural resource ministries. It is advisable that members of this co-ordination panel are seconded from various agencies, rather than being full-time staff of the panel.

The role of senior authorities, coming from diverse organizations such as the DRCs, on the panel is to oversee the review of all programs and activities conducted by the sectoral agencies. They could also examine whether agreed objectives for natural resource management are met. The role of the members from EPAs on the panel is to be the environmental auditors, and also to monitor and evaluate the ecosystem quality against the agreed legal criteria. The panel's task is to ensure that the balance between natural resource utilization and natural ecosystem conservation is maintained.

Conclusion

Poverty, increasing population, economic growth demand and over utilized natural resources jointly pose many obstacles to Gansu Province's progress and sustainable development. The current environmental law regime has the potential to create a more equitable and fairer system for its citizens by sharing in the benefits of natural resources and the environment.

Since the 21st century, Chinese environmental legislative reform has achieved the adoption of *Desertification Prevention and Control Law 2001* and the revision of several major natural resource laws (e.g. *Water Law 2002, Agriculture Law 2002, Grassland Law 2002* etc.). This will compel the legislative reform at the local level including the Gansu Province. The Shiyang river basin management case study proves that capacity of environmental law should be examined through the effectiveness of performance, implementation and enforcement of the legislation. The Chinese environmental law to combat desertification must become more comprehensive by integrating issues of social, economic and environmental development.

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Pastoral strategies and community characteristics: the case of Syrian Badia

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Abstract

An up-to-date characterization of the behavioural patterns of Bedouin communities in the steppe of Syria was done to enhance an understanding of how rangelands are collectively used. Analysis was conducted from a community perspective as pastoral resources are exploited collectively. Based on survey data collected from 359 households and 50 Badiah communities in spring 2005, the main strategies prevailing today were identified and explained in a second step using the agro-ecological conditions and socio-economic factors in the communities. The results show a great diversity of mobility and feeding patterns as well as interconnections with other communities. This diversity is strongly explained by the community's land potential (which decreases as we move towards the dryer zones) and population densities – both indicators defining the average amount of forage resource available for a herder in his community.

Introduction

In Syria, as in many countries of West Asia and North Africa, due to the increasing population and rangeland degradation the pastoral system is facing important structural changes such as the sedentarization of part of the population, the modification of flock mobility patterns with motorized transportation, or the increasing reliance of flock on concentrate feeding (Vercueil and Commins, 2003). The ban on cultivation in the rangelands in 1995 is a public intervention, which had a strong impact on the feeding pattern of Bedouin flocks, as cropped barley was contributing around 20% to stock feeding. Very little quantitative information is available on the variety of behaviors taking place in the steppe and the degree of importance of each of them. In addition, there is need for a better understanding of the differences between the structural long-term behaviors, which strongly depend on the communities' agro-ecological conditions, and the less constrained decisions.

Based on survey data collected in 2005, we analyzed pastoral production strategies according to the characteristics of the communities. Environmental factors (land potential) and socio-economic characteristics (access to infrastructures, human population density, community assets) have been introduced in a model in order to address questions such as: "Are the communities that strongly depended on cultivation before the ban on cultivation in 1995 more likely to intensify their production system?" or "How are rangeland degradation and pastoral strategies interconnected?" In fact, the causal relationship between rangeland degradation processes and the pastoral production choices is very ambiguous, as land degradation and livestock holding or mobility and feeding patterns may influence each other. Before tackling this issue, we are proposing in this paper to first consider the adaptation that occurs in the pastoral production system according to land potential. The paper describes the methodology and underlying model, and identifies and describes the main pastoral behaviours. It also presents the factors that were hypothesized as affecting pastoral strategies and discusses the results of the model estimation.

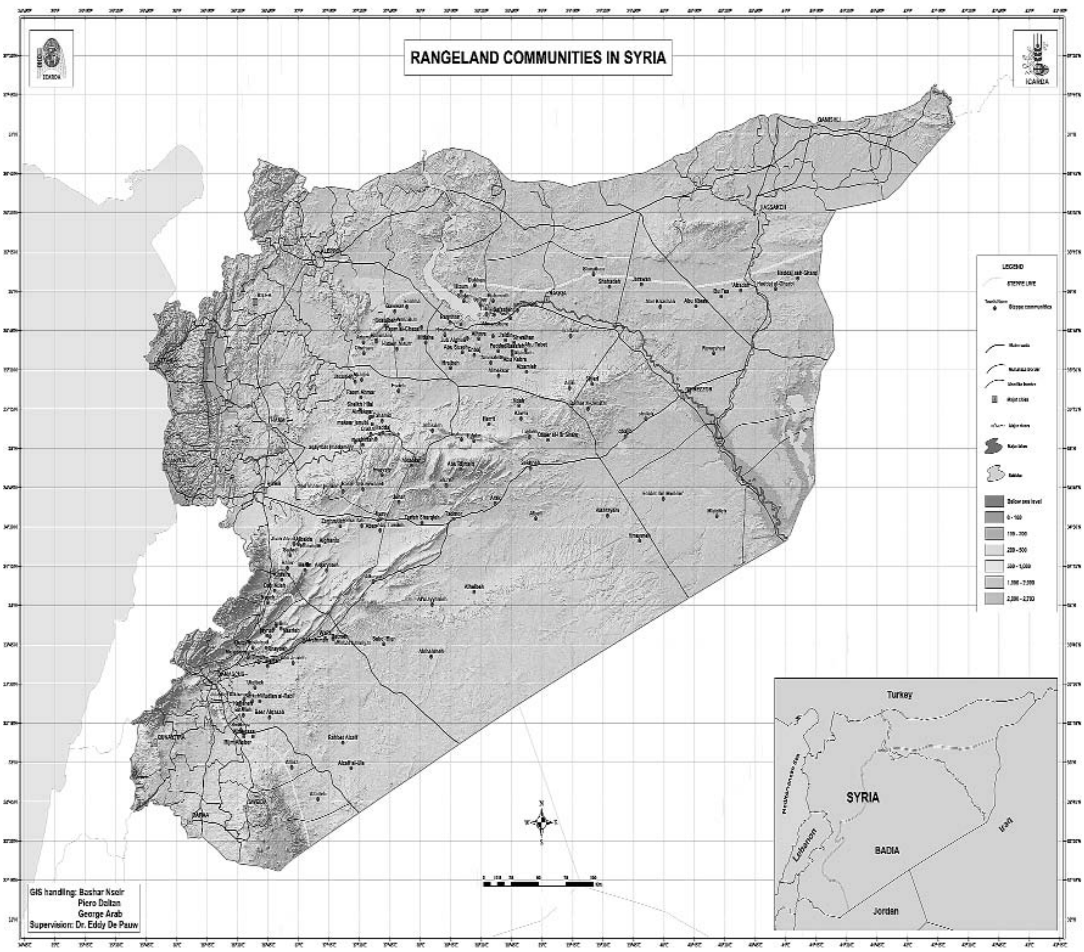
Methodology

Study site

In order to improve an understanding of the pastoral system in its complexity, the International Center for Agricultural Research in the Dry Areas (ICARDA) and the Ministry of Agriculture of Syria, conducted a multilevel survey in spring 2005 in six of the seven provinces of the Syrian Badiah (Aleppo, Hama, Homs, Raqqa, Deir Ezzor and Damascus). The Syrian rangelands, called El Badia, are defined as land with annual average rainfall below 200 mm (see Map1). It comprises 55% of the total land area of Syria (10.2 Mha) and is home to 0.9 to 1.5 million people, of which about 0.5 million are settled (Edwards-Jones, 2003). Traditionally, a good proportion of the population would have been nomads, but after a strong decline in their number over the past 50 years, the nomads were estimated to be 10,000 in 1990, most of the Bedouins today being transhumant herders.

Data collection

The sampling method consisted of three steps: (i) twenty five 'mother communities' were randomly selected among the 125 officially censed in the steppe (see Map1), (ii) two communities were then randomly selected from among the communities that make up the mother community, and (iii) a household sample was taken to be the most representative of the community under three criteria (flock size, tribal sub-group, and average feed cost per ewe), which consisted of a representative sample of 313 households at the Badiah level. The multiple survey instruments consisted of a participative mapping of the community rangelands to locate the main types of rangeland, a characterization of the vegetation of each rangeland type, a socio-economic survey at the community level, and a household survey to collect information on livestock production and mobility strategies.



Map 1. Rangeland 'mother communities' and the Badiah line of Syria.

The model

We present in this paper an up-to-date characterization of the Bedouin strategies from a community perspective. Because herders share the same main input for livestock production, which is the common forage, we were interested in knowing how communities 'behave' collectively. After identifying the main strategies prevailing in the Syrian Badiah, we estimated in a second step the determinants for adopting each of them. There are four broad types of behaviors, which can influence (everything else being equal) the level of rangeland exploitation and degradation, some of which correspond to the sum of household-level decisions and others to community-level decisions. These are: (a) Livestock holding (L) - once the individual strategies are summed up, the community livestock holding is represented by the average flock size and the percentage of community members that have flocks; (b) Intensification pattern (I) - either through improvement of the resource (i.e., shrubs plantation) or through dependence on hand feeding, notably with the development of lamb fattening; (c) Flock's mobility pattern (M) - we considered the total presence of the community's animal on site and the frequency of their presence, as the rangeland is more vulnerable to overgrazing at certain periods of the year (spring); and (d) Linkages with outsiders (O) - because the rangeland is officially an open access resource in Syria, communities receive welcomed and unwelcomed outsider flocks on their land.

We believe that these behaviors are determined by some community characteristics, notably land potential and population density. This will determine how much of the resources will be available to every community member (RA), as well as other factors (X) such as the transaction costs, the community assets, or the governance structure. We also expect these strategies to influence each other as shown below:

$$\begin{aligned} L &= f(I, M, O; RA, X) \\ I &= f(L, M, O; RA, X) \\ M &= f(L, I, O; RA, X) \\ O &= f(L, I, M; RA, X) \end{aligned} \qquad (1)$$

Using a linear reduced form of this system of equation, we can re-write:

$$\begin{aligned} L &= \alpha_l RA + \beta_l X + u_l \\ I &= \alpha_i RA + \beta_i X + u_i \\ M &= \alpha_m RA + \beta_m X + u_m \\ O &= \alpha_o RA + \beta_o X + u_o \end{aligned} \qquad (2)$$

Because this system of equations is composed of the same explanatory variables, correlation between error terms (u) can be suspected and it will be taken into account in the choice of the estimation model. Before estimating the model, we propose to present in the next two sections, the various behavioural patterns and their determinants.

Pastoral behaviour

Livestock holding

One of the first pastoral strategies to consider is livestock holding. We can expect that this will vary according to the land potential, population density and the herders' traditions. Looking at the community level, two variables capture the sum of individual strategies: the percentage of households with a flock, and the average flock size. Considering all the community members (migrants included), 70% of the surveyed community households own a flock. In 10 of the 50 communities, livestock holding is 100%, whereas in 10 other communities, livestock holding is less than 50%. Putting aside one exceptional community where eight members held on average 1900 heads, the average flock size in the communities is 190 heads of productive ewes; a third of the communities own less than 100 ewes on average and another one third own more than 200 heads.

Intensification patterns

Feeding patterns:
Feeding strategies can be described based on household and community information. At the household level, we isolated herders considered to have a more intensive production system. Intensification (defined in our case as the propensity for a flock to depend on hand feeding, mostly concentrate feeds) is a relatively continuous process, and the segregation process is not obvious. Moreover, we separated as a group herders who supplement their flocks in spring when the range-

lands are most productive (called thereafter 'intensive herders'). We then conducted a principal component analysis, adding two more variables: the percentage of households that are fattening their lambs in the community, and the average market price for the male lambs. The results (Table 1) lead to the creation of a factor (*Ifatt*), which is associated with indicators of high fattening activities and the presence of 'intensive herders'.

Rangeland improvement:
Another decision that has an impact on the rangeland is the acceptance to get involved in land improvement activities either by planting fodder shrubs (*Atriplex* species are the most common to be used in the steppe) or resting the land. These activities are undertaken with the support of projects that compensate herders according to the opportunity cost of resting the land. When this strategy is chosen by the community members, they define, in collaboration with the project experts or the steppe extension services, how many hectares to improve and the location of the plantation. In 2004, 22 of the sample communities were involved in land rehabilitation activities, improving on average 10% of their land (with a minimum of 1% and a maximum of 40%).

Mobility patterns

Before the introduction of hand feeding in the mid-20 th century, the mobility pattern of the pastoralists was perfectly associated with the accessibility and availability of pastoral resources (forage and water). The introduction of hand feeding and the introduction of trucks and mobile cisterns led to a change in the pattern of mobility and availability of forage. Today, we find a continuum of situations, from the case of Bedouin households who spend the entire year in their community in the steppe to the other extreme case of staying in the cropping zone in the whole year.

Table 1. Fattening strategy (descriptive statistics, stats and principal component analysis, PCA)

	Stats Mean	PCA *Ifat* (L2)
% Intensive herders	18.4	0.589
% Hh fattening lamb	72.1	0.822
Average lamb price	3908	0.781

In order to characterize these various strategies, we considered a long enough period to include climatic variability between years and short enough for the information to be recalled by the interviewees. In our case, the 1999–2004 period fits these criteria, with two low rainfall years (1999 and 2000), three medium rainfall years (2001, 2002 and 2004) and a very high rainfall year (2003). We then looked at the frequency with which the herders used the site and the number of months spent both at the household and community levels.

At the household level, we could identify four types of mobility strategies (Table 2):

(i) The **opportunist** herders use the community site only in years when forage is sufficiently abundant on the community pasture. Therefore, they are the herders who depend the least on community pastures. We can expect that this category was underestimated in our sample, since the year of the survey was a poor rainfall year and most of the opportunistic herders stayed in the cropping zone.

(ii) The **regular** herders use the community rangelands every year, but only for a certain period, since they regularly move between the Badiah and the cropping zone (two 'round trips' per year on average).

(iii) The **less mobile** are herders who graze on their community rangeland every year and have spent the whole year in the community at least once in the past six years.

(iv) The **immobile** herders are the settled herders who did not move from their site, even during the dry seasons and dry years.

Because the main input in livestock production is common forage (community rangelands), we expected that household strategies would be interconnected among herders of the same community. Using information on the number of households and the period of their presence on the site for each of the past six years, we built at the community level annual indicators of presence level on the site. The indicator is described by: {(Σ herders on site) (numbers of months on site)}/ {(Σ community members) (12)}. However, we could not recover the four mobility types through these community indicators. Therefore, we aggregated household categories at the community level and found that the mobility categories were strongly correlated to mobility indicators built at the community level (last section of Table 2).

Table 2: Mobility pattern (household and community information, 1999–2004

Household pattern	Opportunist	Regular	Less mobile	Immobile
Number of observations	31	75	106	41
Mobility pattern 1999–2004				
Total number of months on site in past 6 years	25.4*	32.2*	51.5*	72*
Variance of residence length	0.51*	0.06*	0.28*	0*
Number of months on site 1999 (low year)	2.8*	4.3*	6.7	12*
Number of months on site 2004 (medium year)	7.8	5.9*	9.8*	12*
Total number of moves in past 6 years	4.0*	11.7*	6.3	0*
Community patternRepresentation in community (%)	13.6	23.5	32.6	11.9
Average herders presence 1999–2004[a]	0.40*	0.43*	0.56*	0.59*
Coef. var. of herders presence 1999–2004	0.66*	0.41	0.42	0.37
Herder presence indicator 1999	0.28*	0.30*	0.40	0.49*
Herder presence indicator 2004	0.52*	0.52*	0.68*	0.65

** Significantly different from all other means at the 10% probability level.*
[a] Indicator of herders presence calculated as: (Number of households with sheep x number of months spent on the site in year Y/Total number of households susceptible to use community rangeland x 12).

Table 3. Community mobility strategies (descriptive statistics and principal component analysis)

	Stats mean	Principal component analysis		
		I. Presence (M1)	**I. Opportunism (M2)**	**I. Immobility (M3)**
Community strategy				
Average herders presence	0.515	**0.273**	0.024	0.067
Coef. var. herders presence	0.433	**-0.223**	**0.299**	-0.057
Presence indicator 1999	0.365	**0.242**	-0.040	**0.250**
Presence indicator 2000	0.620	**0.241**	0.108	-0.160
Households strategies				
Opportunistic	0.136	-0.148	**0.339**	0.318
Regular	0.235	-0.080	**-0.590**	-0.068
Less mobile	0.326	0.118	**0.293**	**-0.573**
Immobile	0.119	0.106	0.117	**0.532**

In a final stage, we conducted a principal component analysis, merging community and household variables and deriving from it three main mobility indexes (Table 3).

- M1: This first factor was strongly associated with the community level indicators and can be interpreted as an index of high presence on the site.
- M2: This factor was associated with opportunistic behaviors, where communities are composed of herders who settled outside the community land and exceptionally grazed on community land in good years and/or herders who settled in the community but moved outside in the dry years. These behaviors are in contrast to the one that consists of grazing on the site regularly every year.
- M3: The last factor can be interpreted as the propensity for a community to be composed of permanent herders who would remain on the site even during dry years.

Interactions with other communities

In the 'commons' literature (Ostrom, 1990), the protection of community borders is considered as a determining factor for the success of cooperation in the management of common resources. In Syria, communities own a traditional land, which in the official context of open access regime can be relatively difficult to protect from outsiders. Nevertheless, some communities are better in doing so either because they acquired through history a strong appropriation power or because they practice irrigated cultivation (which is authorized) or illegal cultivation on rainfed land or lately through the legal planting of shrubs. This last strategy is a response to the current property regime structure in the community and is perceived as a way to exclude outsiders from community land (Ngaido, 2001). In order to characterize the nature of the links with other communities, we relied on several variables as indicated below:

- *Nature of the links:* Three dummy variables were built for neighboring communities, other communities in the Badiah, and communities in the cropping zone. The first one taking the value 1 if it has unilateral relations of sending animals to another community, the second taking the value 1 for unilaterally receiving animals, and the last taking the value 1 if the community has a reciprocal agreement with at least one other community.
- *Indicators of outsiders' presence:* Two variables indicated the level of presence of outsiders: a dummy indicating the presence of unwelcomed flocks within the past 10 years, and an estimation of the number of flocks that crossed the community land in 2004.
- *Indicators of community capacity to protect the borders:* A first variable tried to answer the question: 'Can the community restrict access to unwelcome herders?' and a second one was a self-assessment of the leader's ability to easily protect the border. When cross checking for both, we found some inconsistencies, which we captured in a variable called 'overestimation'.
- Current irrigated and illegal cultivation *in situ*.

These variables, which were aggregated in a principal component analysis, led to the creation of four indexes (Table 4) that can be interpreted as follows:

- O1: Presence of outsiders associated with unilateral relations (possibly flocks coming from the cropping zone).
- O2: Community self-recognized as being able to protect borders.
- O3: 'Free riders' relationship. Community flocks are sent unilaterally to other communities with no presence of outsiders in the community land.
- O4: Reciprocal relationships associated with a strong presence of flocks.

Table 4. Linkages strategies (descriptive statistics and principal component analysis)

		Principal component analysis			
	Stats mean	**I. Welcomer (O1)**	**I. Protector (O2)**	**I. Sender (O3)**	**I. Reciprocal (O4)**
Type of linkages					
Unilateral - welcomer +	0.40	0.580	-0.019	0.215	-0.237
Unilateral - sender +	0.34	0.180	0.068	0.566	0.136
Reciprocal +	0.42	-0.252	0.143	-0.007	0.695
Outsider presence					
Presence of unwelcomed flocks +	0.52	0.103	0.079	-0.541	0.079
Animals crossing land*	3.94	0.228	-0.253	0.069	0.386
Border protection					
Community can protect border +	0.20	0.002	0.545	-0.096	-0.122
Leader can not protect boder +	0.26	0.016	-0.553	-0.067	-0.200
Irrigated agriculture +	0.34	-0.451	-0.056	0.238	0.037

** Indicator varying between 1 and 5; + Indicates dummy variables*

Table 5. Correlation matrix of pastoral strategies

	L1	L2	M1	M2	M3	O1	O2	O3	O4
Livestock holding									
Average flock size (L1)									
% Hh with sheep (L2)									
Mobility									
I. Duration (M1)	0.02	0.13							
I. Opportunism (M2)	0.35	0.00							
I. Immobility (M3)	-0.05	0.02							
Linkage with others									
I. Welcomer (O1)	0.04	0.15	-0.34	-0.13	-0.29				
I. Protection (O2)	-0.17	-0.01	-0.18	-0.13	0.09				
I. Sender (O3)	0.09	0.02	-0.02	-0.11	0.28				
I. Reciprocal (O4)	0.06	-0.04	-0.19	0.42	-0.18				
Intensification									
I. Fattening (Ifat)	0.03	0.29	-0.11	0.06	-0.01	0.09	-0.03	-0.24	0.12
Rehabilitation (Rehab)	0.33	-0.04	-0.19	0.24	-0.39	0.09	-0.05	-0.13	0.23

Interactions between behaviors

As expected, pastoral decisions were strongly interlinked, as we can see from the correlation matrix in Table 5. Communities with greater flock size are also the ones with opportunistic mobility pattern. Animal mobility patterns and linkages with outside communities are strongly interconnected. Finally, intensification strategies are associated with high livestock holding, opportunistic mobility behaviour vs. immobile behaviour, and with reciprocal relations rather than unilateral sender relations.

Characteristics of communities

This section presents the factors that we hypothesized to be influencing pastoral production choices.

Land potential and human population density

The average rainfall decreases as we move from the south to the east within the steppe. Therefore, we expect that the potential conditions for livestock production would get tougher (decrease in forage productivity), and that this would be a strong factor determining the pastoral strategies. In order to capture these overall conditions, we looked at four variables:

(i) The distance between the community and the Badiah line, more or less equivalent to the 200 mm isohyet, which delimits the steppe from the cropping zone (line presented in Map 1);
(ii) The potential household density (total community households per hectare);
(iii) The community land percentage that used to be cultivated in the past; and
(iv) A soil degradation indicator. Out of the three land degradation indicators defined by Tiedeman et al. (2007), (i.e., indicator of soil degradation, indicator of litter movement, indicator of invader plants), soil degradation is the only one that is strongly correlated with the three variables mentioned above and we expect that it is capturing the potential land productivity instead of the current land degradation status.

These four variables were strongly correlated; the soil degradation index increases as we move away from the cropping zone, the percentage of land that was cultivated before the ban decreases, as well as the human population density. We aggregated these conditions in a single factor called *Idens* using a principal component analysis (Table 6).

Table 6. Land potential index (descriptive statistics and principal component analysis)

	Stats mean	PCA Idens
Distance from Badia line	43.5	-0.297
Population density*	3.3	0.358
Previous cultivation (%)	38.6	0.371
Soil degradation**	2.94	-0.335

** Households per km^2*
*** Indicator between 1 and 5, 5 being very degraded.*

4.2. Governance

Communities are represented by a leader (70% of the cases) or a representative committee (30% of the cases). In order to assess the level of leadership they exercise, we asked them if discussing and solving conflicts within the community as well as with neighboring communities was relatively difficult to accomplish, and if they had difficulties in influencing their own people. Using a principal component analysis, these indicators were aggregated to form an index of ‘weak governance’ (Table 7). This index is not correlated with the type of leadership exercised, meaning that the performance of leaders and committees is the same on average.

Table 7. Governance structure (descriptive statistics and principal component analysis)

	Stats Mean	PCA I Governance
Incapacity to:		
Solve conflicts within community	10.2	0.369
Solve conflicts with neighboring community	16.3	0.412
Influence community members	12.5	0.394

Transaction costs and assets

It was difficult to include market price in the model as we suspected them to be strongly endogenous to the pastoral strategies and notably to the mobility strategies. The choice of market to sell the lambs (and the associated prices) is made by the Bedouins and we can see the most productive ones selling their lamb in the more distant markets. Therefore, we will only include in the model the transaction costs, defined as the distance of the community to the nearest paved road and the distance to the nearest water point. Communities are located 6 km on average from both infrastructures; however, 39% and 58% of the communities have direct access to paved road and water point, respectively. Finally, we included in the model, the community human capital, defined as the percentage of educated adults (either through public or Koranic education). On average, 44% of household heads in the communities are educated, with a median of 34%. We also considered if some community members possessed land in the cropping zone, which was the case in 11 communities only. Such land provides an exit option to livestock production or as an extra source of forage.

Determinants of the pastoral strategies

To enhance an understanding of the underlying factors affecting pastoral decisions, we estimated the model presented in section 3 using two alternative specifications. The first one considered the index of land potential, and the second replaced the index with the percentage of previously cultivated land, the current population density, and the distance of the community from the 'Badiah line'. Since we expected the error terms to be strongly correlated between equations, we estimated the 11 equations simultaneously using seemingly unrelated regression estimation (SURE). Since the results were very similar in the two specifications, we report in Table 8 the results of the second specification, with the coefficient and the z-statistic of the land potential index of the first specification on the first line of the table. The results are presented in the following sections, in terms of land potential and population density impact and then considering each strategy block.

Land potential and population density

The impact of the land potential and population density variables on pastoral strategies can be divided into three.

(i) A strong impact of land potential. In five out of the 11 equations, the index of land potential has a significant coefficient. As the land potential is increasing, livestock holding decreases. This result might appear surprising; however, because this land corresponded to the more cultivated and populated ones, we can consider that they are less productive than natural rangeland and the grazing competition might be tougher. In the same way, as land potential and population increase, the annual herder

Table 8a. Determinants of livestock holding and intensification strategies (SURE estimation).

	Livestock holding				**Intensification**			
	Average flock size (L1)		**% hh with sheep (L2)**		**Range rehabilitation (I1)**		**I. fattening (I2)**	
	Coef.	**z-stat**	**Coef.**	**z-stat**	**Coef.**	**z-stat**	**Coef.**	**z-stat**
Land potential and density								
Index of land potential (model1)	-297.6	-3.42**	-0.533	-3.27**	-0.452	-1.28	0.074	0.12
% Previous cropland	-170.9	-3.14**	-0.193	-1.73*	-0.080	-0.36	0.143	0.35
Current population density	-762.7	-1.43	-1.841	-1.69*	-5.560	-2.55**	-3.146	-0.79
Distance to the badia line	0.498	1.20	0.000	0.16	0.000	0.23	-0.002	-0.67
Community characteristics								
Community size	-0.392	-1.39	0.000	-0.56	0.001	0.68	0.003	1.52
Years of establishment	-0.791	-1.13	0.000	-0.20	0.006	2.00**	-0.005	-0.91
Transaction costs								
Distance to paved road	-2.007	-1.78*	-0.005	-1.96**	0.003	0.66	-0.017	-2.00**
Distance to water point	-1.221	-0.70	0.004	1.11	-0.001	-0.12	-0.011	-0.82
Assets								
Education	116.7	1.68*	0.006	0.05	0.465	1.63*	0.786	1.52*
Land in cropping zone +80.51.89*-0.020-0.22-0.069-0.390.1520.48								
Governance								
Leader +	10.6	0.28	0.156	2.04**	0.036	0.24	0.676	2.43**
Index of weak leadership	-43.9	-0.72	-0.006	-0.05	0.428	1.71*	-0.078	-0.17
Constant	27	3.73.50**	0.747	4.66**	-0.140	-0.44	-0.418	-0.72
R2		0.45		0.35		0.26		0.36
Chi2 stat p-value:		0.000		0.007		0.113		0.005

Table 8b. Determinants of mobility strategies (SURE estimation).

	I. Presence (M1)		I. Opportunisme (M2)		I.Immobility (M3)	
	Coef.	**z-stat**	**Coef.**	**z-stat**	**Coef.**	**z-stat**
Land potential and density						
Index of land potential (model1)	-1.503	-2.38**	-2.171	-3.61**	0.874	1.30
% Previous cropland	-0.003	-0.01	-1.013	-2.62**	0.185	0.43
Current population density	-11.065	-2.76**	-4.878	-1.29	9.938	2.36**
Distance to the badia line	0.002	0.49	0.005	1.70*	0.002	0.50
Community characteristics						
Community size	-0.002	-0.79	-0.001	-0.39	0.001	0.38
Years of establishment	0.002	0.44	-0.001	-0.15	-0.013	-2.38**
Transaction costs						
Distance to paved road	-0.002	-0.20	0.006	0.70	-0.013	-1.42
Distance to water point	-0.005	-0.38	-0.018	-1.50	0.019	1.37
Assets						
Education	0.689	1.32	0.397	0.80	0.210	0.38
Land in cropping zone +	-0.291	-0.91	-0.310	-1.03	-0.023	-0.07
Governance						
Leader +	-0.186	-0.66	-0.517	-1.95*	0.112	0.38
Index of weak leadership	0.728	1.59*	0.133	0.31	-0.800	-1.66*
Constant	0.051	0.09	0.637	1.15	0.305	0.49
R2		0.21		0.36		0.31
Chi2 stat p-value:		0.355		0.005		0.029

Table 8c. Determinants of linkages strategies (SURE estimation).

	I. Unilateral welcomer (O1)		I. border protection (O2)		I. unilateral sender (O3)		I. reciprocal unwanted (O4)	
	Coef.	**z-stat**	**Coef.**	**z-stat**	**Coef.**	**z-stat**	**Coef.**	**z-stat**
Land potential and density								
Index of land potential (model1)	0.076	0.11	0.577	0.86	-0.213	-0.32	-1.520	-2.51**
% Previous cropland	0.156	0.34	-0.568	-1.41	-0.560	-1.30	-0.593	-1.50
Current population density	-7.874	-1.75*	13.521	3.43**	5.812	1.38	1.397	0.36
Distance to the badia line	-0.004	-1.19	-0.001	-0.25	0.003	0.77	0.006	2.12**
Community characteristics								
Community size	0.001	0.50	0.003	1.33	-0.004	-1.82*	0.005	2.47**
Years of establishment	-0.002	-0.29	0.005	0.91	-0.002	-0.40	-0.005	-1.07
Transaction costs								
Distance to paved road	0.001	0.07	-0.001	-0.16	0.022	2.42**	0.000	-0.05
Distance to water point	0.013	0.91	0.046	3.60**	0.005	0.36	-0.018	-1.42
Assets								
Education	-0.405	-0.69	0.554	1.08	-0.589	-1.07	0.020	0.04
Land in cropping zone +	0.728	2.03**	-0.099	-0.31	0.807	2.40**	0.334	1.08
Governance								
Leader +	0.043	0.14	0.054	0.19	-0.091	-0.31	-0.256	-0.94
Index of weak leadership	-0.950	-1.84*	0.348	0.77	-0.063	-0.13	0.844	1.91*
Constant	0.332	0.50	-1.109	-1.92*	0.375	0.61	0.061	0.11
R2		0.23		0.42		0.32		0.42
Chi2 stat p-value:		0.231		0.000		0.019		0.000

presence in the community land decreases (I. presence decreases). As expected, as we move deeper in the steppe, reciprocal arrangements with other communities develop and herders in the communities are more likely to follow an opportunistic type of mobility and less likely to graze regularly on the site.

(ii) Impact of the current population density only. In four other equations, the current population density alone has an impact on pastoral strategies. With a higher population density there is a lower probability for the community to be involved in range rehabilitation activities and to be unilaterally receptive to outsiders on one hand, and a higher propensity to 'officially' protect the boundaries from outsiders and be composed of settled households on the other hand.

(iii) No impact. Finally, land potential and population density has no impact on the development of fattening activities and the propensity to send unilaterally the animals to other communities.

Livestock holding and intensification

Looking simultaneously at the other results based on the four equations related to livestock holding and intensification strategies, the more the community is connected to roads and their members educated, the greater their livestock activities; livestock holdings are higher and herders are more involved in lamb fattening and range rehabilitation. Governance and, notably, the presence of a leader has an impact on the percentage of households with sheep and the percentage of those who are fattening their lambs. Finally, a 'weak' leadership leads to a greater probability to plant shrubs on the community land.

Mobility and linkages with other communities

Besides land potential and population density, a few other variables explain mobility strategies. Surprisingly, settlement of herders is permanent in communities that were established more recently, and governance variables have impact on the three mobility strategies.

Considering the inter-linkages with other communities, the bigger the community, the greater is its ability to receive outsiders, instead of being unilateral senders of animals. The greater the distance to strategic infrastructures (road and water), the less likely it is for the community to receive outsider flocks, since their remote location is not attractive to outsiders. Land ownership in the cropping zone favors unilateral relations (sender or welcomer). Therefore, unilateral relationship does not constitute a real 'free riding' indicator as it might happen between members of the same community. Finally, a weak leadership leads to more reciprocal arrangements and less unilateral welcomers.

Conclusion

This study shows clearly that great variation exists in the strategies of rangeland communities in Syria vis-à-vis the use and management of their rangeland. This diversity is strongly associated to the potential resources available for each member at the community level, which is determined by the productivity potential of the land and the population density. This result demonstrates that because the rangelands in Syria are officially openly accessible, herders do not start from the same natural capital and, therefore, exhibit strong differences in their pastoral production system. Therefore, efforts to improve rangeland management should be carefully targeted to ensure that any new system developed takes into account the peculiarities of the communities.

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Rainwater harvesting systems in rural areas of the semiarid loess regions of China

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Abstract

Water is the major limiting factor for agriculture, forestry and animal husbandry in the Loess Plateau of northwest China and it is also the key factor for environmental improvement. Rainwater is the major water source for utilization in this region; however, limited and erratic precipitation often results in serious soil and water loss. Rainfall harvesting can address water shortage and environmental problems such as soil erosion, and there is a great potential to develop this resource. Characterized by simple operation, high adaptation, and low cost, rainwater harvesting has gained popularity in rural areas of the semiarid loess regions of China. There are three types of rainwater-harvesting systems in the Loess Plateau: courtyard rainwater harvesting for domestic use, water harvesting for supplemental irrigation for crop production, and water harvesting system for planting trees. Practice of rainwater harvesting shows great promise in alleviating drinking water and food production problems in the Loess Plateau.

Introduction

Rainwater harvesting implies collection and storage of precipitation for different uses. In large areas of the Loess Plateau of China surface and groundwater resources are often either unavailable or too brackish for human consumption and irrigation. Rainwater is, therefore, the only available water resource for domestic use and agricultural production in rural area. Due to low cost, small scale, simple operation, and high adaptation, rainwater harvesting has gained popularity in rural areas.

Rainwater harvesting is an old technique in the Loess Plateau. One of the very old techniques that are still common is the rain-storm flood diversion technique called “warping” (harvesting water as well as sediment). It has been extensively applied in China's loess areas since the ‘spring and autumn’ period of Chinese history (2700 years ago). Underground clay-lined earthen water storage tanks have been used in Gansu Province in the western Loess Plateau to supply water for household use since the Ming Dynasty (over 600 years ago). Other early rainwater harvesting techniques included mini-dams, terraced fields, and circular bunds on hillsides, which were constructed to retain runoff and prevent soil erosion. Currently, modern rainwater harvesting systems, characterized by using modern materials and engineering structures, are being promoted to solve the water shortage problem for agricultural and domestic use in the rural areas in the Loess Plateau (Cook et al., 2000). The objective of this paper is to introduce the design and application of the rainwater harvesting systems in rural area of the semiarid loess regions.

Rainwater harvesting systems

Rainwater harvesting systems include two basic components, a catchment area, usually prepared to induce runoff, and a storage facility for the harvested water. The collected water may be stored in a tank or reservoir or in the soil. A water distribution scheme is required for those systems devoted to irrigation (Brooks et al., 1991). Generally there are three types of rainwater-harvesting systems in the Loess Plateau: courtyard rainwater harvesting (CRH) for domestic use, rainwater harvesting for agriculture (RHA) for supplemental irrigation for crop production, and rainwater harvesting for afforestation (RHAF) for planting trees.

Courtyard rainwater harvesting (CRH) system:

In the CRH system, catchments are rooftops and courtyards. The popular CRH system in rural area of the Loess Plateau is the "1-2-1" rainwater harvesting system launched by the Gansu provincial government to assist each rural households to build about 100 m^2 of concrete catchment, and two concrete storage tanks (20 m^3 each) to irrigate one *mu* (1 *mu*=1/15 ha) of cropland for production of high value cash crops (Fig. 1). Usually each household also owns 50 m^2 cement-tile rooftops to catch rainwater.

The runoff efficiency ranges from 73 to 80% for the concrete courtyard catchments, 62-75% for the cement-tile rooftops, and 24-49% for the brick-tile rooftops (Table 1). The relationship between runoff efficiency and rainfall amount and rain intensity for the catchments follows the function given by Wang and Mu (1998):

$$E = 1 - cP^{-a}I^{-b} \qquad (1)$$

where E is runoff efficiency, P is rainfall amount (mm), I is rain intensity (mm min^{-1}), and a, b, c are the constant. All the correlation coefficients are over 0.9.

The area of a particular catchment can be determined with the following relationship:

$$S = 1000W/P_pE_p \qquad (2)$$

where S is the area of a particular catchment (m^2), W is the water requirement (m^3), P_p is the annual rainfall amount (mm) under rainfall probability of p, and E_p is the runoff efficiency (%) under rainfall probability of p. The water requirement for domestic use can be estimated by water consumption of persons and livestock.

Table 1. Runoff efficiency (%) for various catchment treatments under different annual rainfall and probability (Zhang and Chen, 1997; Li et al., 2000)

Average rainfall (mm)	Probability (%)	Catchment treatments							
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
200-300	50	78	71	41	34	20	41	66	6
	75	75	66	34	28	17	34	64	5
	95	73	62	30	24	14	28	62	4
300-400	50	80	75	49	40	26	46	68	8
	75	78	72	42	34	21	41	66	7
	95	76	67	37	29	17	34	64	5
400-500	50	80	75	50	41	25	47	68	8
	75	79	74	48	38	23	45	67	7
	95	76	69	39	31	19	36	65	6

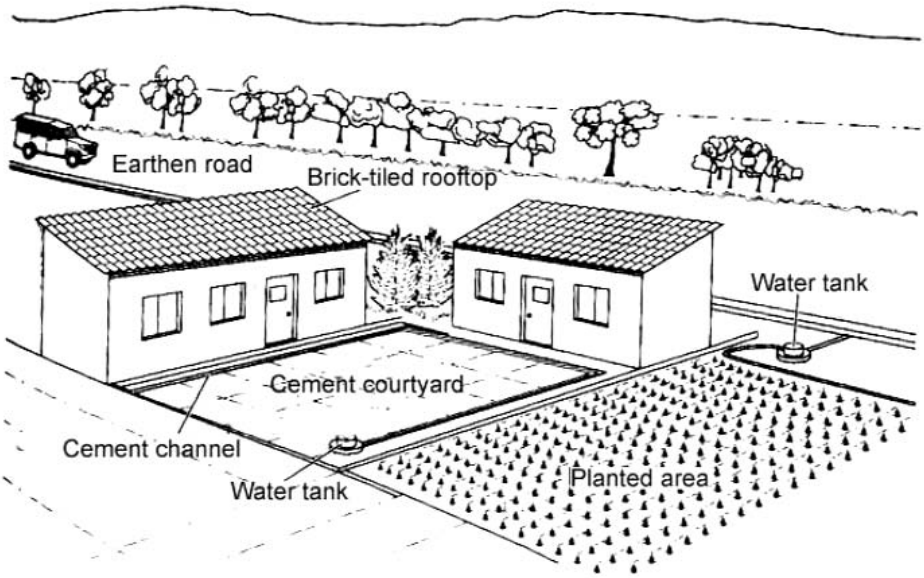

Fig. 1. A schematic diagram showing the "1-2-1" rainwater harvesting system.

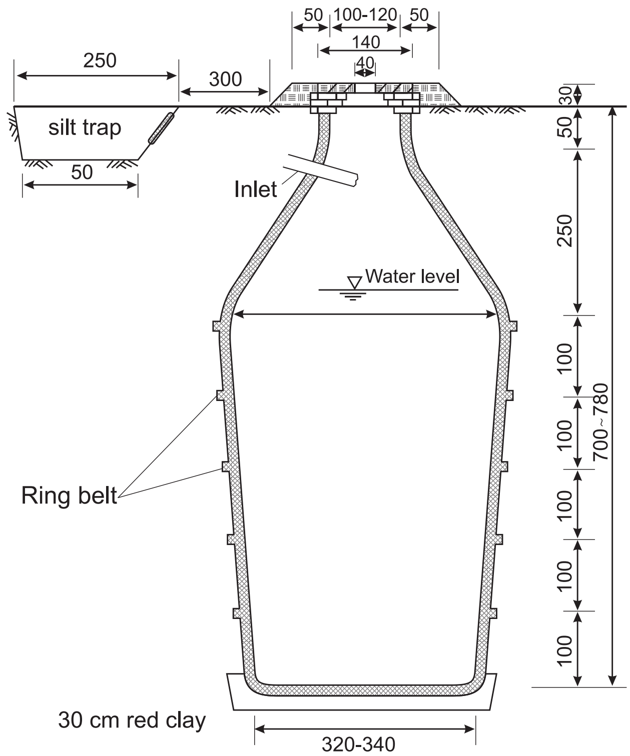

Fig. 2. A schematic diagram showing concrete water cistern (50 m³) in the Loess Plateau (unit:cm).

The popular water storage facility is underground cisterns, which are lined with cement or traditional red clay soil in the Loess Plateau. The shape of water tank is either like a vase or a ball or a column. The diameter ranges from 2 to 4 m and depth 4-5 m. The volume is 15-60 m^3 depending on tank type and water requirement. A schematic diagram of a prevalent concrete water cistern in the Loess Plateau is shown in Fig. 2. A 20-30 m^3 volume tank costs RMB 1200 (about USD 145) including labor cost RMB 500 (about USD 60). The volume of water tank can be determined using the following formula:

$$V = KW/ (1-\alpha) \quad (3)$$

where V is the volume of the tank (m^3), W is annual water requirement (m^3), α is the coefficient of loss due to evaporation and seepage (0.05-0.1), K is the factor of water use whose values can be set 0.8-1.0.

Rainwater harvesting for agriculture (RWA) system:

RWA system consists of a synergetic combination of catchments, water storage tanks, water-saving irrigation system, and water-conservation practices. Catchments are vital to obtain adequate volumes of rainwater runoff. The current popular catchments are lands, or other surfaces with naturally low infiltration rates. They include earth and asphalt-paved roads and natural loess slope. Fig. 3

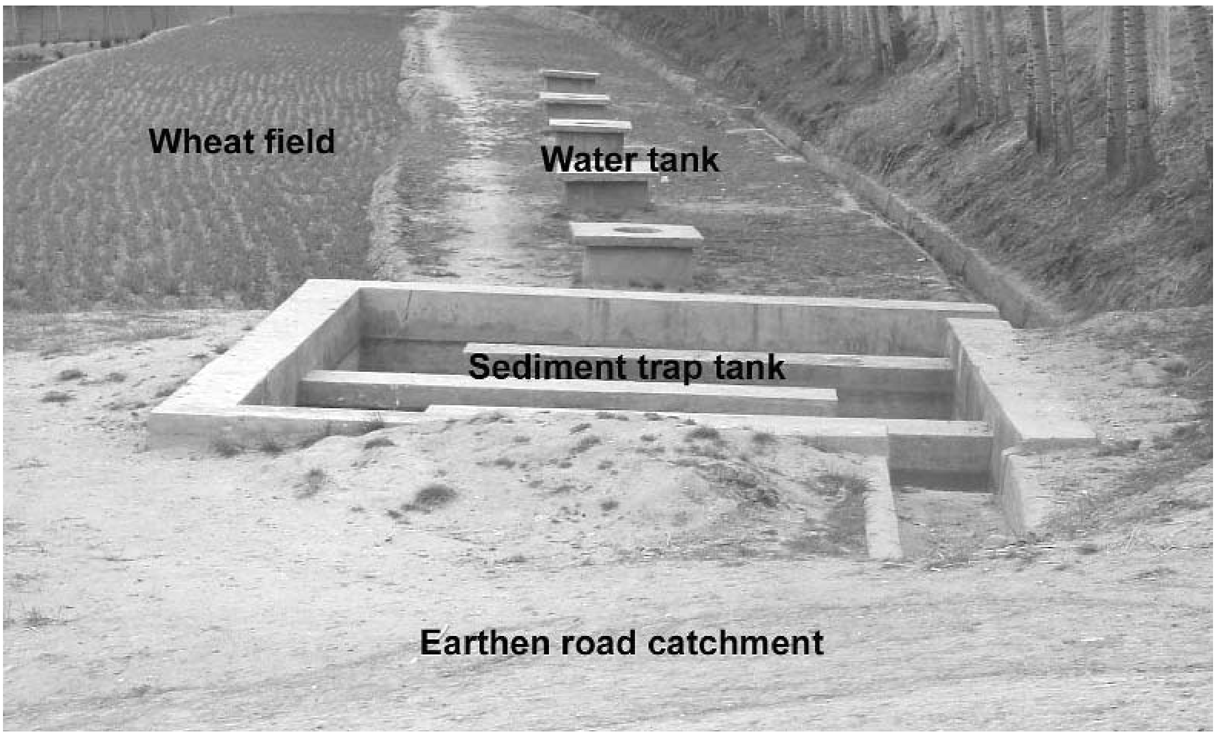

Fig. 3. A combination of earthen road catchment and underground water storage tanks for supplemental irrigation.

shows a photograph of a combination of earthen road catchment and underground water storage tanks for supplemental irrigation for wheat production. Artificial materials such as concrete and plastic are used to improve runoff efficiency in some catchment places.

The proper choice of catchment treatment for rainwater harvesting depends largely on local amount of rainfall and its distribution, soil type and depth, land topography, availability of materials, maintenance costs, and local socioeconomic factors. These tend to be very site-specific (Oweis et al., 1999). More importantly, the water harvesting techniques must be economically sustainable. Among the catchment materials, the simplest, least expensive and probably the most durable is the natural loess soil. However, it suffers from low runoff efficiency and requires relatively high rainfall to initiate runoff. It is possible to compensate for the relatively low runoff efficiency by simply increasing the size of the collection area (Li et al., 2004). The concrete, gravel-covered plastic film and asphalt-paved roads have high runoff efficiencies. They can collect water from rains of less than 1.5 mm. However, such catchments have a high installation cost.

The scale of the rainwater harvesting system for supplemental irrigation can be determined according to the annual amount of runoff production per unit of catchment area, actual area to be irrigated, and the amount of irrigation water required per unit of irrigated area under limited irrigation conditions. The annual amount of runoff production per unit of catchment area in a given area can be estimated by the following formula:

$$Y_w = C_r H_p / 1000 \quad (4)$$

where Yw is the annual amount of runoff production per unit of catchment area (m^3 m^{-2}), C_r is the runoff coefficient from a particular collection surface; and H_p is the annual rainfall depth (mm) under different rainfall probabilities. The annual amount of irrigation water requirements for a certain crop can be determined using the following formula (Li et al., 2000):

$$I_q = (R_w - 10P_e - W_s)/\eta \quad (5)$$

where I_q is the annual amount of irrigation water requirements (m^3 ha^{-1}); R_w is crop water requirements for full yield, namely potential evaporation (m^3), which can be calculated by modified Penman equation; P_e is the rainfall during the crop growing season (mm); W_s is the available water storage in the soil before planting (mm), which can be deter-

Fig. 4. Trees on contour furrow on the loess slope.

mined according to field experiments or can be roughly estimated based on an empirical relationship, (0.15-0.25) R_w , in the absence of field data; and η is the factor of water use and its values can be set 0.8-0.9 when drip irrigation system is used.

In cases where data are not available, the amount of irrigation water requirement can be roughly estimated from empirical irrigation frequency and irrigation amount. For wheat and corn, 3-4 irrigations are applied in the whole growing period with a water quantity of 300-525 m^3 ha^{-1} each time.

Due to the variability of rainfall and runoff, supplemental irrigations should be used in critical stages of the crops such as heading and grain-filling stages for wheat and corn. Point irrigation is a labor-intensive but cheap method adopted by local farmers, who apply water to the root zone of the crop using simple utensils like bowls or cups. For the vegetables, 6-9 irrigations, each of 600-1200 m^3 ha^{-1} are needed in the whole growth period.

Rainwater harvesting for afforestation (RHAF) system:

Rainwater harvesting can significantly increase the rate of tree establishment in drought prone areas by concentrating the rainfall/runoff (Prinz et al., 1998). The most important parameters to be taken into consideration in selecting a water harvesting technique for afforestation are: (1) rainfall distribution and rainfall intensity, (2) topographical condition, (3) runoff/infiltration characteristics of the location, (4) water storage capacity of soils, (5) the type of fruit, nut, or forest tree, (6) available technologies and (7) socio-economic conditions and preferences of the cultivator (Prinz, 2001).

In the loess region of China, microcatchment water harvesting techniques are always used to collect runoff water in the root zone area. Contour furrow is a common microcatchment water harvesting system (Fig. 4). The furrows are often constructed on loess slope (20-60%) with alternate bare catchment in the area with an average annual rainfall of 250-550 mm. The furrow is 50-100 cm wide and the length of the bare catchment is 1-10 m, therefore the catchment to plant area ratio is in the range of 1:1-10:1. By this treatment, contour furrow can catch 25-65 mm runoff per year.

Fish-shaped micro-basins are always used on steep slopes to supply water to single tree or bush. The catchment length is 1.5-3.5 m, the size of the basin is 0.8-1 m and the depth of the basin is 0.4-0.6 m. This technique can be applied on slopes of 1-50% inclination; the steeper the inclination, the more the bunds have to be strengthened. Fish-shaped micro-basins can be applied in areas of 200-600 mm annual rainfall, and the basin can retain 35-44 mm runoff per year.

Rectangular bunds are often applied in the dry level grounds, the catchment is about 0.5-3 m^2 and sometime it is also covered with plastic sheets to induce more water to flow to the rooting area of the tree. These land modification treatments could be effective in average year, but sometimes fail in dry years due to low runoff collection efficiencies and low amounts of collected water. Therefore, other surface treatments such as application of hydrophobic materials (water repellents) and surface binding substances have been proposed and tested in China. Wang et al. (1997) reported that organic silicon treated soil surface had a high runoff efficiency of 90% and significantly increased soil moisture. Generally, advanced water-harvesting technology for afforrestation is still in the experimental stage in China and it has a great potential to develop.

Water quality

Water quality is a major issue in rainwater harvesting system and it determines the nature of use of the harvested water. Water collected from a catchment can contain organism and water-soluble impurities from windblown dust deposited on the surface, chemical pollutant directly from the treatment, and weathering of catchment material by sunlight and heat into water-soluble products. Animal feces can be a source of bacterial and viral contamination (Brooks et al., 1991).

In rural area of the loess plateau, many water harvesting systems have silt traps before runoff enters the cisterns, but no other filter or treatments are applied in most cases. Water quality analysis from the combination of various catchment surfaces and water cisterns indicated that rainwater-harvesting systems could provide a supply of drinking water with good physicochemical qualities; however, bacteriological quality did not meet the acceptable standard (Table 2). The total bacteria and fecal coliform counts in water samples were significantly high. Therefore, several simple and inexpensive measures were proposed to improve water quality for drinking: (1) the first rainwater to be drained off because fecal coliform count was high in water tank at the start of the rainy season; (2) use of a simple sand filtration system to eliminate all suspended solids and thus improve the quality of stored rainwater; (3) boiling the water or disinfecting the water stored in the tank by adding required quantity of bleaching powder. Water from the rainwater harvesting system is adequately safe for supplemental irrigation.

Benefits from rainwater harvesting

The implementation of rainwater harvesting has a profound impact on the development of rural areas in semiarid regions. It has basically solved the drinking-water shortage problem of the people living in the semiarid mountainous areas. The successful example is the “1-2-1” rainwater harvesting program. This has helped farmers to construct 2.18 million storage tanks, supplying water for 1.97 million rural residents in Gansu Province. Rainwater harvesting systems are also practiced in other northwestern provinces such as Ningxia Autonomous Region, Shanxi, Shaanxi and Inner Mongolia Autonomous Region as well as southwestern and southeastern provinces such as Guangxi Autonomous Region and Guizhou Province. Statistics shows that in whole of China rainwater-harvesting practice has solved drink water problem of about 23.80 million rural residents and 17.30 million livestock.

Rainwater harvesting has improved agricultural production. Once the benefits of the rainwater harvesting became evident in solving drink water problem, attention shifted since 1995 to the use of the system for supplemental irrigation of crops. Water tanks or mini-dams have been built adjacent to fields, with roads and hillsides serving as catchments. A 30 m^3 concrete tank can usually irrigate 2-3 *mu* area of farmland. Rainwater harvesting can address the problem caused by temporal discontinuity of rainfall by permitting supplemental irriga-

Table 2. Water quality from rainwater harvesting system in rural area of Gansu Province

	Standards	1*	2	3	4	5	6	7
pH	6.5-8.5	7.6	7.8	7.5	8.0	8.0	8.2	8.1
EC (μ S/m)	500	201	203	198	202	197	197	195
Hardness ($CaCO_3$) (mg/l)	≤450	75.7	127.0	65.5	59.7	137.0	124.0	50.9
Arsenic (mg/l)	≤0.05	0.004	0.005	0.010	0.008	0.010	0.010	0.016
Cadmium (mg/l)	≤0.01	0.003	0.004	0.004	0.004	0.005	0.003	0.004
Chromium (mg/l)	≤0.05	0.009	0.003	0.006	0.015	0.003	0.004	0.005
Lead (mg/l)	≤0.05	0.014	0.01	0	0	0.02	0.02	0.027
Mercury (mg/l)	≤0.001	0	0.0004	0	0	0.0005	0.0005	0
Copper (mg/l)	≤1.0	0.012	0.01	0.006	0.006	0.015	0.02	0.017
Zinc (mg/l)	≤1.0	0	0.04	0	0	0.04	0.05	0.08
Iron (mg/l)	≤0.3	0	0.15	0	0.005	0.15	0.06	0.29
Manganese (mg/l)	≤0.1	0	0.04	0.026	0.005	0.05	0.04	0.067
Selenium (mg/l)	≤0.01	0.004	0.004	0.004	0.005	0.004	0.005	0.004
Chloride (mg/l)	≤250	7.1	7.0	4.9	5.4	2.0	1.0	5.35
Fluoride (mg/l)	≤1.0	0.32	0.76	0.34	0.19	0.32	0.46	0.43
Prussiate (mg/l)	≤0.05	0	0.001	0	0	0	0.002	0
Sulphate (mg/l)	≤250	51	22	25.6	12.8	10	93	6.2
Nitrate (mg/l)	≤20	0.65	0.93	1.27	0.22	0.25	0.38	0.96
COD (mg/l)	≤15	9.1	12.5	8.2	7.2	5.3	7.8	8.6
BOD5 (mg/l)	3.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00
Total bacteria /l	≤100	340	300	700	740	760	720	420
Total coliform /l	≤3	330	230	300	460	350	360	230

1= concrete courtyard + clay-lined earthen tank; 2= concrete courtyard + concrete tank; 3= compacted earthen courtyard + clay-lined earthen tank; 4= compacted earthen courtyard + concrete tank; 5 = earthen road + clay-lined earthen tank; 6 = earthen road + concrete tank; 7 = tile roof + concrete tank.*

Table 3. Effects of rainwater harvesting for supplemental irrigation (SI) on crop yields and water use efficiency

Crop	Irrigation amount $m^3\ ha^{-1}$	Yield ($kg\ ha^{-1}$)	Yield increase by SI (%)	WUE ($kg\ m^{-3}$)
wheat	225-300	897-6843	10.5-88.3	0.7-5.2
Corn	375-400	2940-9050	19.6-88.4	1.5-5.7
Millet	300	2583-2750	20.5	0.9-1.6
Flax	225	530-2505	44.7-120.6	0.9-2.9

tion during the critical stages of the crops and can thus improve crop yield and water use efficiency significantly (Gao et al., 2001) (Table 3). Some 236,400 ha farmland is irrigated at present using harvested water in Gansu Province and 1.51 million ha in the whole country. Rainwater harvesting has a great potential to increase agricultural production in semiarid regions of China, and therefore it has been recognized as one of the effective ways to ensure food security in the country.

Rainwater harvesting has permitted the adjustment of agricultural structure and improved incomes. A combination of growing cash crop with animal husbandry using the harvested rain water has resulted in the increase of income of the rural households. The economic analysis of rainwater harvesting and supplementary irrigation indicated that the highest net economic benefit was 60, 000 Yuan ha^{-1} (about 7,255 US$) for planting vegetables in greenhouse, followed by fruit trees with 19, 914 Yuan ha^{-1} (about 2,408 US$). Zhu and Li (2001) reported that, out of the total area of land irrigated with the harvested rainwater, the area under orchards and cash crops accounted for 17% and 19% respectively in Gansu Province. Besides, farmers have built greenhouses on a total area of 1, 567 ha for increasing their income.

Conclusion

Rainwater harvesting has played a significant role in promoting the ecological and environmental conservation. Rainwater harvesting is in itself a useful measure in soil and water conservation by capturing and storing runoff, which can directly contribute to the reduction of soil and water erosion. Moreover, rainwater harvesting has beneficial effects on eco-environmental improvement through its feedback mechanism in the comprehensive agricultural management system. As mentioned above, rainwater harvesting can increase crop production by implementing supplemental irrigation. Increased productivity in flat and terraced fields can help induce farmers not to cultivate steep slopes, thus converting more steep cultivated lands into forest or grass land, which would reduce soil erosion.

Acknowledgments

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Improving rural livelihood in Afghanistan through the promotion of sustainable production technologies for high value crops

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Abstract

Rehabilitation of Afghanistan's agricultural production capacity is fundamental to any recovery of food security and the improvement of rural livelihoods. Currently, only some 6% of the irrigated area is planted with vegetable crops grown both for family consumption and sale as a cash crop. However, only a limited number of farmers who have access to secure irrigation systems (wells) are able to grow vegetable crops profitably. In areas where arable land is limited and water is scarce, protected (plastic) agriculture (PA) offers an opportunity for vertical expansion and for generating returns per unit of land and of water from the production of high value crops, which would represent an attractive alternative to the cultivation of poppy. Since 2004, a project was implemented under the Rehabilitation of Agricultural Markets Program (RAMP) funded by United State Agency for International Development (USAID). The project established a PA center for adaptive research and technology transfer and a fabrication workshop to manufacture green house structures, and strengthened the capacity of hundreds of farmers, extension agents, NGO personnel, etc. in practicing PA. Results from a socio-economic assessment provide sufficient evidence that PA has the potential to contribute significantly to both the development of rural communities in the dry water-scarce areas in Afghanistan and to the Afghanistan economy. It can play an important role in supplying local markets with fresh produce that could not be grown otherwise, and in creating employment within rural communities and production opportunities for the disadvantaged, particularly women, returning (landless) refugees, and the disabled. It also offers potential for development of a private service sector in the construction and supply of protected agriculture equipment. Ultimately, the PA could be expanded to serve the export market and generate a valuable source of foreign revenue. This would also ease pressure on natural resources of land and water in the drier areas of Afghanistan.

Introduction

Afghanistan's pre-war economy was mainly based on agriculture and livestock production; an estimated 85% of the population was living in rural areas and the bulk of the labor force was engaged in agriculture and the processing of agricultural and livestock products. Despite its difficult terrain, adverse climatic conditions and limited arable land, Afghanistan was largely self-sufficient in food and was a significant exporter of agricultural products, particularly horticultural products. In recent decades, Afghanistan has been devastated by years of war and civil strife and a debilitating five year drought, all of which have resulted in the collapse of the agricultural sector and devastated the country's food production capacity. Compared to the pre-war situation, Afghanistan now is one of the countries with lowest per capita food availability in the world.

The collapse of a productive agricultural base in Afghanistan has also resulted in the lack of employment opportunities and a large number of people have lost their livelihoods. As consequence of the conflicts in Afghanistan, there has been widespread destruction of family life; many women have been widowed or have lost the male members of their household, and therefore many rural households are headed by women, leading to an increasing feminization of agriculture. The country will require substantial humanitarian, rehabilitation and reconstruction assistance over a long period to regain its food security and reduce poverty. Rehabilitation of agricultural productive capacity will be fundamental to any economic recovery.

Simultaneously, there has been a trend for increasing illicit cultivation of poppy by those farmers who fell in the trap of those involved in clandestine narcotic trade. This has lead to global call for banning illicit poppy production in Afghanistan. While the ban on poppy cultivation is a positive development socially, there are serious implications for the rural economy. Poppy farmers and workers engaged in harvesting poppy – a highly labor intensive process—are losing a major source of income. If the ban on poppy cultivation is to be maintained, assistance is urgently needed for creating alternative income-generating activities.

Rehabilitation of Afghanistan's agricultural productive capacity is fundamental to any recovery of food security and improving the livelihoods of the rural population. Currently, only some 6% of the irrigated area is planted with vegetable crops grown for both family consumption and sale as a cash crop. The major vegetable crops include melon, watermelon, onion, potato and tomato, which account for 87% of the total area under vegetable cultivation. However, only a limited number of farmers, having access to secure irrigation water (from wells), are able to grow vegetable crops profitably.

Why protected agriculture?

Protected agriculture, the production of crops under protective covering (plastic houses or greenhouses), represents an intensive form of crop production in which both the growth environment and timing of production can be controlled and yields and water-use efficiency can be substantially improved (Figures 1 & 2).

There is a wide range of vegetable crops that can be grown in the diverse agro-ecological zones of Afghanistan. Their growing season can be extended if they are grown under protective housing. The technology is suitable for use on marginal or other non-productive lands and, if simple structures are used, the technology is both affordable and sustainable for marginalized people. It is, therefore, particularly suited to marginal and water deficient areas where farming communities are highly vulnerable to scarcity of water and are struggling to improve their livelihoods.

In areas of Afghanistan where arable land is limited and water is scarce, protected agriculture offers an opportunity for vertical expansion and for generating returns per unit of land and of water from the production of high value crops, which would represent an attractive alternative to the cultivation of poppy. However, most rural people produce crops to meet their own food needs and are thus involved in subsistence agriculture rather than market-oriented crop production. Constraints to be addressed are the lack of technical knowledge within Afghanistan's farming community about the methods used in protected agriculture, access to equipment and materials for the construction of protective houses, and the identification of the most suitable crops for production for which there is a ready demand in the market.

Technology transfer

To help farmers, and speed-up rural development in Afghanistan, the International Center for Agricultural Research in the Dry Areas (ICARDA) developed a three-year project for transferring the intensive production system (protected agriculture) to farming community in Afghanistan for raising

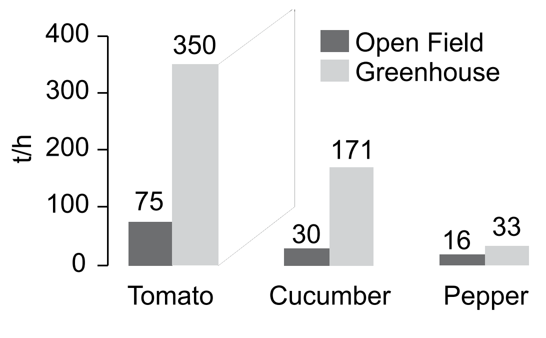

Fig. 1. Production levels of open field and protected agriculture.

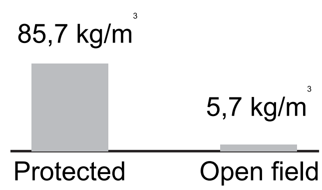

Fig. 2. Productivity per m³ of water for tomato grown under protected agriculture and in open field.

cash crops. The project started in January 2004 with financial support from United State Agency for International Development (USAID). The project promotes the adoption of affordable and sustainable protected agricultural systems to produce high value crops, using marginal or otherwise non-productive lands and limited water more efficiently, by establishing a central demonstration, training and technical backstopping site within Kabul and by installing simple greenhouse structures at selected pilot sites with participation of local farmers. The Project is using participatory approaches for transferring the technology and is conducting such activities as holding Farmers Field Schools (FFS); mid and end-of-season workshops and training for growers and the trainers.

The FFS approach is an effective method to disseminate technical information and to do problem solving at grower's site. The FFS is also a successful platform for growers to get together and to discus their technical problems with specialists in the field. The subjects dealt in the FFS are selected based on the status of the green houses, stage of crop growth and the season.

In order to discuss the production and plant protection problems faced by growers and to insure successful implementation of Integrated Production and Protection Management (IPPM), workshops were conducted in which growers, extension agents, and agricultural policy makers participated. The project paid special attention to capacity building and human resource development to hasten the process of wide adoption. A number of on-the-job training courses for growers, extension agents and NGO personnel were therefore organized. In addition, two on- the-job training courses on GH management were implemented in the advanced production sites and research centers in Oman and Egypt, where farmers from Afghanistan could exchange experience with their counterparts in these countries. The project also conducted a study to survey the cash-crop market in Kabul. This was aimed at finding the best crop options for production by growers in different seasons to maximize their benefits. A database was developed to understand the trends in demand, supply, and prices to facilitate designing appropriate crop calendars and market strategies.

A brief description of various project activities is given below.

Establishment of a protected agriculture center in Kabul

Protected agriculture (PA) is a relatively new agro-industry in Afghanistan. It is, therefore, important to demonstrate to growers, extension agents, NGO personnel, and other stakeholders the potential of PA and all associated practices involved in a successful PA, such as drip irrigation, plant nursery management, integrated production and protection management (IPPM), harvesting, and post-harvest handling of the produce. For this reason, a Protected Agriculture Center (PAC) has been established in Kabul. The PAC is serving not only as a research center for protected agriculture but also as demonstration unit for the production of high-value crops; a training center for growers, extension agents, agriculture engineers and NGO personnel in all aspects of production techniques; and as a central point for technical support and advisory services. During the installation and assembly of greenhouses (GHs) at the PAC, the participation of local extension agents, growers and technician was ensured so that they might gain practical knowledge in the preparation of needed material for, and the installation of, GH structure. Installation of drip irrigation and fertigation systems was also done in each GH with their involvement.

GHs were planted with different cash crops such as cucumber, tomato, lettuce and green pepper. In addition to fulfilling the technical aspects of the research center, these crops also generated some revenues. For example, the first harvest in one of the GHs yielded 182 kg of cucumbers (620 pieces) that were sold at 10 Afghani (AFs) per piece by the Improved Seed Enterprise (ISE) of the Ministry of Agriculture, Food and Animal Husbandry (MAFAH) of Afghanistan. Total production in 75 days was 1.7 t, which was sold for about US$1200.

Establishment of a green house manufacturing workshop

Sustainability and expansion of the protected agriculture in Afghanistan would mainly depend on the availability of the structural material needed for making GHs and other production facilities within Afghanistan. A workshop was therefore established to start producing single span GH structures at the PAC. Local technicians were trained in manufacturing the structures and the majority of the items required were purchased locally. Much of the needed machinery was also purchased locally. The establishment of this facility contributed tremendously to reducing the initial capital required to develop the structure. The workshop produced good quality material for GHs so that the costs of GHs developed with locally manufactured structures was about 40% less than the imported ones.

Selection of pilot growers and establishment of production facilities at grower's fields

The project was designed with the major aim to promote the adoption of affordable and sustainable high intensity production system for cash crops, using marginal or otherwise non-productive lands and water more efficiently. This was achieved by installing simple GH structures at selected pilot farmers' sites. The farmers were selected based on group discussions with them in meetings in which the concept of the project was discussed. All participating farmers were from the active segments of the farming communities in Kabul, Kunduz, Parwan, Ghazni, Helmand and Nangarhar. A total of 35 GHs were installed till April 2005. The pilot farmers received all greenhouse production materials, fertilizers and seeds as well as an intensive training on GH management and crop handling. The technical backstopping and follow-up were provided by ICARDA scientists and consultants using participatory approaches.

Capacity building and human resource development

A human resource development and training program was designed and implemented for improving the knowledge and know-how of local researchers, extension agents and growers on different aspects of cash crop production in the GH. The program included the training activities in plastic house installation, preparation and management, and in the integrated production and protection management (IPPM); on-the-job training for farmers, national agricultural research staff, extension agents and technicians within Afghanistan and in leading farms outside Afghanistan; and production of training manuals and technical booklets in the local language. As of January 2006, the project trained 380 researchers, extension agents and growers through 17 training courses within Afghanistan. Special focus was on training the trainers who can deliver the new technology to the other growers and end users. The project also held 5 workshops and 7 Farmer Field Schools (FFS). During the workshops and FFS different problems and constrains regarding the production of cash crop under the GHs were discussed in detail by growers, extension agents and NGO teams with ICARDA scientists and consultants. Furthermore, 10 growers and extension agents were trained at leading farms and agricultural research centers outside Afghanistan, in Egypt and Oman. The main topic of these courses was GH production management. This is the first time that a project had sent Afghanistan growers overseas for training. Eight training manuals were published in local language by the project. These handouts covered such subjects as greenhouse installation, climate control and irrigation requirement of crops, fertigation, management of drip irrigation, and raising nursery for different crops for vegetable production.

Impact of the project on livelihood of the growers

In the fourth quarter of 2005, ICARDA conducted a socio-economic study to monitor the progress made against the baseline indicators, evaluate farmers perceptions, and identify potential constrains to a wider adoption of PA technology in Afghanistan. Results of the study, based on the cash crop production records of the pilot growers, generally showed the success in adopting the technology. The analysis of the breakeven points and simulations showed that cucumber growers should target yields above 24,000 fruits for summer sales when prices could be as low as Afghanis (Afs) 1.5/fruit. In contrast, the yields could be 8,000 fruits in winter or during Ramadan when the price is expected to be higher than Afs 5/fruit (Figure 3).

Economic comparison between cucumber production in GH and open field are shown in Table 1. Total income generated on one Jerib (2000m^2) land area basis is 6 times higher (the net income is 4 times higher) under the greenhouse condition than that obtained in the open field condition. This is a great advantage given that greenhouses can be installed on marginal lands with very low rental value in rural areas.

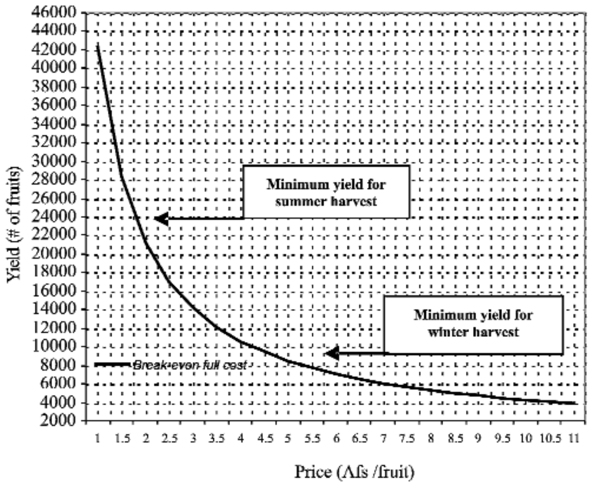

Fig. 3. Minimum yield for given prices to break-even in cucumber production under greenhouse.

The impact of the greenhouse technology on growers' incomes was assessed. All growers interviewed did not change their cropping patterns, the number of crop or the size of land they used to cultivate prior to their induction to PA. Therefore, for these farmers the greenhouses were "add-on" to the portfolio of crops they used to grow and provided additional income. Results show that PA contributed to an increase of 8% and 138% in income generated from crop production in 2005. This success has motivated farmers to erect more structures in the future.

Feedback from policy-makers and growers

The Afghan agricultural policy maker's attention and interest in Protected Agriculture, after what they have seen in the farmer's field, is expressed in their speeches and reflects on the success of the project. H.E. Mr. Mohammad Sharif, Deputy Minister, Ministry of Agriculture, Animal Husbandry & Food said in a gathering of farmers: "Protected agriculture helps growers to generate more income. In the Ministry, we are trying to modernize the agriculture sector. ICARDA has helped us to adopt the new technology of protected agriculture since last year. They established a center in Badam Bag. I have seen the greenhouse in Kunduz province in a private farm producing cucumber. This will help growers to generate more income. All of you should learn this technology and also teach other growers. Each agriculture cooperatives should have at least one GH. We can construct the GHs on a small piece of land and it is very easy for our families and rural women to work inside them to produce cash crops for the market". H.E. Abdul Jabar Tagva, Governor of Parwan Province, in a recent communication wrote, "Protected Agriculture has brought new hope to Afghan growers. I thank God that our country after years of war is starting a new age of development and growth. Establishment of these

Table 1. Comparison of profitability of cucumber production under greenhouse[1] and in open field on the basis of 1 Jerib (2000 m^2) land area. (Information obtained on spring production of cucumbers from the grower in Parwan province, Afghanistan)

Item	Unit	Greenhouse production[1]	Open field production	Change (%)
Production[2]	kg	19,500	3,700	427
Producer price[3]	Afs/kg	24	18	33
Material input cost	Afs	118,200	4,650	2,442
Labor costs	Afs	76,800	18,000	184
Depreciation /season	Afs	60,000	-	
Total production cost	Afs	255,000	22,650	913
Total income	Afs	468,000	66,600	603
Net income	Afs	213,000	43,950	443
Yield	MT/Jerib	20	3.7	427
Water use efficiency[4]	kg/m^3	18	2.1	778
Net return/ person day labor	Afs	1,166	688	69
Net return/ m^3 water	Afs	221	24	805

[1] *For adequate spacing and ventilation 6 greenhouses could be erected on 1 Jerib of land.*
[2]*Open field cucumbers are longer and bigger than those produced in GH due to varietal differences; accordingly 6 cucumbers from open field and 8 from GH weigh 1 kg.*
[3]*Cucumbers are sold by number and not weight; GH cucumber carries a price premium for quality.*
It is assumed that the open field uses 10 times more water than greenhouse cucumber production.

greenhouses was a very good step towards agricultural development and provides the Parwan growers with new hope for a better future. I appreciate all the efforts and dedication …for establishing these GHs which are in production now. I hope that this great movement will expand across Afghanistan, especially in Parwan province to help growers who lost everything during the war."

During the mid-season workshop in July 2005, growers expressed their reflections on PA. Some of these are reproduced here. Mr. Aga Ghol, a grower from Helmand, said his GH area was about 300 m^2 and he produced 9000 cucumbers. "Right now (recorded July 05) in Helmand there is no cucumber from open fields, but my plastic house (270 m^2) is still producing and has given me the same yield I usually get from 2 Jerib. Look at my notebook; this is my yield which I have sold for Afghani 19,500 ($390)." Mr. Gous Mohamed, a grower from Kunduz said, "...I have so far harvested 9,000 cucumbers. The plants are very healthy and I have no problem inside my plastic house. I am expecting about 1500-2000 more cucumbers to be harvested. When I installed the plastic house, my neighbors were suspicious, but now they wish to have a plastic house in their farm. The Governor of Kunduz and many growers visited my plastic house and tasted my cucumbers." Mr. Abdul Ahad, a grower from Nangehar told his fellow farmers, "….brothers, let me tell you (*reaching out for paper from his pocket*), in my plastic house, I had only 380 plants because the frost killed the rest but I harvested 9,950 cucumbers sold at 20,290 Afghani ($400). I planted my seeds on 23 March and on 20 April transplanted the seedlings in the plastic house. I made 10 pickings, starting from 26 May until 27 June. I was checking my plastic house everyday and had no problem with pests."

Mr Mohamed Qasim, a grower from Helmand was even more startling in his speech, "I am from Helmand where most of farmers grow opium. From one Jerib of opium we make US $400-450 profit, but the government has prohibited growing opium. This year I have one plastic house in my farm and it produced 8,500 cucumbers. The income from the cucumbers is more than one Jerib of opium. For opium, we can produce one crop per year and it requires a lot of labor, while we can produce 2-3 crops of cucumber in plastic house on small land with less labor and more income. I think if you give farmers a plastic house they will stop growing opium."

Mr. Moladad, a grower from Parwan and Mr. Zarif, a grower from Nangarhar had similar experience to share about the profitability of their first try with PA. They are the envy of their neighbors as reflected in the statement of Mr. Zarif, "All my neighboring farmers wish to install plastic houses on their farms after they saw my cucumber crop. They are willing to meet some of the costs involved in erecting the greenhouses."

Acknowledgements

We would like to acknowledge the interest and hard work of the pilot growers in Kabul, Parwan, Ghazni, Helmand, Kunduz and Nangarhar provinces of Afghanistan. Thanks are extended to the Research and Extension teams of the Afghanistan Ministry of Agriculture, Animal Husbandry and Food for their support and collaborative efforts in the implementation of the project. The financial support of United State Agency for International Development (USAID) is highly appreciated.

Range management options and transaction costs amongst pastoral households in West Asia and North Africa

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Abstract

Recent proposals for the management of rangelands have focused on the need to account for pastoral mobility to enhance the successes of development interventions in pastoral areas. The general assumptions support that the use of existing pastoral mobility strategies would reduce transaction costs. These proposals, however, face many challenges following the transformation of many pastoral production systems and livelihood strategies. Traditional access-options based solely on institutional arrangements, collective action and reciprocity are eroding or are associated with high transaction costs that are pushing pastoral communities to rely more on markets and individual production and livelihood strategies. Therefore, the reduction of transaction costs might be true when it comes to collective management of the resources but would be different when one considers individual household transaction costs and mobility strategies. This phenomenon is obvious amongst pastoral sheep producers in the West Asia and North Africa region. Sheep producers are increasingly relying on crop residues and market feeds. Institutional arrangements continue to be an important part of their production strategy but the length of their stay outside community pastures is reduced. Moreover, herd movements are associated with high transaction costs, which limit the use of this option, especially for the small livestock owners.

This paper uses the data collected from the property rights research conducted on rangelands from 1999 and 2000 in the Mashreq and Maghreb Project in Jordan and Tunisia. Using econometric analyses, the study fills an important gap over the discussion of the impact of introduced range management options on transaction costs of herd mobility. The study looks at the determinants for herd mobility and evaluates transaction costs associated with mobility and distance of that mobility.

Introduction

Since the publication of the mobility framework (Niamir-Fuller and Turner, 1999) as an approach for the development of pastoral production systems, the discussion around pastoralism and mobility has gained new momentum. The framework builds on the results from numerous pastoral studies that recognized the importance of mobility as a production strategy as well as a critical risk management one (Scoones, 1996; Swallow, 1994; Lane and Moorehead, 1996; Niamir-Fuller, 1999; De Hann, 1999; McCarthy et al., 2000; Ellis et al., 1987; Ellis and Swift, 1988). Even though most of the discussion around mobility focuses on pastoral systems in Sub-Saharan Africa, pastoral systems in West Asia and North Africa (WANA) share identical characteristics and in the past have also relied on very elaborate grazing networks to supplement feed needs during dry and winter seasons or drought periods (Bocco et al., 1993; Berque, 1934; Qarro, 1997; Squires and Sidahmed, 1998). Governments in WANA countries have introduced many policy reforms and range management options to control access and use of pastoral resources. These institutional innovations have destroyed many of these grazing networks and transformed the way pastoral systems operate (Ngaido, 1999).

Scarcity of local grazing resources has been a recurrent, seasonal, and periodical constraint of pastoral production systems, especially when associated with droughts, and a driver for herd mobility (Ngaido, 1999; McCarthy et. al., 2000; Ellis and Swift, 1988; Niamir-Fuller, 1999). Mobile pastoral systems are, however, being challenged by high demographic pressures, government settlement, and range management policies that are prompting growing crop encroachments and breakdown of many pastoral grazing networks. The introduction of new institutional options for managing local pastures, which limit access of community members to their own pastures and restrict the capacity of pastoral communities to negotiate reciprocal arrangements with neighboring communities, add additional constraints to pastoral production systems. These different constraints determine the extent of herd mobility and transaction costs associated with accessing additional grazing resources. Nonetheless, individual livestock owners continue to privately negotiate grazing contracts with members within and outside their communities to access private fields and ranges.

Pastoral production systems in WANA countries are, therefore, undergoing important structural changes both in terms of how the industry operates as well as the feeding strategies adopted by herders to satisfy the feed requirements of their herds. New types of livestock entrepreneurs with very large herds, who are producing for exports to the Arabian Peninsula markets, are intensifying their production systems by using concentrated feeds to fatten sheep. Other livestock producers maintain their extensive systems by relying on their own pastoral resources for grazing and on market access options for concentrated feeds and crop residues for supplementation (Ngaido et al., 2001; Ngaido and McCarthy, 2003).

Generally, it is assumed that the management of pastoral resources under common property enhances mobility and lowers transaction costs for accessing grazing resources (Roe et al., 1998; Niamir-Fuller 1999; McCarthy and Vanderlinden, 2002). The main caveats for low transaction costs under common property systems are the existence of adequate local grazing resources and a strong network of neighboring pastoral communities that grant to each other access and use of grazing resources through reciprocal and other institutional arrangements during periods of feed shortages. We postulate that given the transformation of range management systems and the erosion of traditional grazing networks and reciprocal arrangements in WANA countries, pastoralists operating under traditional collective systems may face higher transaction costs than those operating under new range management systems. We further considered that transaction costs for grazing included herding costs, animal trucking, and rental costs for grazing resources.

These higher transaction costs are associated with the difficulties herders face to operate under an extensive production system characterized by increasing scarcity of grazing resources and qualified herd managers. To illustrate our argument, we compare the effects of different rangeland management options in Jordan, where state have asserted ownership rights over rangelands (Roussan et al., 2001; Ngaido and McCarthy, 2002), and Tunisia, where the government implemented full privatization in the central part of the country while maintaining collective management systems in the southern regions (Elloumi et. al, 2001). In both countries, rangeland policies forced many pastoralists to settle and become agro-pastoralists (Lahmar, 1994; Blench, 1998; Ngaido et al., 1998).

The aim of this paper is to evaluate: 1) the effects of introduced range management options on the propensity of herders to move; 2) the extent of transhumance amongst livestock owners; and 3) transaction costs associated with their mobile production systems. It is clear that mobility must be considered as a long term strategy and that a one-year observation cannot capture the behavior of pastoral households during good, poor, and medium years. However, given that 1999 was the second consecutive drought year in the region, the data collected should be fairly representative for the type of strategies that pastoralists would undertake during drought periods. We hypothesize that the introduction of new range management options reduces mobility and transaction costs for access to grazing.

Range management options, mobility and transaction costs

It is critical to distinguish, when one talks about mobility, between local resources, which are recognized as territories for particular pastoral groups, and access options which include all the different mechanisms and institutions used by pastoralists to gain/grant additional grazing resources during specific periods of the years or during droughts (Ngaido, 1999; Ngaido and McCarthy, 2002; Ngaido and Shomo, 2001). Local pastoral resources include croplands and grazing areas and constitute the territory of a specific group. Grazing access options, which are composed of multiple grazing resources located under different agro-ecologies, are of different quality and importance, and under different tenure regimes. Contrary to local resources, where membership is the main criteria for accessing and using grazing resources, access options are obtained through institutional arrangements and market mechanisms.

Increasingly, however, mobility is a costly activity that requires: 1) renting access from different sources including private farmers, state institutions on forest and pasture reserves, and communities; 2) paying herders in cash instead of sharecropping arrangements whereby owners and herder shared production risks; and 3) trucking herds, feeds and water to more remote areas. Moreover, the type and nature of the management options governing access and use of the local resources determine pastoral production strategies. Some range management options may be less conducive to mobility than others, even if herd mobility is desirable, because communities' pastoral resources, which formerly allowed them to set up reciprocal arrangements with other communities, have evolved into different tenure and production systems, especially farming. In the following section we discuss the different range management options that have been introduced in Jordan and Tunisia.

The scope of this section is not to discuss about common property resources (CPRs) because there is a very impressive body of literature tackling different aspects of the management of common resources (Hardin, 1968; Bromley, 1984; Bruce, 1986; Blaikie and Brookfield, 1987; Lawry, 1990; Ostrom, 1990; Wachter, 1992; Baland and Platteau, 1994, 1996, 1998; Knox-Mcculloch and Hazell, 1998). Though, it is important to highlight that most of the introduced range management options result from the debate over the management of the commons, which led numerous governments to undertake different reforms. Yet, there is very little discussion on the effects of introduced management options, which have changed or precluded such reciprocal arrangements, on the extent of livestock mobility and transaction costs associated with such mobility. Jordan and Tunisia, as indicated before, exemplify two different institutional approaches to range management. In Jordan, the government asserted ownership rights over rangeland resources but granted to settled pastoralists registered use-rights on their cultivated lands and private property on their house plots. In Tunisia, the government privatized central Tunisia and transformed pastoralists into cereal and tree crop producers while pastoral communities in the south continued to operate under their traditional systems. Six different management systems were identified in the two countries including collective systems, state reserves, forest regime, cooperatives, private ranges, and improved collective systems.

Situation under the "Tribal collective management" option:

Collective systems are the pseudo continuation of tribal management systems but tribal institutions have very limited role in the management of their resources. In the case of Tunisia, communities continue to assert ownership rights over their pastoral resources, especially in the southern regions. Each tribal group knows the boundaries of their territories and exercise quasi control over their lands. Under this system, transhumants gain access freely as host communities expect to receive similar arrangements when they move to the transhumants' pastures at a given season or during drought periods. This system performed very well as long as none of the groups, transhumants and hosts, invested in the management of grazing resources. However, once one of the groups invests or the state invests in improving the productivity of the ranges located in their territories, the use of reciprocal arrangement becomes very difficult because new rules will be enacted to govern access and use of improved pasture resources.

In our sample, pastoralists operating under tribal collective systems in Jordan and Southern Tunisia accounted for 22% and 31% respectively (Table 1). These systems have not experienced the introduction of new range management systems on their local resources. Contrary to our expectations, pastoralists operating under this system did not own the largest flocks and ranked second for the average distance of herd movements after state reserves in Jordan and improved tribal collective in Tunisia. However, pastoralists under the collective system had the highest average transaction costs per TLU and on average spent 12.63 JD per TLU in Jordan and 51.14 TD per TLU in Tunisia.

Situation under the "State reserve" option:

State reserves are areas fenced off and rehabilitated with exotic shrubs (*Atriplex* and cactus). These state reserves have been a major strategy to reverse rangeland degradation and provide fodder to livestock (Osman et al., 1994; Leybourne et al., 1993; Nordblom and Shomo, 1995). Forest services are responsible for the management of these reserves and periodically grant grazing licenses to pastoralists. Once pastoral resources are transformed into state reserves on the territory of a specific pastoral community, members can no longer grant reciprocal access to the other pastoral communities. There are numerous examples where pastoral communities refused grazing access to other groups following the improvement of their ranges even if improvements were carried out by the state and guest pastoralists had possibilities to purchase grazing licenses (Ngaido et al., 1998; Rae et al., 1997). Pastoralists may, however, on an individual basis continue to access other pastures outside their local resources through grazing contracts.

This system was mainly found in Jordan and accounted for 9% of our sample (Table 1). The average herd size was 21 TLU and the average transaction costs per TLU were 11 JD. Moreover, pastoralists parts of whose pastures were transformed into reserves migrated farther than all the other groups with an average of 26 km. Many of them had to travel to very remote areas of the rangelands.

Situation under the "Forest regime" option

Forest regime options include forest pastures in the case of Jordan and collective pastures, which are entrusted by landowning communities to forest services for the rehabilitation and improvement, in the case of Tunisia. The entrusted common pastures are generally remaining pasture areas that were not suitable for cropping. Similarly to state reserves, communities operating under these systems pay fees to graze or cut and carry fodder from these pastures. Under these conditions, pastoral communities cannot grant reciprocal access rights to other communities and, therefore, affect the capacity of the community to move their herds to other areas.

Livestock owners operating under this system accounted for 13% and 28% of our sample in Jordan and Tunisia, respectively (Table 1). The average migration distance was 4.9 km in Jordan and 1.6 km in Tunisia while the transaction costs per TLU were 1 TD in Tunisia and 4.97 JD in Jordan. Moreover, in Jordan, these households had the second largest average livestock ownership with 28 TLU while in Tunisia households of this group owned 6.24 TLU.

Situation under the "Herder cooperative" option

These cooperatives, which were part of the agricultural modernization agenda, were a means to break down tribal organizations and modernize livestock production systems. However, these cooperatives had very little range management roles and have remained very much service cooperatives mainly to distribute feed subsidies. In recent years, however, some pastoralists from Jordan have been organizing themselves into cooperatives that have requested and received from the government parts of their community pastures to manage. Such cooperatives are found in the villages of Oulad Beni Hamadeh and are conducting range improvement activities. This option offers many opportunities for pastoral cooperatives to reciprocally charge similar fees for accessing their respective grazing resources. However, the success of such arrangement depends on many factors including range productivity, flock sizes, and the transaction costs for accessing these resources. The common belief would be that only the rich pastoralists would gain access to these resources at the expense of poor pastoralists.

Under this management option, pastoral households moved on less than households operating in the other systems. On average, they moved 1.5 km in Jordan and 8.5 km in Tunisia. However, the average herd size of the group was the highest in Jordan while in Tunisia it was the third largest. Moreover, the transaction costs per TLU were 4.51 JD in Jordan and 9 TD in Tunisia.

Situation under the "Private range" option:

Private ranges were mainly found in central Tunisia and were planted with forages such as barley, cactus, and shrubs (Elloumi et al., 2001). These ranges are privately owned and landowners have the possibility to title these lands under their names. Landowners work with the Livestock and Pasture Office (*Office d'élevage et de pâturages*, OEP) to improve their private ranges and receive subsidized livestock feeds and other services to compensate for their losses during the periods when their pastures are under improvement. Following the improvement of their private ranges, owners have the possibility to rent their ranges to other pastoralists. The survey found that range owners relied heavily on their private ranges and crop residues for grazing. Moreover, households had smaller herds and have been intensifying their production systems with the introduction of dairy cows. In this group, households owned 4.28 TLU on average and did not migrate.

Table 1. Range management options, herd size, mobility and transaction costs

State ownership regime (Jordan)

Management options	Distance of herd movement	Transactions costs of mobility per TLU	Number of households	Percent of the sample	Average household livestock holding (TLU)
Tribal collective	9.56 (14.36)	12.63 (21.15)	64	22	22.15 (21.12)
Forest regime	4.92 (4.53)	4.97 (6.21)	39	13	27.98 (33.11)
Herder's cooperative	3.91 (3.71)	4.51 (5.16)	77	26	29.34 (30.82)
State reserves	25.59 (54.17)	11.04 (16.97)	27	9	21.21 (26.17)
Herder's cooperative and state reserves	1.32 (2.87)	4.9 (3.77)	88	30	20.39 (16.48)
Total	6.48 (18.92)	7.05 (12.22)	295	100	24.18 (25.27)

Private and collective ownership (Tunisia)

	Distance of herd movement	Transactions costs of mobility per TLU	Number of households	Percent of the sample	Average household livestock holding (TLU)
Tribal collective	34.7 (28.73)	51.14 (108.61)	76	31	14.73 (19.94)
Improved tribal collective	49.39 (51.37)	29.53 (31.36)	59	24	25.40 (37.73)
Cooperatives	8.53 (5.23)	8.95 (28.45)	30	12	10.52 (5.59)
Forest regime	1.63 (3.62)	1 (6.65)	68	28	6.24 (7.53)
Private ranges	1 (0.00)	0 (0.00)	11	5	4.28 (4.87)
Total	24.30 (35.74)	24.45 (66.51)	244	100	13.95 (23.18)

Standard errors are in parentheses

Situation under "improved collective management" option:

This type of management system was found in Tunisia. These pastures, which were under tribal collective management, were improved by the Tunisian government with watering points and access roads. In addition, the government implemented shrub plantations and rotational grazing. Community members had open access to all their local resources according to the norms and practices of their tribal groups. Moreover, all tribal groups and fractions continue to exercise their rights over the grazing resources. Households operating under this system represented 24% of the sample. They went the farthest with an average of 49 km, had the largest average livestock holdings, and paid the second highest average transaction costs of 29.5 TD per TLU.

Situation under mixed management options:

In addition, to the above six systems, we found in some communities like Ader in Jordan, two management options on the community traditional pastures: state reserves and herder cooperatives. The existence of two management options side by side was a good illustration of the importance of granting stewardship to communities and fostering collective action. The state reserve, which was run and managed by the forest services, was heavily dependent on public funding, fenced and guarded, while the cooperative range was unfenced and unguarded. Moreover, the range productivity measures conducted in the area showed that the productivity on the cooperative's range was 10.6 kg per ha while in the state reserve it was 9.7 kg per ha. These results confirm the importance of granting stewardship to herders' organizations, especially if they created these organizations (Bruce 1986; Lawry, 1990; Ciriacy-Wantrup and Bishop, 1975; McKean, 1992). Households from this community accounted for 30% of our sample. These households moved less than all households in all the other groups and own 20.39 TLU on average.

In general, these results show that households operating under tribal collective systems had the highest transaction costs per TLU. Moreover, there were more variations of transaction costs and herd size between households operating under different range management options within privatization policy framework than under state ownership. Except communities with tribal collective and improved collective systems, pastoral communities in all the other range would have difficulties in negotiating reciprocal arrangements. However, new range management options offer opportunities for communities under similar systems to contract for reciprocal arrangements by charging an access fee. Yet, none of the studied communities use such arrangements.

Models and data

To conduct a stronger test on the effects of institutional innovations on the propensity to move, the distance of the movement and transactions costs associated with herd mobility we use Probit, Tobit and OLS models. The propensity to move was measured using Probit analysis with a discrete dependent variable of one if herd moved and zero if not. The distance of herd movements was measured using the average distance of movements from the house to all visited pastures during the year. Transaction costs included all the costs incurred by the household to access grazing resources. Right hand side variables included age of household head, dummy variables for education levels, household size, flock size, household operated land, total income and dummy variables for range management options. These relationships were estimated using the following reduced form:

$$y_i = b_0 + b_i x_i + b_r D_r$$

y_i is vector of dependant variables for household *(i);* x_i are vectors of household characteristics
D_r is a vector of dummy variables for different range management options; and
b_0 ,b_i, and b_r are coefficient vectors to be estimated

The data used in this paper were collected under the research project funded by the CGIAR Systemwide program on Collective Action and Property Rights (CAPRi) and Ford Foundation-Cairo Office as a component of the ICARDA-IFPRI regional program on Development of Integrated Crop/Livestock Production Systems in Low Rainfall Areas of the Mashreq and Maghreb Regions, involving eight countries (Algeria, Iraq, Jordan, Lebanon, Libya, Morocco, Syria and Tunisia) and co-financed by IFAD (International Fund for Agricultural Development), AFESD (Arab Fund for Economic and Social Development), and IDRC (International Development Research Centre).

The research built on the country reviews of the policy and legal environments under which pastoral communities make their decisions and rapid rural appraisals (RRA) conducted in ten to fifteen communities in each country. This exercise was followed by an in-depth pasture characterization to evaluate range productivity and floristic composition under each management option; and in-depth household surveys to evaluate the effects on these options on household feed expenditures. In-depth data was collected among 295 households in Jordan and 265 in Tunisia. A separate questionnaire was administered for each visited pasture to record pasture characteristics, institutions governing access and use of the pastures, perceptions on range quality, problems, and potential solutions. Herd movements, costs associated with herding, trucking, and renting for grazing were also recorded.

Results and discussion

Estimated parameters for the three equations are summarized in Table 2 and presented in Table 3. Amongst the 295 households in Jordan, 63% migrated while amongst the 244 households in Tunisia only 38% moved to other areas to seek additional grazing (Table 1). These differences suggest that pastoral households in Jordan are more mobile than those in Tunisia. What are the factors that determine such household behavior? The average age of pastoral households in Jordan and Tunisia was 55 and 58 respectively.

Propensity to move

In Tunisia, the probability of pastoral households to move was significantly affected by two variables: total gross income and forestry regime management option. The positive and significant sign of gross household income, which suggests that pastoralists with higher gross income were more likely to migrate, may be associated with the increasing demands of herders to be paid cash for their services. In some localities, livestock owners reported having difficulties to find good herders. Paying cash is not always desirable for the livestock owners because under such contract arrangements, they bear all production risks contrarily to traditional sharecropping arrangements where livestock owners and herders share all the production risks and will only share herd growth.

The negative and significant sign of the forestry regime management dummy variable indicates that households operating under this system

Table 2. Summary of Effects of Management options on mobility, distance of migration and Transaction costs

	Propensity to move		Transaction costs		Average distance of herd mobility	
Independent variables	**Jordan**	**Tunisia**	**Jordan**	**Tunisia**	**Jordan**	**Tunisia**
Average distance of mobility			(+)***	(+)*		
Age of household head	(+)**	+	-	+	+	(-)*
Education						
Primary	+	+	+	+	-	-
Secondary	(+)*	+	+	(+)**	+	-
University	(+)***		-		+	
Household assets						
Household size	+	-	+	(-)**	+	-
Herd size (TLU)	(+)***	-	-	-	(+)***	+
Household land holding	(+)**	+	-	+	+	-
Total income	-	(+)***	0	(+)***	0	0
Pasture Management Options						
Improved collective pastures		-		-		(+)*
Private		(a)		(-)***		(-)***
State reserves	-		(-)***		(+)**	
Cooperatives/state reserves	(-)***		(-)***		(-)***	
Herder Cooperatives	(+)***	(a)	(-)***	(-)***	-	(-)***
Forestry regime	(+)***	(-)***	(-)**	(-)***	-	(-)***
Observations						

(a) These variables were associated with prefect failure migrate less than households operating under tribal collective option, which was used as the control variable. In addition, the coefficients of private and cooperative variables were missing because they predicted perfect failure and hence 40 observations were dropped from the analysis. These results suggest that in general, pastoralists operating under new range management systems in Tunisia migrate less than those operating under the traditional collective system.

In Jordan, the situation was quite different and eight variables had significant effects on the propensity of households to move. All household variables, except household size and primary education, had positive and significant effects. The positive and significant signs of age of household head, and flock size, household land holding were expected. Indeed, older pastoralists are more likely to opt for mobile production systems because they have built, through the years, social capital with different groups, which eases their access to additional grazing. Likewise wealthier livestock and land owners are expected to rely more on mobile production systems than poor pastoralists (Ruttan and Mulder, 1999; McCarthy and Vanderlinden, 2002). Moving and using their social networks constitutes the cheapest way for gaining additional feeds for their livestock.

The positive and significant coefficients of the high school and university variables confirm that many well trained people are entering livestock production and intensifying it. Such livestock entrepreneurs have been the main drivers of the change of pastoral cooperatives and the development of new types of multifunctional herder-cooperatives, which are involved in managing cooperative pastures, milk processing and marketing, and providing numerous services to cooperative members.

The effects of the different management options on mobility were mixed. State reserves and the state reserve/cooperative variables had negative coefficients but only the latter was significant. These effects might be directly associated with lower flock sizes (Table 1) and more reliance on concentrate feeds for supplementation (Roussan et al., 2001). The coefficients of the cooperative and forest regime variables were positive and significant. These households had the largest average household livestock holdings but had lower feed expenditures (Roussan et al., 2001). These results illustrate that pastoral households under these four management options carry out different strategies for accessing additional feeds. The fist group relied more on their local resources and on market mechanisms while the second moved more and relied on different access options for grazing.

Apart from cooperatives and forest regimes in Jordan, pastoral households in both countries moved less than households operating under tribal collective systems. This lower mobility of households, where pastures are being managed under the new management options, results partly from the limited capacity of these communities to establish reciprocal grazing systems with other communities and the growing dependence on concentrated feeds and crop residues for supplementation.

Distance of herd movements

The results of the distance equations in both countries are mixed. Only two household variables had significant effects on the distance of herd movements. The positive and significant coefficient associated with herd size in Jordan corroborates the results obtained previously regarding the propensity of pastoral households to move. The negative and significant coefficient of the household head variable in Tunisia suggests that older heads of households move less than younger heads.

However, situation for the range management options on distance was quite different. In Jordan, two range management options had significant effects on the distance of herd mobility, state reserves and cooperatives/state reserves variables, while in Tunisia all the four management options had significant effects on the distance of herd mobility. The effects of range management options could be divided into three groups: the first group includes options that had positive and significant effects, improved collective pastures and state reserves; the second group comprises options that had negative and significant effects, cooperative/state reserves, herder cooperatives, private cooperatives, forest regimes; and the third groups consists of forest regime in Jordan with a negative and non significant coefficient.

The management option variables in the first group were associated with negative but insignificant coefficient suggesting that even though the propensity to move of households within this group was not appreciably different from those operating under the tribal systems, these groups moved farther. The reasons for such strategies are different but the implications for resource management are quite similar. In the Jordan case, the fencing of community pastures and government reserves obliged pastoral households to move to remote areas of their rangelands, Hamad, while in Tunisia the improvement of roads and watering points allowed better access to remote ranges. In both cases, however, the possibility of pastoral households to access these remote areas increases the probability of land degradation because these areas are very dry and very fragile.

Table 3. Effects of Management options on mobility, distance of migration and Transaction costs

	Propensity of Mobility		**Transaction costs**		**Average distance of herd mobility (km)**	
Independent variables	**Jordan**	**Tunisia**	**Jordan (JD)**	**Tunisia (TD)**	**Jordan**	**Tunisia**
Average distance of mobility			0.178 (0.056)***	0.454 (0.259)*		
Age of household head	0.006 (0.003)**	0.002 (0.003)	-0.105 (0.074)	0.658 (0.790)	0.104 (0.116)	-0.4 (0.236)*
Education						
Primary	0.027 (0.070)	0.123 (0.108)	0.215 (1.706)	7.886 (20.030)	-0.2 (2.726)	-10.086 (6.949)
Secondary	0.156 (0.081)*	0.136 (0.130)	3.106 (3.187)	81.015 (39.729)**	1.611 (5.043)	-4.444 (6.714)
University	0.226 (0.055)***		-5.645 (5.054)		2.993 (7.414)	
Household assets						
Household size	0.007 (0.009)	-0.003 (0.012)	0.248 (0.188)	-7.236 (3.136)**	0.128 (0.291)	-0.212 (0.801)
Herd size (TLU)	0.185 (0.007)***	-0.001 (0.002)	-0.043 (0.034)	-0.215 (0.245)	0.185 (0.050)***	0.113 (0.087)
Household land holding	0.001 (0.003)	0.002 (0.001)	-0.006 (0.056)	0.368 (0.266)	0.014 (0.086)	-0.079 (0.084)
Total income	-9.620E-06 (7.610E-06)	1.830E-05 (6.60E-06)***	0.000 (0.000)	0.002 (0.001)***	0.000 (0.000)	0.000 (0.000)
Pasture Management Options						
Private		(b)		-569.309 (134.782)***		-31.121 (5.581)***
Herder Cooperatives	0.366 (0.050)***	(b)	-6.698 (2.163)***	-257.731 (64.796)***	-2.105 (3.237)	-33.664 (9.442)***
Forestry regime	0.315 (0.043)***	-0.39 (0.077)***	-6.593 (2.584)**	-200.439 (51.822)***	-0.657 (3.88)	-53.308 (6.642)***
State reserves	-0.053 (0.123)		-10.224 (3.470)***		11.014 (5.042)**	
Cooperatives/state reserves	-0.244 (0.087)***		-6.34 (2.154)***		-15.961 (3.597)***	
Improved collective pastures		-0.139 (0.094)		-24.969 (18.914)		15.206 (8.509)*
Constant			14.231 (5.099)***	3.906 (55.520)	-5.59 (8.02)	55.595 (14.697)***
Observations	274	196	274	236	274	236
R-squared (Pseudo)	0.37	0.12				
Wald Chi-squared			35.57	34.55	61.61	113.85
Prob> Chi-squared			0.0007	0.0006	0.000	0.000

(a) * 10% significance, ** 5% significance and *** 1% significance
(b) Predicted failure perfectly

The results of the second group are consistent with our expectations that the introduction of new range management options induces pastoralists to move less and for shorter distances. Moreover, herders operating under forest regime and cooperatives in Jordan moved more than those operating under traditional collective system but moved shorter distances. The special distribution of pastures, and the size and quality of local resources are important factors that were not included in the analysis to avoid the autocorrelations between these variables and range management options.

Transaction costs

As expected, the variable average distance of household movement increased significantly transaction costs of mobility in both countries. However, other household variables were only significant in Tunisia. Household heads with secondary education and higher total income have higher transaction costs. These results reflect strategies of the new livestock entrepreneurs who are investing in livestock production and are paying cash herders to mange their herds and also rent grazing access for different types of resources. The negative and significant coefficient associated with household size in Tunisia was expected because households with large members tend to rely mainly on their members to manage their herds.

The general hypothesis that pastoral households operating in a system whereby pastures are under collective tribal management would incur lower transaction costs than those that have their pastures under new management options was not confirmed by this study. Indeed, the results from the transaction cost equations in Jordan and Tunisia show that the costs of pastoral households operating under the new range management options were significantly lower than of those operating under tribal collective systems (Table 2). All of the coefficients were negative and significant except for the variable for improved collective management in Tunisia. These lower transaction costs illustrate the different strategies adopted by pastoral households operating under these systems, especially with the reduction of their individual herds.

However, differences in the magnitude of effects were higher between different rangeland policy frameworks, privatization or state ownership, than between management options within a specific policy framework, except in Tunisia where large differences were found between private management option and the other management options (Table 3). This situation results from the fact that under the state ownership, government institutions are responsible for the management of the pastures and regardless of the option, pastoral households were confronted with similar issues. Under the privatization framework, however, pastoral communities and households operating under these systems were responsible for the management of their pastures. The lower transaction costs of households operating under the private management option were expected because such households rarely moved to other areas except few rich livestock owners.

Conclusions

There is no doubt of the importance of mobile pastoral systems for managing common resources and environmental risks and sustaining pastoral production systems. This study challenges the old convention that pastoral households from communities, whose pastures are being managed under new range management options, had lower propensity to move than those operating under tribal collective systems. Furthermore, the paper postulates the importance to consider individual transaction costs because increasingly pastoral households are more responsible for their strategies of mobility than group common institutions.

In the case of Tunisia, positive and significant effects on the gross household income variable on the propensity to migrate result from the increasing demands of herders to be paid in cash rather than kind, where they would share production risks. This situation precludes small livestock owners to move their herds. They tend to stay closer to use pastures all year round and hire the services of a herder that is paid monthly according to the number of sheep or goats. Such practices promote overstocking and environmental degradation of the pastures located near the villages. In Jordan, herd size had positive and significant effects on the propensity of households to move. These two results point to the fact that the wealthy are more likely to resort to mobile pastoral systems because many tribal mechanisms and institutions, which were used to negotiated access for all community members, regardless of wealth status, have eroded.

The transaction costs associated with herd movement were lower amongst communities operating under new range management than those operating under tribal collective systems. Range management variables had the largest effects on household transaction costs.

Future development project, which aims at using the mobility framework to recreate pastoral mobility patterns, must look at the implication of such changes not only on the group as a whole but also how it impacts pastoral households production strategies.

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Evaluation of agricultural sustainability in rural villages in the suburbs of Yan'an City, Shaanxi, China

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Abstract

In China, the "Natural Forest Conservation Program (NFCP)" has been conducted to conserve forests and mitigate land degradation and desertification. The purpose of this study was to clarify the agricultural sustainability that is evaluated by comparing the actual population density and human carrying capacity (HCC) in this area. To estimate HCC at the village level in China, we investigated four rural villages, designated A, B, C and D, in the suburbs of Yan'an City, Shaanxi Province using a questionnaire submitted to village farmers, literature, and a cutting survey. We calculated HCC using data obtained from this investigation. Results indicated that the "Grain for Green" project has progressed rapidly, and that cropland had decreased and forest increased in this area. Farmers' total income increased because they cultivated orchards, raised cash crops, employed plastic greenhouses, and worked in town when they could not engage in agricultural activities, besides the subsidy from the government. The HCC for 2004 ranged from 2.9 to 22.3 persons per ha, while the population accommodation (PA) ranged from 0.233 to 0.696. However, after termination of subsidy, the PA at one village (D) increased from an estimated 0.70 to 1.03, potentially rendering the continuation of agriculture there economically infeasible. Indications are that the agricultural sustainability in economic dimension would decrease slightly in villages A, B and C, and greatly in village D. However, much would also depend on the government's future policy.

Introduction

Serious soil erosion on the Loess Plateau in China due to irrational land use such as excess cultivation on sloped cropland has caused a decrease in agricultural sustainability in the region (Fu, 1989). To mitigate this soil erosion the 'Grain for Green' project has been conducted since 1999. An area of cropland is set aside and then afforested for ecological recovery. Farmers set aside sloped cropland and plant trees. The government compensates them with food supplies and maintenance fees. However, these subsidies will terminate in two to eight years. There is a possibility that the planted areas may be converted once again back to farm land because of the decrease in farmer's household economy after the termination of the subsidy given by the government (Ye et al., 2003; Uchida et al., 2005). Therefore, it is necessary to evaluate agricultural sustainability by considering the effects of the termination of subsidies.

Agricultural sustainability is a multifactor concept. It can be divided into three dimensions: the ecological dimension, the economic dimension, and the social dimension (Yunlong et al., 1994). Agricultural sustainability in the economical dimension can be evaluated by comparing the human carrying capacity (HCC; i.e. the number of persons ha^{-1}) as determined by the availability of the natural resources of the land to the population. In this study, we investigated a village that is considered to be in good economic condition and estimated its HCC. The purpose of this study was to compare the village-level HCC with the actual population density and to evaluate how the 'Grain for Green' project has affected agricultural sustainability.

Materials and method

To clarify the region-level natural resources and the economic situation of the farmers, households in an area in a suburb of Yan'an City, Shaanxi, China, were interviewed during August and September 2005. The questionnaire used included the production and use of natural resources in the area and the farm household economy. Figure 1 presents the study area. We selected four villages, A and B in Baota district and C and D in Ansai county, which are typical Yan'an City villages from an economic and agricultural system viewpoint. The number of households surveyed was 59 at villages A and B and 65 at villages C and D. Households were selected by random sampling. HCC can be calculated by dividing the productivity of the natural resources of the land by the demand for natural resources per person, using an HCC estimation model (Komatsu et al., 2005). We improved the Komatsu et al. HCC estimation model and used it in this study.

The economic productivity (EP) of the natural resources (in RMB ha^{-1}) was calculated by subtracting the cost for fertilizer, fodder, and other agricultural demands from the total productivity of the available arable land. The demand for natural resources (D_{cap}; in RMB $person^{-1}$) was calculated by adding up the demands for food, fuel, and building, as well as other items necessary for life. The HCC (in persons ha^{-1}) was calculated by dividing EP by D_{cap}. The population that can be supported by natural resources ($PD_{np}p$; in persons ha^{-1}) was calculated by multiplying the actual population density by the ratio of farm income to gross income. The rate of population accommodation (PA) was calculated by dividing $PD_{np}p$ by HCC. PA is an index of the balance between supply and demand. If PA increases to 1 or a bove, the productivity of the land is insufficient to meet the demands of the people.

Result and discussion

Estimation of HCC and PA

In 2004, the productivity was the largest in village A and the smallest in village D. In village A, the arable area available for cash crops is large (Fig. 2). The cash crops, namely cucumber, Chinese cabbage, tomato and watermelon, can be sold for a large amount of money. In contrast, in village D, the arable area available for cash crops is small and the arable area used for cereals like maize and millet is large. The HCC in 2004 was 22.3 persons ha^{-1} at A, 13.5 persons ha^{-1} at C, 4.5 persons ha^{-1} at B, and 2.9 persons ha^{-1} at D. The PA in 2004 was 0.285 at A, 0.233 at C, 0.354 at B, 0.696 at D. Thus, increasing the productivity of the arable land tends to increase HCC in these villages.

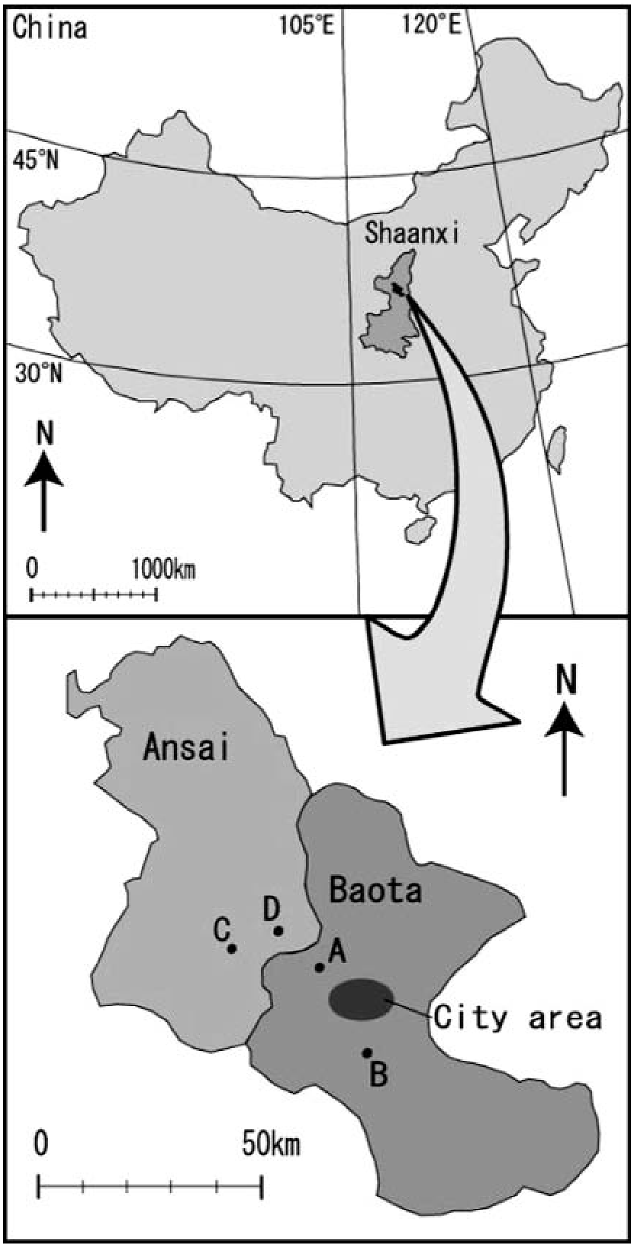

Fig. 1. Map of the study area. A, B, C, and D indicate study villages.

Ecological and economic effects of 'Grain for Green' project

In all villages investigated, arable land had decreased by more than half while forest land had increased by 1.3 to 10.4 times over the period of six years, from 1998 (before initiation of the project) to 2004 (after completion of the project). Therefore, it may be concluded that the project contributed to ecological improvement such as the mitigation of soil erosion. In all of the villages, the gross income of farmers increased between 1998 and 2004. Taking the average of all the villages, the farmers' income increased by about 2.8 times. Because farm income increased through the cultivation of cash crops and orchards, and non-farm income increased through the expansion of migrant work and the subsidies provided by the government, the 'Grain for Green' project contributed to the economic improvement of all the villages.

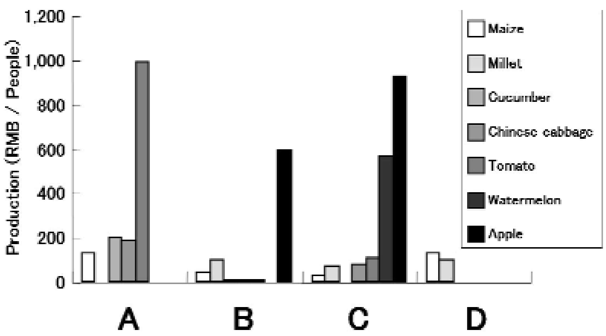

Fig. 2. Productivity of arable land in 2004. Four characters indicate study villages.

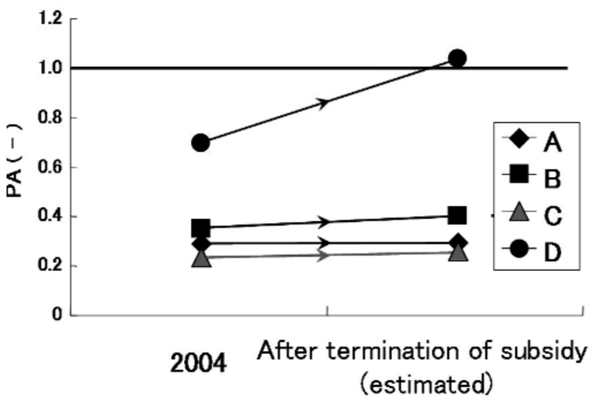

Fig. 3. PA after termination of subsidy. Four characters indicate study villages. The solid line indicates the baseline for over-exploitation of natural resources. If PA increases to 1 or above, the productivity of the land can no longer meet the demands of the people.

The effects of subsidy termination

When the subsidy associated with the 'Grain for Green' project was terminated, non-farm income decreased by the amount of the subsidy. The change in PA after termination is depicted in Fig. 3. After termination of the subsidy, the PA for village A is largely unchanged because of the small ratio of the subsidy to the farmer's gross income. For villages B and C, the subsidy ratio was larger than for village A and the PA rose slightly, by about 10 percent. At the same time, the PA for village D rose significantly, from 0.70 to 1.03 because the ratio of the subsidy to the farmer's gross income for village D was 30 percent or more. Therefore, in villages where the ratio of the subsidy to the farmer's gross income is large, it is predicted that the PA will increase after termination of the subsidy. With the farming system currently in use in village D, which includes the cultivation of cereals on sloped cropland, the continuation of agriculture would be problematic.

Conclusion

In the four villages, all suburbs of Yan'an city, Shaanxi, China, the 'Grain for Green' project reduced the arable land area by half. Despite this, the farmers' gross income increased because of an expansion in cash crops and orchards, increasing migrant work, and the provision of a subsidy by the government. For 2004, the HCC ranged from 2.9 to 22.3 persons ha^{-1}, while the PA ranged from 0.233 to 0.696. Therefore, production in an area was estimated from the level by which demand was filled in 2004. However, after termination of the subsidy, the PA at village D increased from an estimated 0.70 to 1.03, potentially rendering the continuation of agriculture there economically infeasible. It may be said that the agricultural sustainability in the economic dimension decreased slightly in villages A, B, and C, and decreased greatly in village D.

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Sustainable development of desert communities: from pastoral to sedentary farming systems in northwest Egypt

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Abstract

Ecologically balanced pastoral systems in semi-desert region of the northwest Coast (NWC) of Egypt evolved into sedentary, more productive farming system due to the development implemented in the last few decades. However, settlement of the Bedouins and changes in their social norms and living style, and random development and urbanization have increased human and livestock pressures on an inherently poor and fragile resource base, engendering resource degradation and poverty. The paper summarizes the experience of the Matrouh Resource Management Project (MRMP) in involving desert communities of the NWC and their socioeconomic setting to achieve its objectives of sustainable development and poverty alleviation. The paper analyzes the biophysical, socioeconomic, and policy factors that have influenced the evolution process of the systems. It describes the bases used to identify and characterize the systems evolved and major problems, specific to each. The paper highlights the positive effects of the social setting, traditions and customs of the Bedouin community in sustaining the pastoral system over the time, and how these were employed by the project for adopting participatory, community-based approaches to R&D. The paper presents lessons learned from relatively recent changes in socioeconomic setting, norms and traditions of Bedouin communities and their negative impact, threatening resource sustainability and possibly causing social disputes within and between communities. The need for conducting socioeconomic studies and respecting the property rights to guide balanced and equitable development of semi-desert areas is an important lesson learned from MRMP.

Introduction

The pastoral Bedouin communities in northwest Coast (NWC) of Egypt have accumulated indigenous knowledge, skills, and resource management practices that have sustained for ages ecologically balanced systems in the harsh semi-desert environment. They developed drought-coping strategies, social customs and traditions, and a lifestyle that have sustained their livelihoods, and maintained equity and social peace between and within the Bedouin tribes. The relatively recent settlement of the Bedouin tribes and conservation and better use of the resources, especially water, had promoted a sedentary life style and more intensive and productive farming system (FS). However, these development efforts, aggressive tourism industry and modernization of Bedouin lifestyle started affecting the ecological balance, engendering cyclic resource degradation and poverty. Vast areas of rich natural vegetation were damaged, overgrazed and/or cultivated. Natural habitats and ecological systems have deteriorated, biodiversity eroded, and resource productivity declined.

The Matrouh Resource Management Project (MRMP) was therefore initiated to control degradation of the natural resources, improve agricultural production, and alleviate poverty in dryland areas of the NWC. It is a rural development project that operated from 1995-2002 with a strong adaptive research and technology transfer base. It was co-financed with US$ 29.6 million by the World Bank (WB), Government of Egypt (GoE), and the project beneficiaries. The community-based, participatory project addressed its goal by the programs of adaptive research for agricultural production improvement; integrated watershed management, water harvesting and soil conservation; rangeland rehabilitation; extension and training; rural credit; monitoring and evaluation; and empowering women in development.

The Project contracted ICARDA (1996 – 2001) for providing technical assistance (TA) to develop, test and disseminate packages of technical, institutional and policy options (TIPO) for achieving the project objectives. ICARDA delivered about 4000 person-days of on-site TA to the various research and development (R&D) programs of the project. TA was provided by 51 scientists from 18 nationalities. Particular emphasis was given to human resource development through extensive on-the-job and in-house and overseas training for project staff and local Bedouin farmers and herders.

MRMP gave special attention to promote on-farm and off-farm income-generating activities, particularly among women and the rural poor. The project provided technical, managerial, logistical and financial support to the local Bedouin communities for implementing improved approaches to sustainable natural resource management and socioeconomic development. Due to evident success towards achieving project objectives, the WB and other donor agencies (IFAD, and GEF) supported the extension of the project to a second 5-year phase. However, the GoE decided to fund the extension phase locally, and the project is still ongoing.

Biophysical and socioeconomic setting

Area and beneficiaries

The project area (20,000 km^2) is dryland having semi-desert environment. The population of 18,714 households (HH) registered in MRMP database was 132,326 people of Bedouin ethnicity. Agriculture is the main livelihood for 80 % of these project beneficiaries. Cultivated area is only 7 % of the total area, fallow is 9 %, and rangelands 48 %. The remaining 36 % area is under barren lands and it generates runoff water that can be harvested. Generally, resources are extremely limited and crop productivity and diversity is very low. Off-farm employment and economic opportunities are scarce, and the population is among the poorest and most deprived in the whole of Egypt. Farming in the project area involves risks and uncertainty problems. Rainfall, the main source of water, is low and erratic; 145 mm on the coast, rapidly declining in-land. Water harvesting is therefore needed for agricultural production. Barley, the principal crop, is integrated with 'degraded' rangeland and livestock production. Good soils are mainly allocated to figs and olive trees, and for the production of mint and melons.

Socioeconomic profile

Poverty and infrastructure: Population of the NWC is very poor; over 56 % of HHs is below the lower limit, and 24 % within the upper limit of poverty. Farm income for the ultra poor is not sufficient to survive, and they have to seek off-farm employment (WB, 1993). Infrastructure and public services (credit, marketing, education, health, housing, transportation, etc) are deficient. Naggar et al. (1988) estimated illiteracy at 70 %, but the rate in the year 2000 reduced to 31 %; 40 % for females, and 23 % for males (Matrouh Governorate, unpublished data). It is worth mentioning that the women intensive development program of MRMP educated during the last few years over 4800 illiterate Bedouin girls. Except cooperatives, farmers/herders institutions are lacking.

Social structure: Most Bedouins in NWC live in widely dispersed settlements, with individual dwellings in a settlement separated from others by 50-100 m. The tribal social status system (Zoghby et al., 1992) is based on socially inherited privileges and consists of a virtually unchangeable order of ranks. Leaders '*Sheikhs'* are designated at the level of each tribe, and there is a customary law council *'Majlis Urfi'* at each level controlling the social life. Group solidarity is maintained with recognized communal responsibility at each level. Bedouin traditions and tribal solidarity was very helpful in implementing participatory approaches to R&D. The traditional Bedouins do not lack the attitude to change. They have rapidly adopted proven technologies, and adjusted to modern life requirements as long as their pride and privacy were not threatened.

Land tenure: Although legislations allowed individual tribesmen to gain title over the land they cultivated, but 80 % of landholdings were still without legal title. However, except communal range, individual land boundaries are well defined and respected. The government has recognized the *de facto* usufruct rights of established tribal territories, and the usufruct system of land tenure has sustained. No outsider can purchase and utilize the land from the state without the consent of the Bedouin occupiers and payment of a handsome compensation to them (Zoghby et al., 1992).

Communal water and rangeland: Each tribe has its own range and water sources, and territorial boundaries of tribes are respected. Water runoff, although used for localized farming, can not be blocked from running to other downstream localities. Water for domestic and livestock use is harvested and stored in excavated cisterns, or concrete reservoirs. A neighboring water-deficient household can use the nearest stored water regardless of property rights. According to Bedouin traditions, members of a tribe/sub-tribe have exclusive rights to graze their flocks on the area allocated to their tribe/sub-tribe. Members of other tribes are forbidden from grazing their animals on other tribes' territories, unless permission was given in advance.

Women in Bedouin society: In the traditional pastoral society, both men and women participated in livestock management. Bedouin women today are further involved in crop production and processing. Settlement has restricted women's mobility, but tree plantation, handicrafts making and provision of water and firewood all brought new responsibilities to the women. Gender segregation has increased with urbanization and development of tourism and with greater exposures to religious centers (WB, 1993). MRMP implemented extensive programs for improving literacy of Bedouin girls, training for skill building, and awareness workshops for improving health and nutrition. It also supported women in establishing small-income generating projects to enhance their economic independence and helped alleviate drudgery in their work through provision of pumps, gas ovens, and donkey-carts.

Objective of the research

The objective of the research undertaken in the project was to:

- Analyze the evolution process of the pastoral system into sedentary FS in the NWC of Egypt;
- Analyze the sources of risk and vulnerability of farming;
- Assess the outputs and outcomes of MRMP and its impact on resource sustainability and productivity, and poverty alleviation; and
- Derive the lessons from MRMP experience that could be applicable elsewhere in the semi-desert drylands.

Materials and methods

The authors of the paper were effectively involved in project management, implementation, and monitoring and evaluation of activities, and have easy access to all documents of the project. They reviewed analyzed or synthesized, as appropriate, the secondary data (reports, maps, databases and other documents) produced by or available at the project on all technical (biophysical and socioeconomic) and managerial activities. Primary data (technical research results and socioeconomic studies) were also analyzed to meet the third objective listed above. The primary data needed were obtained though on-farm trials and field demonstrations; rapid rural appraisals (RRAs); structured farm surveys; field observations and informal meetings with the local Bedouin communities; and specific case studies. Common sense and intuitions were also intensively employed.

Results

System evolution: from pastoral to sedentary FS

Types and distribution of FS evolved: The term FS in this paper is defined by the different combinations of main agricultural enterprise practiced in the farm, which in the targeted areas were field crops (mainly barley), fruit trees (mainly figs and olives) and livestock (mainly sheep and goats). FS analysis, using the beneficiary database of MRMP, established in 1997 and updated in 2001, showed the following types and distribution:

Farming system	*% of total HHs*
'Fruit Trees/Field Crops/Livestock'	48
'Fruit Trees/Field Crops'	14
'Livestock/Field Crops'	13
'Livestock/Fruit Tree'	9
'Fruit Trees only'	4
'Field Crops only'	8
'Livestock only' or 'Pastoral'	4

These FSs differ widely in their basic resources; the first being the more naturally resourced, intensive and productive and the last two are the poorest. The FS situation outlined above is dynamic; it changes by time according to changes in resource availability and development of infrastructures.

Factors affecting FS evolution: The pastoral system first evolved into semi-settled 'livestock/ barley' FS with the introduction of barley in land depressions that received natural runoffs from the vicinity. Establishing simple water harvesting structures allowed the semi-settled Bedouins to settle and grow fruit trees, promoting further the FS to the more productive 'Livestock/Crop/ Horticulture' FS. Hence, development policies should carefully recognize the FS dynamics, so that measures taken would not disturb the ecosystem balance. Major biophysical and socio-economic factors affecting system evolution, in terms of type and distribution, were: (a) geo-hydrology and topography of an area determining the suitability of the area for establishing water harvesting structures; (b) soil characteristics (structure, depth, physical and chemical characteristics, etc) determining the suitability for growing fruit trees; (c) economic conditions of the Bedouin community determining its capacity to construct water harvesting structures and spending on new farming technologies and practices; and (d) community organizations and members' aspiration and attitudes affecting the acceptance of changes and adoption of new technology (water harvesting, new crops, new practices, etc).

Challenges to sustainability: risk and vulnerability

Sustainability of FS evolution and agricultural development in the NWC is challenged by many constraints/ risks and vulnerability factors; biophysical, socioeconomic and institutional.

Biophysical vulnerability: Poor soils and erratic rainfall constituted the primary source of risk and vulnerability. Crop and livestock yields are low and highly variable, with low genetic improvement potentials. Crop yields are dramatically affected by rainfall variability. In a good-rainfall year, barley yield may exceed 1600 kg ha^{-1}, but in a dry year it is grazed green by livestock. Orchard productivity fluctuations, because of the variations in rainfall, range from 40 to 50 %. Farming involves risks and uncertainty even in years of relatively high rainfall if it was not properly distributed. With good early rains, farmers sow barley on most of the marginal cropland, saving the best and most productive parts for watermelon—a highly profitable summer cash crop. However, no rains in spring cause multiple losses including poor barley produce, no seed for next year and it should be bought at additional cost, and no cultivation of watermelon. On the other side, strong torrents of heavy rains and windstorms may damage the dikes and wash away good soils and small tree plantations. Pests are another source of risk that has recently increased with enhanced agricultural development. Rodents may damage earth dikes and crops. Insects and diseases coupled with improper management had resulted in many unproductive orchards in the area that needed substantial measures for rejuvenation (Salkini, 2001).

Socioeconomic and institutional vulnerability: Poverty is a serious source of vulnerability. Farm income is low and variable. Farm income might be reduced by one-third in 2 years out of 5 and it could be negligible in 1 out of 5 years (Zoghby et al., 1992). Bedouin traditions and tribal solidarity have always stood against all kinds of threats and hardships, maintaining socioeconomic sustainability and community survival. These started becoming loose with development and modernization. Recently, some new developments in the upstream areas of some watersheds have badly affected water runoff to 'well-developed' downstream areas, initiating disputes that may threaten social peace between and within the tribes. Illiteracy, scarce economic opportunities, and poor infrastructure (credit, education, health, electricity, roads and transport, and lack of experienced local staff and communities) have aggravated the socioeconomic and institutional vulnerability.

Coping strategies dealing with risk and vulnerability

Farming system coping strategies: The FS developed by the Bedouin communities, based on integrated combinations of 'field crops, horticulture, and livestock' is the most impressive coping strategy with biophysical and economic uncertainties common in the area. Multi-enterprise FS provided good sustainability buffer for the HHs; if one enterprise failed in a year, others would survive. MRMP has supported improving the present FS, rather than introducing the new ones that may adversely affect the coping strategy. The project supported making good use of the scarce natural resources for production sustainability.

Barley, the least water-demanding cereal crop, is grown to feed animals (grain, straw and stubbles). In very dry years when no grain produced, barley is green grazed by livestock. To cope with rainfall uncertainty, most farmers do not sow barley until after the first rains. When early rains were delayed or there was low precipitation, crop area would be reduced by 40-50 % of the area sown in wet years and lower seed rates would be used to save cost. In years of timely early rains, farmers would sow all the barley area. The best of the land saved for watermelon would not be planted if the late or spring rains were lacking; it would in stead be kept fallowed for good pasture.

Horticulture is a highly remunerative cash enterprise, and contributes to feeding livestock on bi-products and residues. A few decades ago, horticulture was practiced by a very small proportion of farmers. However presently, with water harvesting systems, over 75 % of HHs are practicing horticulture growing the most drought-adapted and marketable species such as fig, olive, grapes, melons and mint. The Bedouins allocate best soils for horticulture; cultivate the land after every effective rainstorm to minimize evaporation losses, and use minimum monitory inputs not only due to poverty but also to cope with uncertainty and risks (ICARDA/MRMP, 1997 – 2001).

The Bedouins manage their livestock as an effective measure of their coping strategy. In addition to being a good cash income source, the Bedouins manipulate the livestock (sheep and goats) number as an economic buffer against drought and other hardships. They increase their herd size to the maximum affordable level in the wet years of good barley produce and pastures, gaining a good asset that could be used anytime the need for cash arose. Livestock numbers are reduced to the minimum that can be managed under hardships.

Socioeconomic and institutional coping strategies:
In addition to the FS coping strategies, which have their economic implications, the Bedouins try to keep reserves. Some of these are in-kind, to face income shortages in low rainfall years. Confined to limited resources, the Bedouins tend to keep a near-stationary economy emphasizing more on its stabilization than rapid development.

Vulnerability has been recognized in the design of MRMP, and the project can be considered the first major endeavor targeting resource sustainability in the NWC. It established research and training centers for rainfed agriculture and institutionalized community-based participatory R&D approaches to cope with dryland vulnerability. The project also enhanced women contribution to economic coping strategies, training and supporting them to establish small-scale economic enterprises including home-gardening, rearing chicken, rabbits, and pigeons, producing jam and conserves, sewing, carpet weaving and other handicrafts.

Technical, institutional and policy options tested and adopted

MRMP has developed and disseminated technical, institutional and policy options (TIPOs) for natural resource conservation, productivity improvement and poverty alleviation. Main TIPOs (ICARDA/MRMP, 1997 – 2001) are listed below:

Technical options
Technologies tested and disseminated included the following
Soil and water conservation:
- Integrated watershed development approach;
- Earth, stone, and cemented dikes and spillways for water harvesting and to control runoff;
- Excavated cisterns in hard soils and cemented cisterns in soft soils for water harvesting;
- Stone and cemented structures for soil conservation; and
- Cultural/plant measures for soil conservation

Rangeland rehabilitation:
- Collection and multiplication of local and introduced new adapted range species;
- Planting fodder shrub seedlings such as *Acacia* spp., Atriplex spp., and spineless cactus;
- Reseeding deteriorated pasturelands by annual and perennial shrub species, including those mentioned above, medics (*Medicgo* spp.) and various species of grasses; and
- Encouraging interested farmers to establish small nurseries.

Barley production:

- Improved varieties for rainfed production; the project provided considerable amount of seed of Giza 126, which had proved best in the field trials, to farmers to enhance its adoption;
- A seed rate of 62 – 75 kg ha^{-1} was recommended as against less than 60 kg/ha used by most farmers.
- Two times cross-cultivation (before and after sowing) as against one only after sowing used by farmers;
- A rotation of 'barley/ local vetch' (most accepted) as against barley mono-cropping system;
- 'Barley- vetch' mixture, 75 % barley and 25% vetch; and
- Alley planting of *Atriplex* in rows 10-15 m apart with 3 m spacing between the shrubs within the row, and land in between planted with barley.

Horticulture:

- Introduction of new species and varieties of fruit trees and vegetables;
- Cultural practices such as pruning, fertilizer, supplemental irrigation, harvest, post-harvest handling; and
- Introducing greenhouse technology, at a small scale.

Livestock:

- Improved fattening regimes;
- Veterinary and health improvement; and
- Improved flock management, including nutritional aspects using local feed materials.

Institutional and policy options

These comprised the following:

- Inter-disciplinary, inter-institutional and effective community participation;
- Provision of seeds of new improved and better adapted variety;
- In-kind incentive or pay-for-work for poor beneficiaries to adopt new technologies;
- Land tenure (encouraging transfer from usufruct to private property); and
- Availability of easy credit facility for women.

TIPO packages and their dissemination

TIPOs were combined in packages for addressing specific R&D objectives. These packages have been successfully upscaled and out-scaled to other areas of similar environments in Egypt and other countries (Pakistan, Afghanistan, and in the countries in Central Asia). Some packages were commodity-based aiming at improving one commodity (crop, soil, water, rangeland), and others were multi-commodity or multi-system based aiming at improving agro-ecological systems or sub-systems. Each package comprised technical, institutional and policy options. Some examples of these TIPO packages are: barley improvement; integrated watershed management approach (IWM); horticulture improvement; improving the cropping systems; and integrated crop/range/livestock systems.

To disseminate the TIPO packages developed by MRMP, a variety of methods and tools were used such as community meetings, field demonstrations and field days, training, annual review meetings, local and international workshops, publications, multi-media, etc.

Achievements, adoption, and impact

Monitering & Evaluation (M & E) of the project performance and assessing the impact of its outputs was a built-in component of the methodological approach. An M&E unit was established at the time of the project initiation, and was upgraded (in terms of staff and facilities) as needed throughout the duration of the project. M&E activities were conducted in the communities to assess the effectiveness of the participatory approaches, performance of the project's implementation units, adoption of new technologies and the socio-economic impact of R&D programs on the project's beneficiaries and the natural resource base using the tools of remote sensing and GIS and field verification techniques.

More than 58 % of the total households increased their income because of the project interventions, most of them by 25 % or more. Examples of the adoption and impact of some specific technologies are presented below (Salkini et al., 2001a)

Water harvesting: Structures constructed, with technical and financial support of the project, almost doubled the water availability for domestic use and crop production in an extremely water-poor region. Over 10,000 HHs (58 % of total HHs) got benefited from the establishment of cisterns, and 8,200 HHs from the construction of dikes, on more than 3,000 ha of orchard and crop area (Salkini et al., 2001a; 2001b).

Range and livestock: More than 7.5 million fodder shrubs and trees planted or interplanted for improving fodder production on about 10,000 ha of rangelands and 2000 ha of barley area. These, with the improvement of barley production, increased fodder supply by about 10.5 million Feed Units (one FU is 1 kg barley equivalent), reducing the total feed gap in the project area by 20 %. More than 7000 HHs (67 % of rangeland holders) were benefited, and 45 % of total herders increased their income by over 25 % (Salkini et al., 2000; Salkini et al., 2001a).

Crop improvement: The package of barley production improvement increased the yield by an average of 65 %. The farm survey (Salkini et al., 2001a) showed that more than 53 % of barley producers adopted the package, increasing their yields on about 30,000 ha by 20 – 100 %. Some case studies (Moselhy et al., 2001) indicated that barley yield increased from 300 kg/fed (1 fed= 0.405 ha) to 580 kg/fed (93 %), increasing net benefits by 105 % (520 – 1065 Egyptian Pounds per ha).

Fruit production: About 62 % of producers increased yields on about 15,000 ha of orchards by 25 – 100 %. The case study showed that the average yield of figs and olives increased by 60 % (50 – 80 kg per tree for figs, and 30 – 50 kg per tree for olives), and average net benefit increased by 52 % from 57,000 to 86,000 EP per farm (Salkini et al., 2001a; 2001b).

Women in development: The Bedouin women realized impressive achievements; 4800 illiterate girls and women were educated, more than 3100 women benefited from skill-enhancing training activities, and many women were supported enabling them to establish small income-generating projects (1500 home gardens and over 610 small poultry projects). They also contributed to environmental improvement by partially replacing the conventional fuel wood ovens by gas ovens, establishing latrines, and using manual water pumps.

Conclusion and lessons learned

The main reasons for the impressive achievements of the MRMP can be summarized as follows:

- Development and dissemination of technologies that were seriously needed by the target Bedouins.
- Effective community participation in R&D programs facilitated by an operational model based on decentralized management, multi-disciplinary teamwork, and community-based action planning. However, achieving effective community participation was not easy as it was a new approach for the area. It was time-consuming and required intensive training for project personnel and communities. This should be considered by donors when funding new projects.
- The availability of sufficient resources, especially the budget, and providing some in-kind incentives to poor beneficiaries, and salary incentives to project staff, mostly coming from other provinces to the remote areas of the NWC.
- On-the-job training for up-grading the skills and capacity of project staff and local communities. The overseas study tours for leaders from the communities enhanced adoption of new technologies. The skeptics got convinced, observing large-scale adoption of the technology and discussing its impact with colleague farmers from other countries.
- The experience showed that injecting research and technology transfer programs in large-scale rural development projects was very effective for achieving impressive adoption and impact of new agricultural technologies in a developing country. It also showed that international agricultural research centers, like ICARDA, can play important role in this respect.
- Socioeconomic parameters are important factors influencing the design and implementation of rural development projects, especially when planned for a fragile and poorly resourced environment. They become critically crucial in an environment where a poor Bedouin society is settled without the prior establishment official property rights of resources.
- Sustainability of project impact on the resource base and poverty has not yet been fully investigated; it will be done by ICARDA and the project in 2007, five years after the credit closure.

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Housing design performance affected by sand deposits in the Sahara Desert

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Abstract

The aim of the paper is to investigate the effect of aeolian sand deposits on the building environment of human settlements in the Sahara Desert. The flow of sand and dust presents a complex problem to the architects, as it demands attention not only to certain aspects of building design but also to planning the settlement as a whole. In addition, control of wind-blown dust and sand involves many different factors affecting vital aspects of environmental design. These include such planning measures as layout and the orientation of buildings. The use of specific layout and building forms in a few existing traditional towns in desertified areas in the Sahara has at least been partially successful in mitigating the particular problem of sand deposition. The region of Souf in Algeria is an example of an area suffering from sand erosion and deposition. It is situated in the southeast Algeria, a vast territory consisting mainly of sand dunes (the grand oriental ergs). Its traditional housing has special design features, which help to mitigate the problem. In addition, it has an area of modern housing. To improve the standard of architectural design for use in the design of new settlements in such areas, the study and comparison of the traditional and the modern housing schemes were carried out in addition to the laboratory testes using wind tunnels in order to identify the physical features of the traditional housing which mitigate sand deposits, and assess how these features can be adapted into the new housing design to combat the problem.

Introduction

The transport and deposition of sand by wind are important factors which contribute to desertification process in arid lands. It is estimated that a third of the world's hot arid lands are covered by aeolian sand deposits, forming extensive sand bed forms. These regions contain more than 350 cities. Sand encroachment and deposition in the built environments cause a number of problems such as erosion of building materials, and substantial coverage and often complete burial of urban features such as buildings, transport facilities and roads, which then need continuous clearing, incurring costs. In addition, the coverage of vegetation and agricultural lands has led residents in some areas to abandon their houses or even entire settlements. This presents a complex problem to the architects as it demands attention not only to certain aspects of building design but also planning the settlement as a whole. However, there is evidence that specific layouts and building forms of some local settlements in areas of active sand dunes, such as the region of Souf in the Algerian Sahara, have survived and mitigated the impact of sand encroachment and deposition. The destructive effects of sand deposition are more pronounced around contemporarily designed housing projects, resulting in many cases for the residents to abandon them.

The aims of this research were to investigate the relationship between dwelling forms and the sand depositional patterns formed around them, in particular around those located in areas of active sand dunes in hot arid lands, and to propose some possible design indicators for building forms which may mitigate the undesirable features of sand deposition around them.

Algerian Sahara

Aeolian sand deposits, excluding non-arid coastal dune systems are found in extensive sand accumulations called `ergs': large sand-covered areas (Thomas, 1989). The Sahara desert covers about a third of the total surface of Africa, stretching right across northern Africa from the Atlantic sea to the Red Sea coast in Egypt and Sudan and the highlands of Ethiopia, an area of some 9,100,000 km^2. A quarter of this area lies south of the Atlas Mountains, within the national boundaries of Algeria (Cloudsley, 1984). There are three major sand ergs with areas greater than 12,000 km^2. Erg Chech in south-western Algeria has an area of 319,000 km^2, the Grand Erg Oriental in eastern Algeria covers 192,000 km^2, and the Grand Erg Occidental to the west, has an area of 103,000 km^2 (Fig.1).

Region of Souf

The region of Souf in the north east Algerian Sahara lies in the sand dunes of the Grand Erg Oriental (Gerster, 1976). It extends over roughly 80,000 km^2, is 500 km long (north-south), and is bounded to the north by the Atlas Mountains and to the east by the Tunisian border (Tindert, 1986). The sand bed thickness ranges between 40 and 60 metres. The main settlements located in this area are continuously affected by the risk of sand encroachment and deposition.

The population of Souf is descended from nomadic tribes. The first Arab tribe, called Adowan, arrived in Souf in the eleventh century; they soon became a sedentary population and inhabited the villages of Souf, Guemar, Taghzout and Zqoum. In the fourteenth century, an Arab nomadic tribe, the Troud, who lived most of the time in the Sahara, settled in the region, together with another tribe called Rebaia, who arrived from Libya three hundred years later, inhabiting mainly El-Oued, Kouinine and part of Guemar. They settled close to the palm groves, encouraged by the ease of agriculture without irrigation (Etherton, 1976; Tindert, 1986). The entire population of Souf lived on agriculture, mainly the produce of palm trees, for several centuries; since colonisation, the towns' character has changed from rural to urban with the population getting employed in administrative and commercial occupations.

Farming in Souf is quite different from that in most other oases. Because the water table is quite shallow, close to the sandy surface which is characterised by mounds of sand dunes, the region has a special technique for its plantations: the palm-groves called ghitane (singular: ghot) (Fig.2, Fig.3). The method is not to bring up water out of the ground (i.e. by digging wells) and then use it to irrigate the fields, but instead farmers have dug out in the middle of the dunes deep circular depressions about one metre above the ground water table (the water table in some areas reaches 20 metres below the surface), and date palm trees are planted in these excavations. They are protected from sand deposition by a row of low hedges of palm fronds or palm-leaf hedges which act as wind breaks, called Djerid.

The region of Souf possesses a typical hot and dry desert climate. The wind is the most important physical constraint on the structure of the buildings

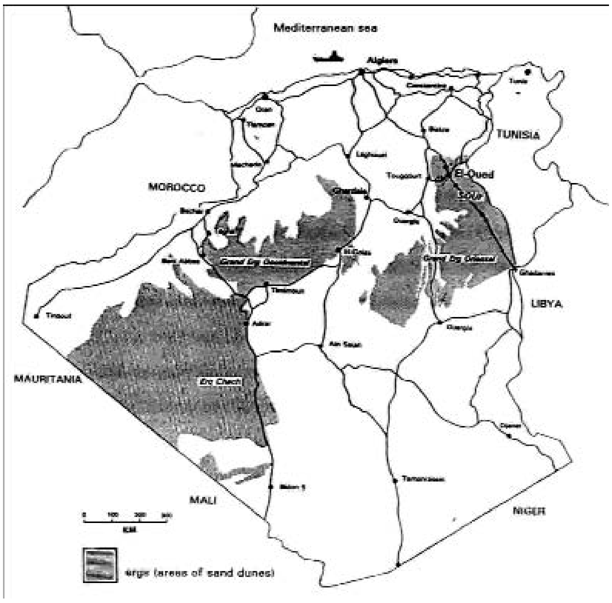


Fig. 1. Ergs location in the Algerian Sahara.

Fig. 2. Ghitane (palm grove) in Souf.

and the lives of the settlers. The Bahari, the prevailing wind from the east and 80 degrees north-east, is the most violent, causing sand storms (Salah, 1987). The mean velocity reaches 9 m/s, enough to cause wind-blown sand to cover the streets and the squares, in addition to causing problems by sand encroachment and accumulation around the buildings. Sand storm frequencies are intense during the months April to August. However, sand erosion and deposition seems to be a continuous process, mainly due to the characteristics of sand particles in the areas (very fine; 0.1-0.25 mm diameter).

Most of the Souf settlements are located along a dry river bed, stretching from the north to the south. Their locations are close to the palm groves (Ghitane) and some are surrounded by them. Two types of settlement form are found in region of Souf: (a) Ksar, and (b) Nezlah (Tindert, 1986).

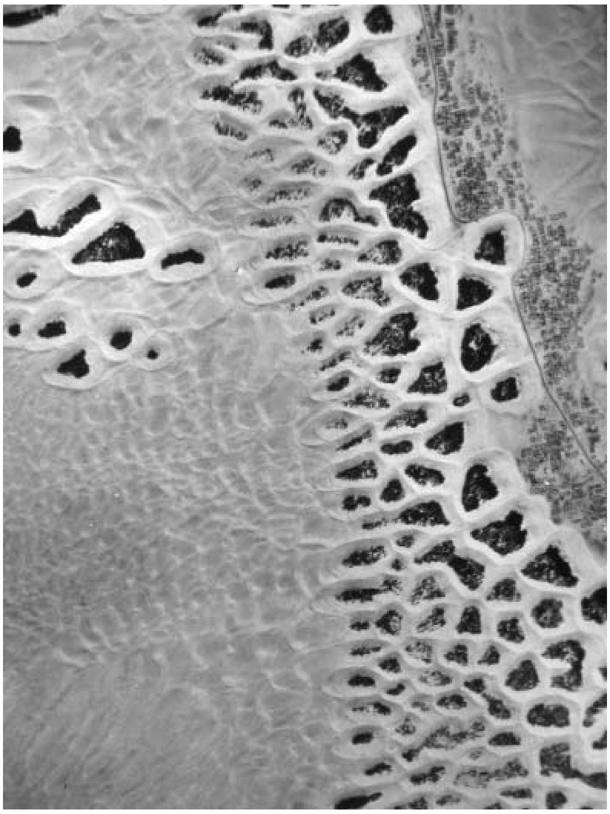


Fig. 3. Arial photograph of sand grove distribution in the region of Souf.

Ksar:

The term ksar defines concentrated desert villages with an urban pattern and with a sedentary farming population. The traditional quarters cluster around the market place (Souk) and the main mosque. The main ksar-type settlements in the region of Souf are El-Oued, Guemar, Taghzout and Kouinine. In general, the influences of religion and culture, which created a certain type of social organisation and the need of privacy in most of traditional Saharan desert settlements, have created a system of semi-public, semi-private and private spaces, forming residential quarters. This has resulted in a particular form of micro-environment, reflected in the way the houses open inwards toward their courtyards (Cherif, 1988).

In most of the Saharan settlements, other than in the region of Souf, the physical structure as a whole is a pattern of clustered and compact courtyard houses, two or three storeys high, densely packed together, and separated by narrow alleyways and *cul de sacs*, providing natural shading, and minimizing the impact of the harsh external environment of extensive heat, dryness, glare, direct radiation and frequent sweeping dust storms.

Fig. 4. Aerial photograph of the traditional quarter of Souf settlement (after Serjeant, 1980).

The urban fabric of the traditional quarters of Souf settlements exhibits a uniform modular type of architecture; the layout displays a visible regularity in the street pattern, as well as a distinct house form. The layout is an agglomeration on a continuous modular plan of rectangular or square shaped one storey high, courtyard houses, connected together by a regular grid-like pattern of wide sandy streets and narrow alleyways (Fig. 4, Fig.5). The main streets axes are parallel to the prevailing wind direction. In some quarters the rectangular residential blocks are grouped around a Rahba (a square around which a quarter is organised) or a mosque, from which straight narrow alleyways begin. The uniform and regular layout of the physical structure of all Souf settlements may raise the question of whether the nature of their location in the middle of the sand dunes and the continuous processes of sand erosion and deposition have resulted in the physical structure (grid system) of the settlements, in order to minimize the undesirable consequences of sand deposition around and between the buildings.

The traditional houses in the most desert settlements are the outcome of several factors, social, climactic, and building materials available. The house units have an inward-looking pattern; the rooms cluster around small enclosed open spaces (courtyards), which are partially shaded by walls and plants, and protected on all sides. The courtyard functions as a source of air, light and view. The courtyard is covered with sand; it is used for sleeping in the summer. Individual rectangular shaped rooms are covered by plaster domes or vaults, to prevent sand settling on the roofs surrounding the courtyard, and form a uniform modular, rectangular one story built form, with a solid blank external facade, sometimes decorated with false arches (Fig. 6).

Two main building materials available in the region of Souf were sand stone and gypsum, and both were used in constructing the traditional quarters (Cherif, 1988). Domes or vaults are easily

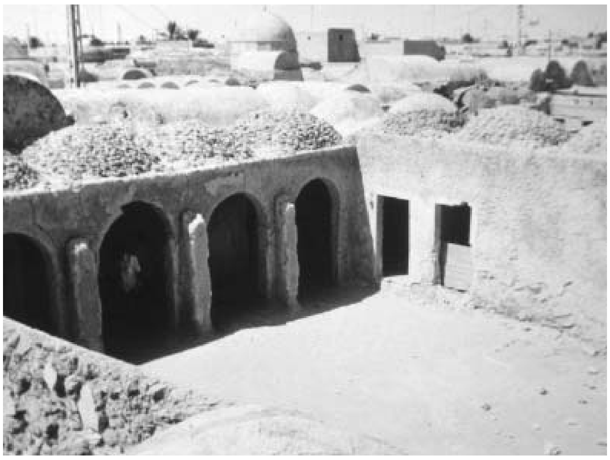


Fig. 6. Courtyard house in the town of Guemar (region of Souf).

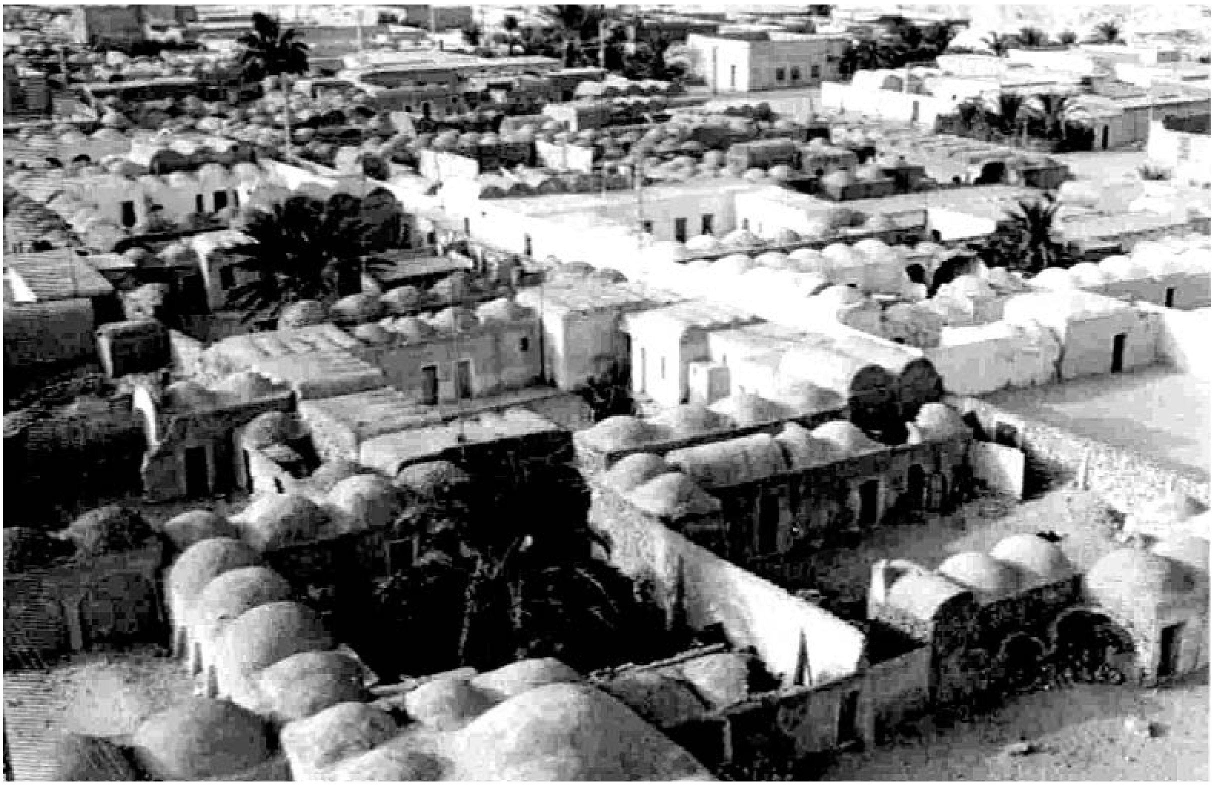


Fig. 5. Traditional housing quarter in the region of Souf.

built with gypsum and sandstones called loussa, and determine the form and height of the house and the room size. Most rooms are rectangular; they can be two to three domes long. The diameter of the domes varies from 1.5 m to 2.2 m, with their height not exceeding 2.5 m.

The access to the house is not visible from the outside. The lobby, called a skifa, is generally roofed by two domes and its floor covered by sand. The skifa serves as an important transition between public and private realms (Fig. 7). Opposite to and close behind the front door, a wall protects the courtyard from the view of possible visitors; in most cases, the lobby is directly connected to a reception room for the male guests. The door of the courtyard is set off from the axis of the front door and gives direct access to the courtyard, around

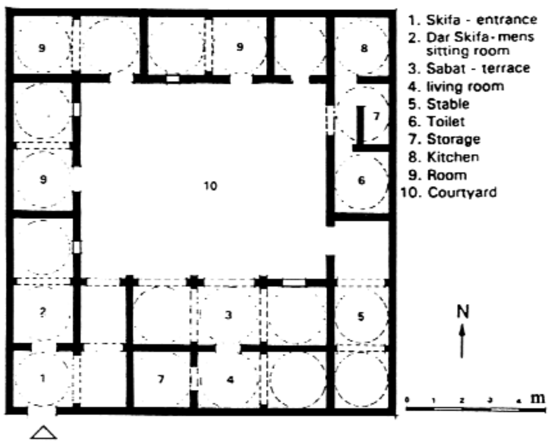


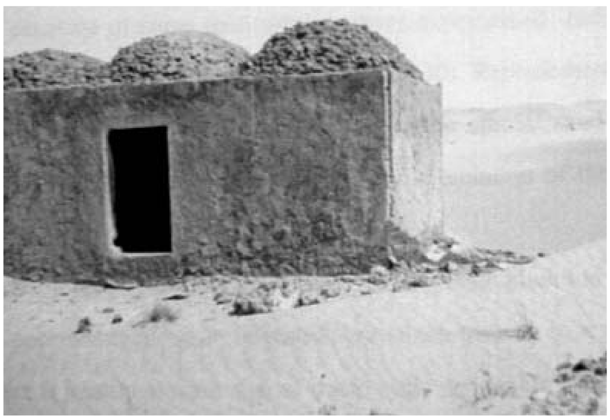
Fig. 7. A plan diagram of a traditional house in the region of Souf.

which different rooms and spaces are organised.

The habitable rooms are traditionally orientated to the north and south, as in the sabat, which is a sort of arch-designed gallery open to the courtyard and living room, oriented to the north, and used by the family in the hot summer. To keep it cool, the floor is covered by sand. The opposite row of rooms is used in the cold season, leaving the two remaining sides for utility rooms, such as kitchen, toilet and stable for the domestic animals.

Nezlah:

In the Souf region, Nezlah means hamlet (a small village), but elsewhere it means the nomads' camp. These hamlets are characterised by their dispersal, each one isolated from the others. The dispersion of hamlets is much more characteristic of villagers than of nomads (Tindert, 1986). Their house built forms are similar to those found in the major settlements (Ksour). However, they are built individually (Fig. 8) or attached to each other in a spontaneous layout; hamlets are located between the palm groves, forming an alignment of habitations. These are used as summer residences by the farmers for the surveillance and maintenance of the ghitane; some are one room dwelling types, usual-



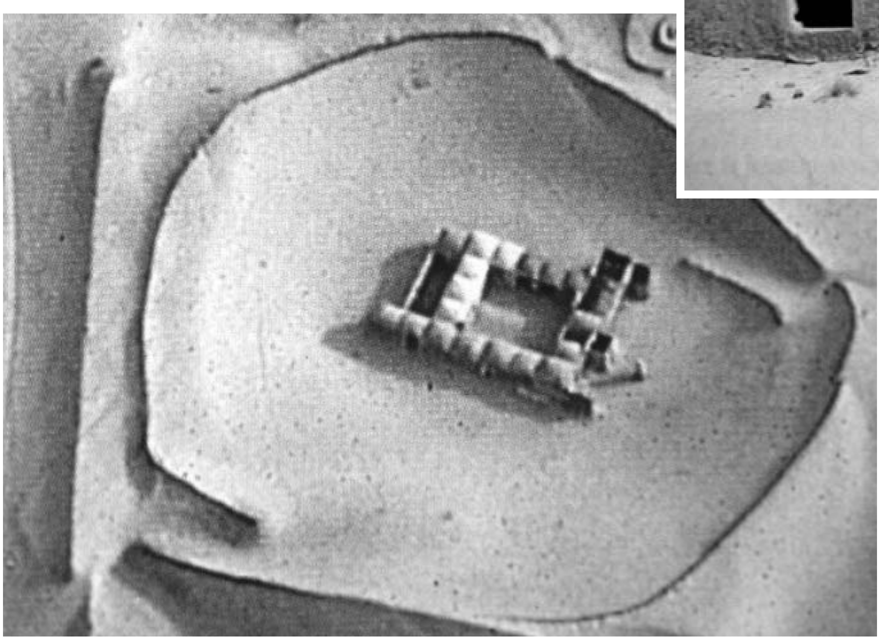


Fig. 8. Sand deposition around a hamlet (Nezlah).

ly built for storage or for a short stay in the harvest season. Most of the hamlet buildings are rectangular in shape, but of different sizes, and oriented perpendicular to the prevailing wind direction. In these hamlets, it is possible to distinguish the different patterns of sand deposition created around and between different building forms.

The existing situation

Although the traditional layout and building forms in region of Souf exhibited a unique physical structure, and architectural features and building techniques which survived hundreds of years of the destructive impact of sand deposition, a large num-

Fig. 9. Sand coverage of the deteriorated and abandoned houses.

Fig. 10. The rise in the water table in the palm groves.

ber of traditional houses are now slowly deteriorating and becoming overwhelmed by sand deposition. This could be related to the following factors:

- A new social pattern, new materials of construction and building techniques and changing economic possibilities are now leading to an acceptance of new forms of habitation and urban structure (Tindert, 1986). This leads people to move to new, modern-style houses, leaving the old ones without any regular maintenance and vulnerable to sand deposition and coverage (Fig. 9).
- The physical structure of some traditional quarters experienced radical changes, e.g. when streets were widened to allow vehicular access. Replacement of the traditional buildings with new buildings seems to increase the rate of sand deposition in the street, causing a serious problem to the buildings and movement of the inhabitants.
- The other factor affecting the buildings and the economic situation of the residents is the poor and inadequate infrastructure. There is inadequate drainage of waste water and pipes leak which cause pollution and rising of the water table. This has caused erosion of gypsum, (a main building material in traditional houses) and therefore the deterioration of the load-bearing walls. The rise in the water table in groves (Ghitane) has poisoned palm trees and the ghitane have become places of waste (Fig.10).
- The lack of knowledge and awareness by planners, architects, engineers and developers of good design principles in areas affected by sand deposition are reflected adversely in the design of the new buildings. In order to control the urban spread of the towns and the demand for new housing, since 1985, many new low and medium rise buildings have been built and many are under construction. Some of the housing schemes were designed to create a cultural image by using some traditional features such as domes or vaults; in some cases even traditional building material were used. However, the building layouts and forms were based on the design of buildings built elsewhere, or were designed by architects and engineers not concerned with or aware of the effect of sand deposition and drift patterns on buildings. The rate of sand deposition around these buildings seems to have increased rapidly in comparison to sand deposition around the traditional quarters. In some cases, sand piling up has led to the destruction of building walls, in turn leading to many of these new buildings being deserted (Fig. 11).

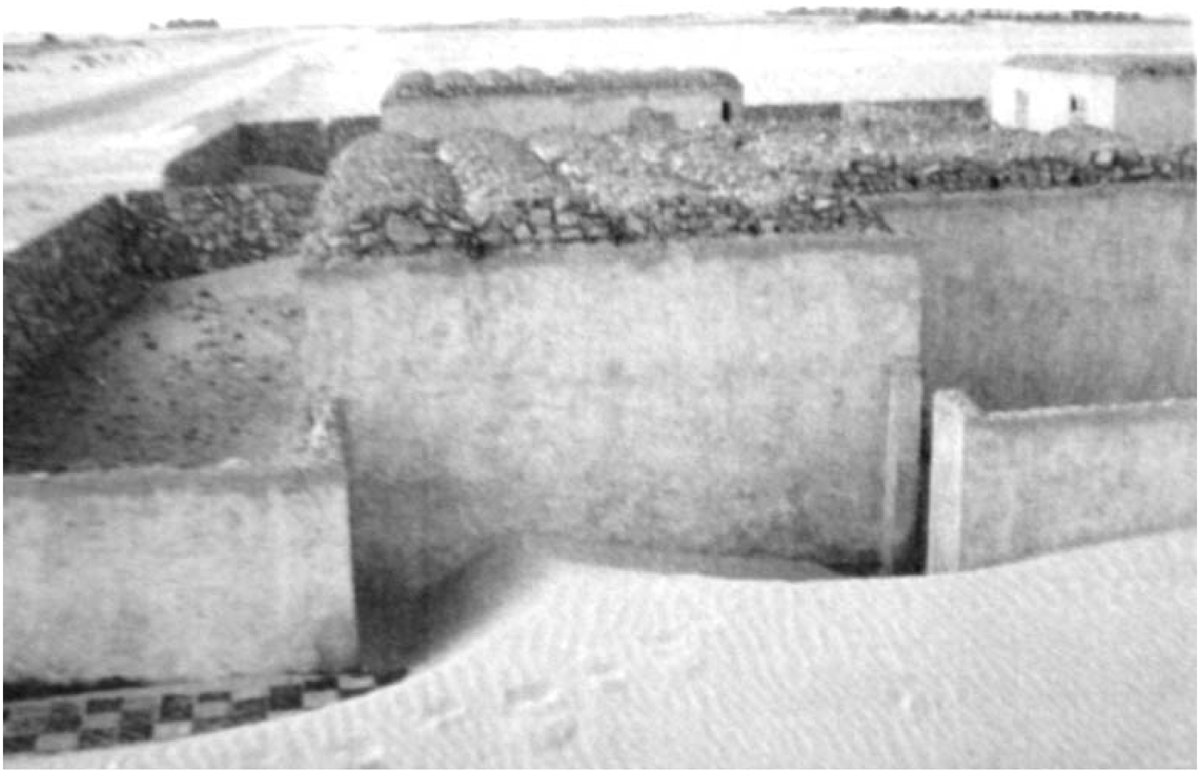


Fig.11. Sand encroachment and deposition around new housing scheme

Research method

Field work and wind tunnel experiments were carried out to evaluate the relationships between the alteration of building form (height, width) and the sand depositional patterns around them. The field survey and measurements were essential to provide data cross-check with the results of the wind tunnel experiments on models representing the buildings in the filed and were used to control wind tunnel parameters for simulation purpose.

The settlement layout is that of the Nezlah type; its buildings are scattered, some sited individually and some grouped together as blocks. Individual single storey cubic and rectangular buildings of different heights, widths and lengths, and the topographical geometry pattern of sand deposition around them, were measured and documented on a two dimensional map.

The geometrical pattern of sand deposition around the buildings in the field showed a symmetrical crescent shape, with a single ridge sand deposition formed adjacent to the windward face of the individual buildings and sides forming a horseshoe-like shape of sand accumulated around the individual buildings. The windward sand deposition had a gentle windward slope of 10 degrees and a lee slope or slip face at the angle 32-36 degrees. The area between the upwind deposition and the windward face of the building where no sand deposition was observed was called upwind sand scour hole and the area between the sideways deposition and the lateral side of the building was called sideways sand scour hole.

The buildings were classified according to their size ratios (e.g. H/W, W/H). The way the sand accumulated or formed around them was also used for classification: (a) windward and sideways depositions, and (b) leeward deposition. The measurements were taken of the windward sand deposition: upwind distance (Ud), windward crest distance (WCd), windward crest height (WCh) and sideways deposition distance (Sd) (Fig.12).

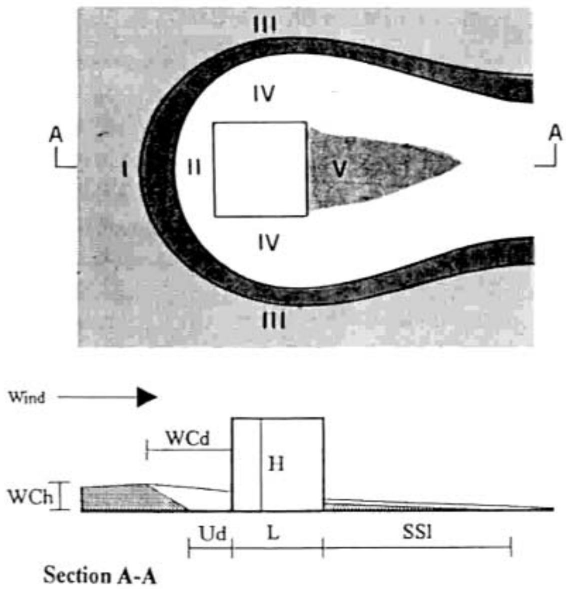


Fig. 12. Section diagram of the sand geometry features around building. I-windward sand deposition, II-upwind sand scour hole, III-sideways sand deposition, IV-sideways sand scour hole, V-sand shadow.

Wind tunnel experiment

The study used special wind tunnels for simulating sand depositional patterns around models of buildings. It developed a sand depositional technique to control the wind tunnel parameters in order to simulate successfully the situation in the field. The experiments were conducted using Arizona State University wind tunnel designed to simulate sand particle movement. This technique is used to simulate wind-blown sand through inserting sand particles into the air stream by using a sand feeder, or laying sand bed surface along the test section and upwind of the model. A series of experiments was conducted to examine the changes in the sand geometrical pattern in the windward and sideways of square and rectangular shaped models. The wind tunnel experiments, using the sand depositional technique exhibited sand depositional geometrical patterns similar to those measured around the buildings in the field.

Field and wind tunnel results

The results of combining field work with wind tunnel experiments to evaluate the relationship between an alteration in building (height, width) and the sand depositional geometry pattern showed the following:

(a) An increase in the windward and sideways sand scour hole areas (areas free of sand formation) are dependent positively on building height rather than building width. The optimum building height/width ratio (H/W) is 2.5, at which windward sand deposition upwind distance (Ud) and sideways deposition lateral distance (Sd) reach to a maximum distance where they remain in a steady state, as does the windward sand deposition crest. (Fig.13).

(b) The piling up of windward sand deposition in the windward side of the building is dependent positively on building width rather than height, and conversely its upwind distance decreases when building width/height ratio is greater than 1.5 m. Single storey buildings require wider ratios of W/H than multi storey buildings. If this was achieved, the maximum W/H ratio should not exceed 3, to avoid windward sand deposition attaching to the building's front elevation (Fig.14).

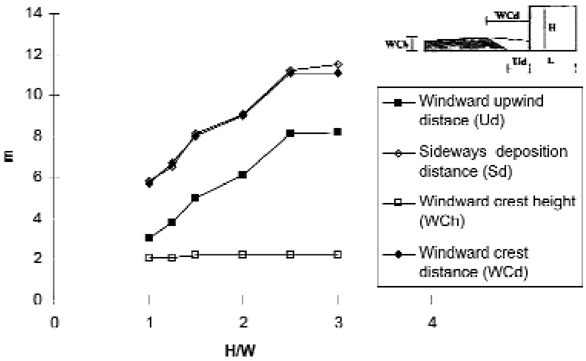


Fig. 13. Relationship between altering H/W ratio and the sand depositional features around buildings.

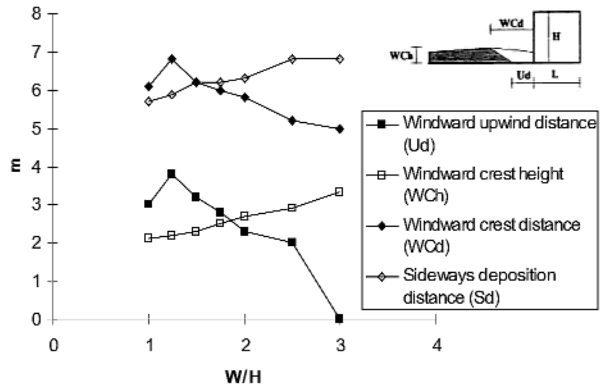


Fig. 14. Relationship between altering W/H ratio and the sand depositional features around buildings.

Sand depositional pattern around clustered buildings

As mentioned earlier the layout of the traditional quarters in region of Souf exhibits a grid like pattern with streets axes parallel to the prevailing wind direction. A group of contemporary residential dwellings was selected to observe the effect of setbacks in walls on the sand depositional patterns. Similar detached houses were grouped together as blocks in a grid system layout. Their street axes were almost parallel to the prevailing wind direction. The entrance to each house from the main street was set back from the main fence wall, as seen in (Fig. 15).

Sand accumulated in the areas of the setback in the walls (Fig.16). This may generate a strong vortex in these gaps or in the setback areas and may lead to formation of the pattern of sand accumulation. Sand deposition was also observed in all the internal open spaces and was deposited mainly in the corner areas (Fig.17). In addition to the problems caused by the extent of sand deposition against the walls and in the internal open spaces of the houses, deterioration of parts of the walls led to an increase of sand accumulation in the internal spaces of the houses. Eventually the residents deserted the entire area.

The same situation has been observed in different residential schemes which have adopted this design. It is mainly caused because of the lack of knowledge about sustainable building design and layout in such areas. This emphasises the need for research to establish an understanding of the effect of built form on sand deposition and to develop some design guidance to limit the undesirable consequences resulting from sand deposition around or against buildings.

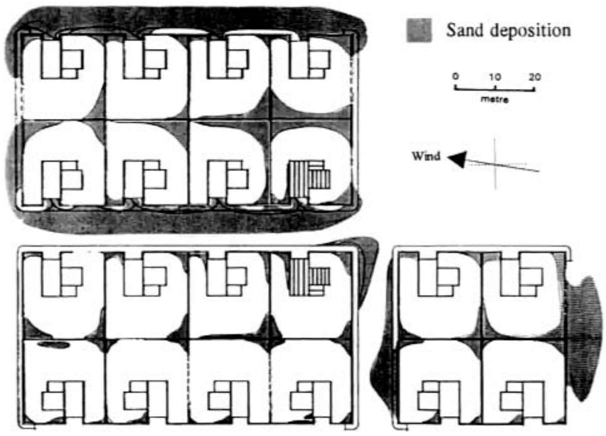


Fig. 15. A diagram of the sand deposition and drift pattern around a new housing scheme in the region of Souf.

Fig. 16. Sand deposition in the setbacks entrances of a new housing scheme

Fig. 17. Sand deposition in the internal open spaces of a new housing scheme.

Conclusion

This research provides an understanding of the relationship between built form and aeolian sand depositional patterns, from which some design guidance could be derived. The results suggest that optimum measurement ratios of built form could be set out to help to control the sand features created around the buildings, and to minimize the piling up of sand deposition and enlarge the area free of sand around the buildings. It is hoped that this research would increase awareness and knowledge, and encourage investigations in the field of aeolian sand deposition while designing human settlements.

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Detecting and monitoring impacts of ecological importance in semi arid rangelands

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Abstract

The paper reviews the characteristics of arid ecosystems and the factors that have ecological significance in desertification processes. The problem of what constitutes an ecologically significant impact in dryland ecosystems has been considered, and accelerated soil erosion is regarded as a prime indicator because it determines the resilience of these systems. The role and purpose of monitoring is discussed. In this context three potential inventory and monitoring systems (satellite imagery, aerial photography, including videography, and ground photography) are compared. On the basis of these evaluations a cost model is suggested as a guide in formulating optimal multistage frameworks for monitoring remote arid sites. The decision support systems and remote sensing are tools that are being integrated into management aids for use by land administrators and land users.

Introduction

The functioning of arid ecosystems is strongly controlled by the amount and flow of energy and the amount of water. They are essentially rain-driven systems. Nutrients are cycled but energy, carbon and water cascade through them with the flows and pool sizes of energy and carbon limited by the availability of water (Thomas and Squires, 1991). Consequently, the temporal and spatial distribution of water has exaggerated importance in determining the structure and functioning of these ecosystems.

Arid ecosystems are often labelled “unstable” and consequently “fragile” because they show great variability and turnover in biomass and populations of plant and animals (including soil biota) over short intervals, or remain inert for long periods of time. They are, however, very resilient (Ludwig et al., 1997).

Also in arid rangelands, populations of plants, herbivores (including insects), predators and decomposers are more adversely influenced by variations in the physical environment (specifically rainfall) than by interactions with each other (Noy- Meir, 1980). This has important implications for evaluating and monitoring impacts on semi arid rangeland ecosystems, because weak interaction between populations of plants and animals means they can be monitored in relative isolation from each other.

From this one might deduce that impacts affecting the redistribution of water within arid ecosystems are the most important, because they determine the amount and distribution of primary production (Le Houerou, 1984). More specific impacts (selective grazing or perdition, pollutants etc.) will affect the populations of only a few organisms and, since the interaction between populations is small, they are unlikely to influence the system as a whole. In arid landscapes the most effective process is land degradation characterized by any alteration of the soil surface that enhances runoff and diminishes infiltration (Stafford-Smith and Pickup, 1990). Any redistribution of water is followed by nutrients, because their flows are coupled. Soil erosion and loss are the greatest threats to the resilience of semi arid and arid ecosystems. Desertification is a particular manifestation of land degradation in drylands and is characterized by losses of soil, nutrient and water and by loss of vegetative cover.

This paper reviews the characteristics of arid ecosystems and impacts that have ecological significance in desertification processes. It considers the role and purpose of monitoring, compares three potential inventory and monitoring systems, and suggests a cost-effective model as a guide in formulating optimal multistage frameworks for monitoring remote arid sites. The decision support systems and remote sensing tools are being integrated into management aids for use by land administrators and land users (Squires et al., 1990; Squires, 1998; Squires and Bennett, 2004).

Land degradation monitoring

Desertification has been defined as a long term trend in vegetation and soil degradation, in contrast to more short term variations in biomass growth due to drought and other types of climatic variation (Grainger, 1990). It arises from interactions between biophysical and socio-economic and policy causes (Fig. 1).

The process of monitoring is defined as repeated assessments over time. Reliable desertification monitoring demands that any short-term fluctuations disguising long-term trends be removed from the overall temporal sequence of vegetation maps. The task is made even more difficult by the fact that the fluctuations are spatial as well as temporal (Grainger and Bradley, 1998). Box 1 sets out some of the key factors in spatio-temporal variability in rangelands and points out some of the constraints that apply when designing effective monitoring systems.

Box 1. Types of spatio-temporal variability in rangelands

Temporal variation: Rangelands are highly variable in space and time. Periodic drought and high year to year rainfall variability are superimposed on seasonal shifts in precipitation, temperature regimes and variation in day length and other factors of significance to plant and animal physiology

Altitudinal variation: Rangelands may extend from highlands to lowlands and in many places altitudinal migration (transhumance) is practiced to take advantage of the distribution and seasonality of the various forage resources.

Spatial variation in grazing pressure: Grazing is rarely even. The distribution of the various vegetation communities, proximity to villages or to watering points etc. can influence this. Often there are large "sacrifice areas" near to permanent water or to villages.

Temporal variation in grazing pressure: As livestock go through their breeding cycle the herd size rises and falls. In addition to changes in number of livestock there is considerable variation in the demand for forage. These two influences lead to variation in grazing pressure throughout the year.

Rangeland degradation is often difficult to measure successfully over extensive land areas.

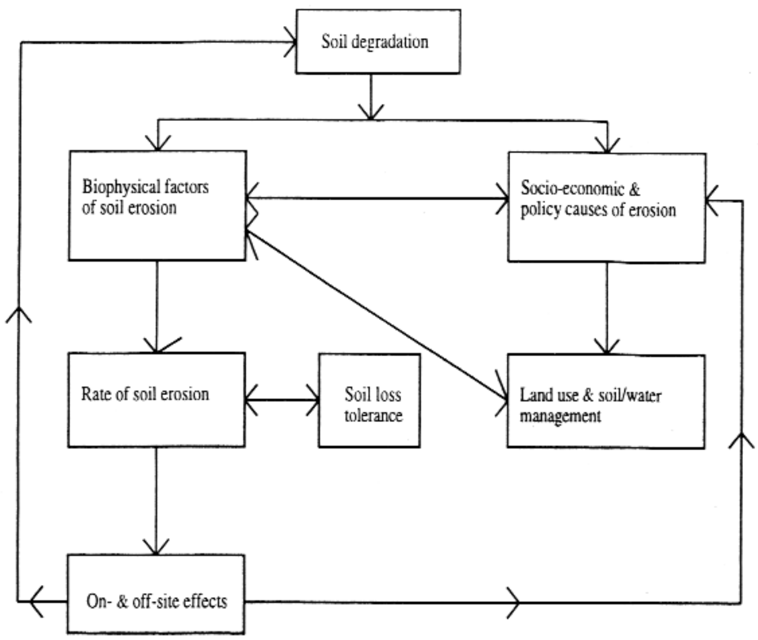

Fig. 1. The interplay of biophysical and socio-economic factors implicated in soil eroosion and land degradation.

Ground-based vegetation sampling techniques must be sensitive to changes in parameters capable of defining this degradation or lack thereof. These parameters include species cover, frequency, density, and botanical composition, along with various surface soil characteristics. Both the vegetation and the soil must be examined in a monitoring program to determine if grazing practices are successful in maintaining ecological health of the range landscape (Ludwig et al, 1997). Some parameters can be monitored by remote sensing (Pickup et al., 1994)

Requirements for inventory and monitoring

The monitoring methodology must combine the characteristics of low cost, to cover a vast area and capability of stratification, to account for the mosaic of differing land types, and yet retain sufficient resolution to detect processes such as soil erosion. In addition, the time scales of climatic events must be considered. Figure 2 shows some of the attributes of the temporal and spatial characteristics of a hypothetical "test" area on which the three monitoring systems are compared, Landsat imagery, large-scale aerial photography, and ground surveys.

A suitable monitoring system requires a spatial resolution of 1 m or less with aggregation or sampling spread over five orders of magnitude. Time scales range from a one-day rainfall event to an upper limit of 10 years or so. Both large-scale aerial photography (say 1:1000) and (oblique) ground photography have a lower spatial resolution limit of say, 10 cm, adequate to resolve all of the micro scale features. Landsat MSS data are composed of pixels sized 80 m x 60 m approximately; however, the presence or absence of smaller higher contrast features can be inferred. Landsat TM has a pixel size of 30 m x 30 m. SPOT (20 m x 20 m) has been used in some situations and AVHRR data of low resolution (1 km x 1 km) have been used for many studies because of their high temporal resolution (i.e. daily). Table 1 gives a comparison of the utility of three sampling approaches for rangeland monitoring.

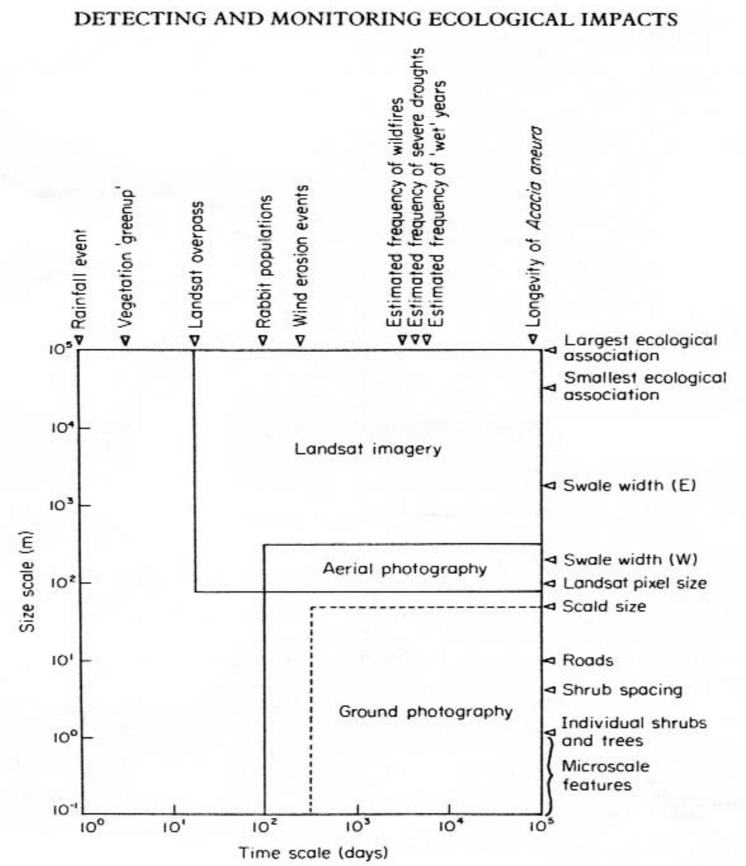

Fig. 2. Attributes of the temporal and spatial characteristics of a hypothetical "test" area on which three monitoring systems are to be compared.

The best frequency of observations is provided by Landsat with coverage every 16 days (cloud cover permitting), declining to realistic estimates of once or twice per year using photography. An important feature here is not just the total number of possible assessments, but also the flexibility to choose the most appropriate times for measurement. Within the framework of Figure 1, there appears to be a sharper division of capability between Landsat and the two photographically based methods. These methods are not interchangeable but complementary. The value of multi-spectral airborne videography with high resolution (0.3 - 1.0 m pixels) will be very important in the future for the monitoring of rangeland vegetation and soils. There is also potential to couple the small-scale satellite imagery such as Landsat TM to these near-earth large–scale images for overall analysis and interpretation, of range condition and trend.

The trade-off involved in assessing and monitoring sites in extensive rangelands is the cost of the information acquired compared with the costs associated with its use in regulation and management of

Table 1. A comparison of the utility of three sampling approaches for rangeland monitoring

Landsat is limited by its relatively coarse resolution but has the advantage of frequent acquisition, large area coverage and the unique capability of assigning a reasonably accurate geographical location of any detected features	In many aspects the best tool to assess sites in this situation, because a skilled interpreter can extract and quantify variables that relate to erosion, its causal agents and the process of Revegetation.	Can be dismissed as a quantitative and landscape assessment technique. It is restricted to an illustrative, qualitative role or to an approach for getting detailed data on a few sites.
Many features could be detected by their spatial context, rather than brightness level alone	Is excellent for assessing soil erosion. Resolution at scales up to 1:50,000 are sufficient to detect most erosion features, and schemes for quantifying the assessments are easily constructed.	In spite of its popularity, is very inadequate method of sampling and recording landscapes. The capability of resolving quite small features (e.g. seedling establishment, rodent damage, is counterbalanced by the inadequate sample size and distorted perspective
Landsat is able not only to detect the amount of vegetation cover but also to record the pulse of vegetation following a rainfall event	The revegetation of areas can be readily assessed accurately and quantitatively but at considerable cost in labour.	Within the limitations records revegetation can be made if permanent sites are established, although problems of exact relocation are appreciable
The data generated is amenable to data management, especially through GIS	Disadvantage lies in its restricted and costly coverage, subjectivity in interpretation and uncertainties associated with site relocation for monitoring.	Disadvantage lies in its restricted and costly coverage, subjectivity in interpretation
In spite of the low spatial resolution, "problem' areas can be detected by Landsat, although the identification of causal agents (human, grazing etc) may not be possible.	'Problem' areas easily seen and can be studied as a sub-set	'Problem' areas can be studied in great detail but at considerable cost
The use of rectified image data, means that the exact location of a feature in the image can be read by geographical coordinates.	The technique by itself cannot be used to give precise geographical location to any point on the ground unless the aircraft is fitted with GPS or similar navigation systems.	Cannot by itself provide any geographical reference
Because of their resolution limitations, Landsat data are not optimal to detect and assess invasion of pest species such as mice or locusts.	Most suited to assess the impact of pest species. The trade off is between resolution and the area of the sample site.	Limited to only selected facets of any pest problem
Problem areas (e.g. tracks precipitating the extensive blowout of dunes or scalding of swales etc) should be identifiable if they become extensive (more than 2-3 pixels wide)	Problem areas can be studied in detail	Problem areas can be studied in detail

[1]*The flush of green vegetation may be apparent even though the new growth covers only a small percentage of each pixel.*

the rangelands. The most efficient approach to monitoring is usually by a carefully selected and accurately measured network of permanent sampling sites. Because successive measurements at each permanent site are positively correlated, estimation of change (the difference between the two means) can be more precise than the estimates of either mean. This requirement can most readily be met by Landsat, because it provides complete coverage and can be rectified to any system of geographical coordinates. The two photographic methods require that the sites be marked in some way which will incur additional costs.

An operational monitoring system requires a framework for efficient data organization and reporting. Computer-based geographical information systems (GIS) have been developed for this purpose when data are geographically referenced. A GIS might include basic information from various sources – land tenure or use rights, soils, land systems, infrastructure with data on changing parameters such as vegetation being added and updated by the monitoring process. Landsat data are ideally suited to this form of information management.

The capabilities of Landsat and large-scale photography or videography are complementary, and can be combined to form a multistage method. Obviously there is need for a cost-allocation model to provide guidelines for optimizing the combined use of Landsat and aerial photography.

A cost model for determining optimal sampling strategies

The model described here is derived from Maxim and Cullen (1977) and is based on the assumption that the known sites of impact can be classified into two groups, "good" and "bad" (satisfactory versus problem areas), and the ground inspection reveals the truth. Ground inspection has a very high cost in terms of money and time, so the task of remote sensing is to minimize the number of field visits, or to eliminate them. Classification using satellite or aircraft imagery gives rise to four possible outcomes (1) a "bad" site is classified as "bad" (ii) a "good" site is classified as "good"; (iii) a "bad" site is classified as "good" or (iv) a "good" site is classified as "bad". Outcome (iii) is the undetected problem area, whilst (iv) generates an unnecessary (and costly) field inspection. The last two occur with probabilities β and α respectively. The probabilities will be different for aircraft and satellite interpretation, so are designated α_a, β_a and α_s and β_s, respectively.

For a system containing N sites of which N_1 are

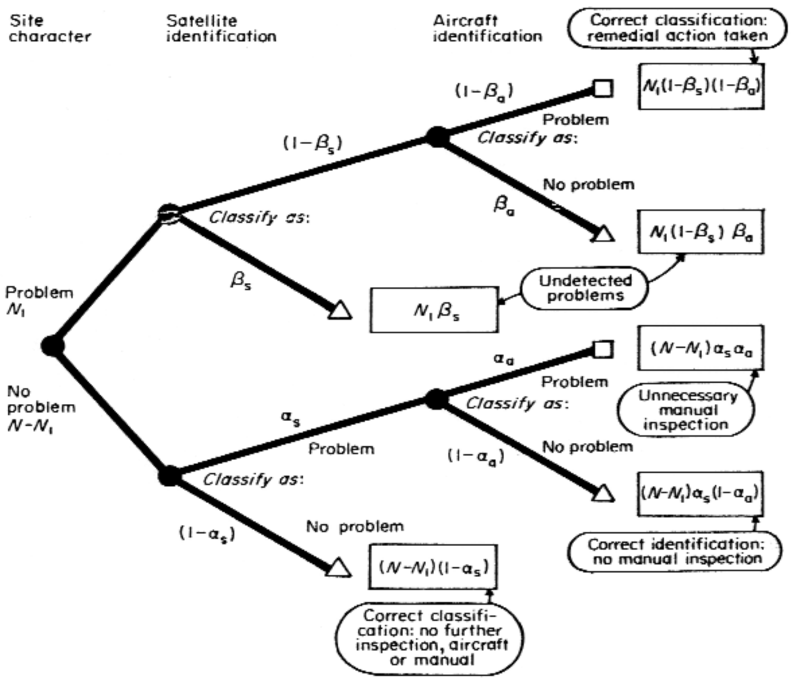

Fig. 3. The structure of a three-stage inspection system for remote dryland sites. Nodes represented by triangles indicate that no further inspection is conducted. Nodes represented by squares indicate ground inspection. The calculated number of sites in each category in each box. Source: Maxim & Cullen, 1977.

Table 2. Cost formula derived from Figure 3 for each of the four options for multistage assessment. (The symbols are defined in the text).

Option	satellite	Aircraft	Ground	penalty	Fixed cost
(i)	–	–	NC_m	–	F_m
(ii)	C_s	–	$C_m[(1-ß_s)N_1+\alpha_s(N-N_{1)}]$	$C_pß_sN_1$	F_m
(iii)	–	C_aN	$C_m[(1-ß_a)N_1+\alpha_a(N-N_{1)}]$	$C_pß_aN_1$	F_m+F_a
(iv)	C_s	$C_a[(1-ß_s)N_1+\alpha_s(N-N_{1)}]$	$C_m[a_sa_a(N-N_1)+(1-ß_s)(1-ß_a)N_1]$	$C_p[ß_sN_1+ß_a(1-ß_s)N_1]$	F_m+F_a

"problem" or "bad" sites (see Fig. 3) the structure of three-stage system would start first with satellite inspection, then aircraft and finally ground or manual inspection. This system aims to minimize the number of ground inspections and it assumes that as soon as a site is classified as "good" at any stage, it is not considered further. In Fig. 3, the final expressions at stage 3 for classifying the sites assume that satellite and aerial inspections are statistically independent.

The cost of the procedure is the sum of four components (i) the cost of satellite inspection (C_s) which covers all sites; (ii) the cost per site (C_a) of aircraft inspection; (iii) the cost per "problem" area not detected (C_p) (these are 'penalty' or 'social' costs which are high); and (iv) the cost per site (C_m) of ground inspection which applies to all sites labelled "bad". In many remote rangeland areas there is need to add "fixed" costs such as those associated with aircraft and ground systems, which represent the substantial cost of just getting aircraft and people to the sites, and the comparatively smaller costs (C_a, C_m) of measurements made per site thereafter.

Using this approach it is possible to compute the likely cost of various configurations of a multi-stage assessment and monitoring system. The cost functions of four options are listed in Table 2. These options are (i) ground inspection only; (ii) satellite and ground; (iii) aircraft and ground; and (iv) satellite followed by aircraft and ground.

The model outlined here has general application to the assessment and monitoring of remote rangeland sites and should be a useful guide in the choice of assessment strategies.

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Eco-economic analysis and integrated development pattern of the Heihe River Basin in arid northwest China

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Abstract

It is argued that ecological environment in the lower reaches of the inland river basin would always be destroyed as the socio-economic development would occur in the middle and upper reaches in the arid regions of northwest China. In this paper, taking the Heihe River Basin as a case study, we analyze some critical ecological and economic problems of the inland river basin, such as desertification, water resource shortage, oasis shrinkage, imbalance in economic development, poor household income, etc. By analyzing the ecological and economical factors of the Heihe River Basin, we discuss the structure, character and concept of the eco-economic system. And then, the system integration theory is applied to put forward a sustainable development pattern of the Heihe River Basin. The pattern is divided into two sub-patterns: (1) animal production pattern of pasture areas in the upper and lower basins; and (2) agriculture and animal production pattern of the farming areas in the middle oasis basin. At the same time, the detailed approaches and methods of each sub-pattern are analyzed. The result shows that the energy out put of the integrated system can be improved greatly compared with the summation of the systems before integration. The main reason for the improved energy output from the integrated system is that the system takes advantages of each sub-system to improve the resource-use efficiency. And the system integration development pattern can be a brand new approach to improve the efficiency of water-resource use and water resource distribution in the Heihe River Basin.

Introduction

The arid region in northwest China would be an important region for socio-economic development and potential area for human habitation in the future (Wang et al., 2001). As a result of the dry climate, the main landscape in northwest China is characterized by arid desert. However, due to a series of high mountains located in this region, the landscape is undulating with mountains alternating with the basin plains. On the windward slope of high mountains, the precipitation is abundant. As a result, there is normally flourishing vegetative cover and forestry in the middle windward slop of the high mountains, making the area look like a humid island in the arid northwest China. Generally, the mountain areas above 4000 m elevation are covered with permanent snow and ice, and these are solid reservoirs of water in the arid northwest China. In spring and summer, with increasing air temperature, the snow and ice begin to thaw and the snow and ice melt, together with rain water, flows down as rivers (Tang, 1992). These rivers, originating from high mountains, flowing to large arid desert areas, nourish some oases in the arid northwest China. This process indicates that there is a close interrelation between oases and mountains, forming a harmonious regional system in arid northwest China (Wu and Zhang, 2000). The majority of the rivers in arid northwest China are inland rivers, except River Etris, which finally flows to the Arctic Ocean. There are therefore many inland river basins in arid northwest China.

The inland river basin in arid northwest China is located in the center of the Eurasian continent, north of 35° N and west of 106° E, a land mass which includes the entire Xinjiang Autonomous

Region, the Hexi Corridor in Gansu Province, and the western parts of the Helan Mountains in the Inner Mongolia Autonomous Region. Occupying nearly 24.5% of China's total land area, it is one of the most rigorous arid regions in the world (Shi, 1995). This region is characterized by alternating bands of relatively humid mountains and arid plains (Wang and Cheng, 2001).

Several rivers such as Heihe, Shiyang, Shule, and Tarim originate from the mountainous regions, nourish some oasis in the middle reaches, and then flow to some small lakes or disappear among the large arid desert plain. Although there is more agricultural and animal husbandry production in these basins than in other arid regions, water resource is the most significant factor restricting the basins' development (Zhu et al., 2004). The places with sufficient water supply have formed oases, and the places with insufficient water supply have become degraded desert lands.

Heihe River Basin, one of the typical inland river basins in the arid northwest China, has received much attention not only in China but all over the world in recent years, because of its serious environmental degradation and associated eco-economic problems. Taking the Heihe River Basin as a case study, this paper focuses on some critical eco-economic problems that have arisen in recent years in the inland river basin, and a sustainable development pattern has been put forward according to the system integration principle.

Study area

Heihe River Basin (HRB), the second largest inland river basin in arid northwest China, is located between 97°42´–102°E and 37°41´–42°42´N, and covers an area of approximately 128,000 km^2. Administratively, the basin includes part of Qilian County in Qinghai Province, some counties and cities in Gansu Province, and part of Ejin Banner of Inner Mongolia Autonomous Region (Fig. 1). The main stream of Heihe River, with a length of 821 km, originates from the Qilian Mountians, flows through the Hexi corridor of Gansu Province, and enters into two terminal lakes in the desert of western Inner Mongolian Plateau. The landscape and human livelihood is very different in the HRB. In the upper reaches of the HRB, mountain grassland and mountain forest constitute the main landscape, while in the lower reaches the main landscape type is desert grassland. Therefore, the main human livelihood in the upper and lower reaches of the HRB depends on animal husbandry, based on the mountain grassland and desert grassland. In the middle reaches of the HRB, the irrigated oases are distributed along the sides of the Heihe River. This constitutes the 'golden' zone for economic development in the entire HRB, being one of the major grain producing regions in China. Some 88.47% of the HRB population resides here and 87.93% of the HRB GDP originates here. However, important changes in the hydrological conditions, ecology and environment have taken place in the last 50 years. The discharge in the lower basin of the river has decreased significantly and more than 30 tributaries as well as the terminal lakes have dried up. Such hydrological changes have resulted in a marked degradation of the eco-environment in the entire basin. The main reason for water shortage is the dramatic population growth and an increase in the irrigated oasis area in the middle basin over the past decades (Chen et al., 2005).

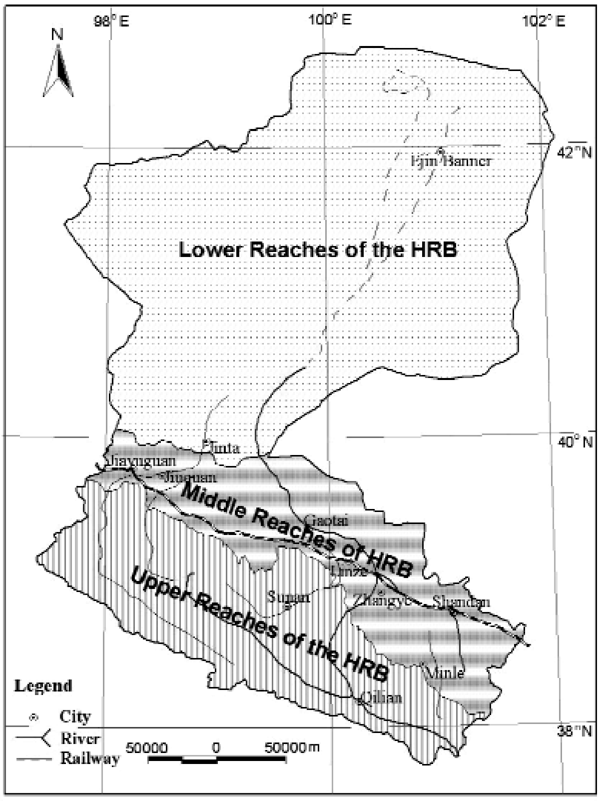

Fig. 1. Map of the the Heihe River Basin.

Eco-economical problems

It is argued that eco-environment in the lower reaches of the inland river basin always gets destroyed as the socio-economic development of the middle reaches and upper reaches in the arid region of northwest China occurs. For example, in case of Tarim River, the largest inland river of China, the most serious problem is that its terminal lake (Lop Nur) has dried up and land desertification has quickly expanded in the middle and lower reaches of the basin. The same problem is also affecting the HRB and Shiyang River Basin. The typical eco-economic problems of the HRB are vegetation degradation, land desertification and salinization, oasis shrinkage, and poor household income. Especially in the recent years, because of the water shortage and drying up of terminal lakes, the lower reaches of the HRB have become one of the major sources of sand for the storms in northern China, posing danger not only to the whole basin’s ecological safety but also endangering the entire northwest China.

Vegetation degradation in the upper reaches of the HRB

The Qilian Mountains area is water source of the entire river basin. Because of deforestation, the forestry area has decreased by 16.5%. The biodiversity has also decreased and the lower altitudinal boundary of the forest-covered area is shrinking, moving upwards from 1900 m to 2300m during the past 50 years (Wang, 2004). All these factors have weakend the capacity of the forest to conserve water. In turn, this has caused severe deterioration of the eco-environment in the whole basin.

Several studies have shown that overgrazing is the most important reason for vegetation degradation. Taking the Sunan County as an example, there were initially only 264,000 sheep-unit livestock (one camel = 7 sheep-unit, one horse or cattle = 5 sheep-unit, and one donkey or mule = 3 sheep-unit) in 1954, but the number increased to 878,000 units in 1980. Owing to over browsing and trampling, palatable grasses decreased, unpalatable and poisonous weeds increased, grass yield greatly reduced, and surface soil structure destroyed. As a result of destruction of vegetative cover and soil structure, wind erosion increased leading to desertification. The livestock carrying capacity of the pastureland also declined at the same time. It declined from 1,242,000 sheep-unit in 1968 to 600,000 units now. Because of this decrease in grassland productivity, nearly 1/3 of total livestock population needs to be fed on grain and hay brought in from out side the pasture region in winter or the spring.

Land degradation in the middle reaches of the HRB

The irrigated oases are mainly distributed in the middle basin of the entire HRB. However, human activities have significantly changed the distribution and allocation of the limited water resource in the oases, leading to a contradictory developments (Lu et al. 2003), resulting in land desertification, secondary salinization, and grassland degradation. Land desertification mainly expanded in the interlaced zones of oasis and desert, which occupy 18.87% of the middle basin area. Secondary salinization developed mainly inside the irrigated oasis, covering 5.46% of the middle basin area, due to defective irrigation and farmland reclamation. Along with the reclamation and desertification, the grassland area became smaller and smaller, and now more than 50% of grassland has been degraded in the middle reaches of the HRB.

Water shortage and the environment degradation in the lower reaches of the HRB

Of the entire HRB, the eco-environment degradation is most serious in the lower basin. Land desertification area here has expanded to more than 50% of the lower basin oasis area during the past 40 years (Liu and Li, 2004). Forestry and grassland in the oasis has degraded quickly. From 1958 to 1980, the forestry along the river and the oasis decreased by 57,300 ha, and from 1980 to 1994, another 192,400 ha of forest had been degraded. Up to now, more than 60% of the forest area has degraded or died, and has become desert. At the same time, grassland has also been degraded during the past 50 years. The diversity in the herbage plant species decreased from 130 to 30, and the grassland carrying capacity decreased by 46%. The eco-environment degradation was mainly caused by water shortage. Observations showed that the annual discharge of the river from middle basin to the lower basin decreased from10.5×10^8 m^3 in 1940s to become 8×10^8 m^3 in 1950s, 4× 0^8 m^3 in 1970s, and only 1.29×10^8 m^3 in 2001 (Fig. 2).

Adverse effect of economic activities on eco-environment

Increasing smallholder incomes and improving the environment are often viewed as conflicting objectives (Ramadhani et al., 2002). Because of lower household incomes in the HRB, especially in the upper reaches and lower reach basins, people have taken up such activities as over-cultivation, overgrazing and over-cutting wood, to improve their incomes, that are harmful to the local eco-environment. For example, owing to the country's policy of "putting grain in top priority position in agricultural production", 9,246 ha grassland in Sunan County had been brought in to cultivation from 1958 to 1961. And now, there are still 4,964 ha planted with lower yields, or left fallow with poor grass yield. In order to increase their incomes, some people resorted to collecting medical and other high value plants, by removing sod and digging root, which seriously disturbed soil layer, destroying grasslands. It is very obviously that these irrational economic activities are all triggered by lower household incomes and are harmful to the eco-environment.

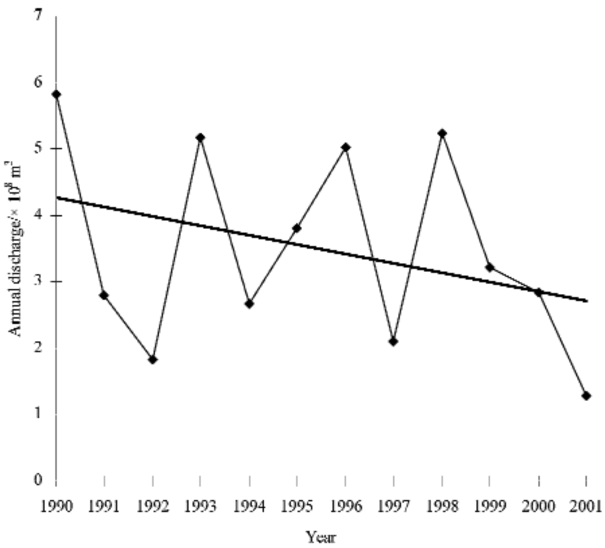

Fig. 2. The annual discharge of the Heihe River from the middle reaches to the lower reaches during 1990-2001.

Analysis on eco-economic system of the HRB

According to the system theory, the above eco-economic problems are basically caused by the conflict of the ecosystem and social-economic system in the HRB. Water resource is the key connection between the upper, middle and lower reaches of the HRB. Considering the regional ecological economic relations, the three parts of the HRB should be viewed as an overall integrated eco-economic system, the so called 'eco-economic system of the HRB'.

The eco-economic system of the HRB is a compound system which is an integration of the natural ecosystem and the socio-economic system of the HRB (Fig 3). Water recourses as well as correlative economic actions are the main factors of

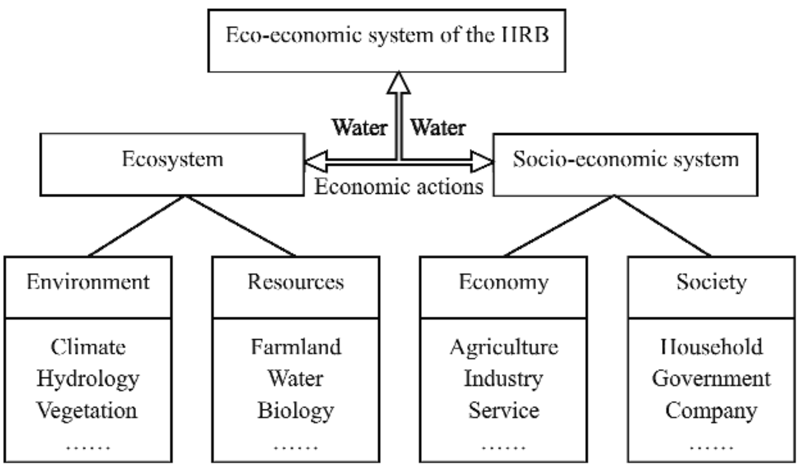

Fig. 3. The structure of the eco-economic system of the HRB.

the eco-economic system of the HRB. The structures of ecosystem and socio-economic system and their interaction compose the structure of the eco-economic system of the HRB. But the eco-economic system has more functions as compared to either the ecosystem or the socio-economic system, as it aims to harmonize the relationship between ecosystem and socio-economic system. Hence, to solve all the above ecological and economic problems in the HRB, the most important step is to couple the feedback mechanism of the ecosystem and the socio-economic system so as to achieve sustainable development of the HRB in arid northwest China.

System coupling - a possible development pattern

In this paper, the system integration theory is applied to achieve a sustainable development pattern in the HRB. The upper basin, middle basin, and lower basin of the HRB comprise an interlaced regional structure of land use and human production. The upper basin and the lower basin are mainly pasture based animal husbandry production systems, and the middle basin is mainly irrigated oasis agricultural production system. According to the system coupling theory (Ren et al., 1995), the best pattern of animal production should be “pasturing area propagation and farming area fattening”. By adopting this system-coupling pattern, connection of the pasture-based animal husbandry of the upper and lower basin and the agricultural production of the middle oases basin can be established, which can fully make use of the advantages of low-cost pasture grazing regions and abundant fodder and grain production in the oasis farming regions, greatly increasing the output of livestock products and improving their quality. At the same time, the livestock pressure on the pasture area of the upper basin and lower basin can be greatly released, so as to enable the eco-environment to recover step by step.

Animal production pattern of pasture area in the upper and lower basin

Following the system coupling pattern of “pasturing area propagation and farming area fattening”, households in the pasture areas of upper and lower basin can enhance the percentage of female adult sheep and shorten lambs’ feeding period to increase their income. Furthermore, this pattern can lighten pressure on grassland and enhance economic gains of animal husbandry production in the upper and lower basin of the HRB.

As a case study for this production pattern, Hongshiwo village in Sunan County has been taken. Adopting this animal production pattern during 2003-2004, the female adult sheep number was enhanced to 60% and after 100 days 75% of the lambs were sold out of the middle basin to oasis regions for fattening. Before 2003, without this pattern, the female adult sheep percentage was under 45% and the sheep were often sold when they were 2 to 5-year old. Results showed that this was a very successful experiment as the household income of this village increased 2.5-3 times compared with the pattern followed before.

Agriculture and animal production pattern of farming areas in the middle oasis basin

According to the “pasturing area propagation and farming area fattening” pattern, lambs from the pasture areas should be delivered to oasis farming areas to make short-term fattening. Experiences from United States of America and Germany indicate that areas in between the farming and pasture lands are often the optimal site for livestock fattening due to the abundance of feedstuff and hay. Therefore, the animal fattening location should be in the areas in between the three parts of the HRB, which are pasturing and farming areas. In these fattening sites there should be good system of transportation and perfect access to market to ensure that the fattened livestock is easily sold out (Fig. 1). In fact, we have already found several successful fattening units in these regions. These have proved to be a successful way to improve household incomes in the farming areas, the increase in the household income being 2-5 times compared with the crop production before.

At the same time, efforts have to be made to change the current farming structure by popularizing grain-grass intercropping, to introduce fodder grasses such as medic pasture into the cropland farming system, to develop a three-crop planting rotation for grain, forage, and other cash crops to enhance soil fertility, to develop animal production, and to form a stable eco-agricultural system. The system integration development pattern is therefore a new and promising approach to improve the efficiency of water resource use and distribution in the inland river basin.

Acknowledgments

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The changes of vegetation structure along oasis-desert ecotone in northwest China

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Abstracts

The vegetation structure was examined to explore changing environment along oasis-desert ecotone (ODE) during oasis degeneration. In this study six parallel sample bands were selected from oasis to desert in natural and semi-natural vegetation regions. The biomass, coverage and density of every species were quantified using sampling plots of 10×10 m at intervals of 50 m along each ODE of Minqin oasis in northwest China. The soil resource was also determined in each plot. Results indicated oscillating distribution with spotty patterns in vegetation structure of dominant species and soil resource along ODE. The vegetation structure has changed in semi-natural ODE under human disturbance. The structure of individual plant showed differential response along ODE to oasis degeneration and natural plants were more stabile than artificially introduced plants. Oasis health could be assessed according to the variation in the dominant species along ODE.

Introduction

Ecotones are transitional zones between adjacent ecosystems (Holland and Risser, 1991). Four characteristics of ecotones give them value for ecological research: as indicators of the response of plant species to environmental gradients; as a locus for species diversity dependent on immigration; as indicators of climatic change; and as regulators of the spatial flux of species, matter and energy (Overpeck et al., 1990; Malanson, 1997; Chen, 2002). The ecotone between oasis and desert is highly sensitive and is characterized by low capacity to bear the eco-environment there because it is easily exposed to sandy desertification under the joint action of the harsh environment and the irrational human activities (Zhang et al., 2003; Wu and Ci, 1999).

In the recent years, sandy desertification has been expanding continuously and strongly in Minqin oasis, leading to sand deposition and salinization because of excessive withdrawal of groundwater for agriculture, overgrazing of ranges by livestock, and excessive gathering of plants for medicinal purposes (Ma et al., 2003). This oasis is located between the Badain Jaran Desert and the Tengger Desert. Consequently, Minqin, with shrinkage of native vegetation, has become a typical example of many other oases lying on the desert fringes of northwest China.

The threat of sandy desertification is first faced as vulnerability at oasis-desert ecotone (ODE). So it is important to study the ODE in order to manage sandy desertification (Wang and Cui, 2004). The ODE is a special ecotone because of the obvious differences between oasis and desert. Oasis has lower air and soil temperature, higher air and soil moisture and weaker wind speed than the adjacent desert. This oasis effect can strongly affect the spatial structure of desert community (Gao and Lu, 2001; Du and Taichi, 1994)0. Environmental variation exerts a strong influence on vegetation patterns. Recent researches have showed that the diversity of vegetation patterns is associated with sandy desertification and the dominant driving forces in arid land are water scarcity, plant competition for water resources, and redistribution of water by runoff (Hardenberg et al., 2001).

Vegetation composition and distribution is also affected by soil conditions and disturbances. Water and nutrients are the limiting factors for plant growth in arid and semi-arid areas (Campbell et al., 1991; Singh, 2004). Oasis declines when water resource utilization is non-rational (Feng and Cheng, 1998). Therefore, the vegetation pattern and individual plant growth would change with an expansion in sandy desertification because of the loss of water and nutrients along ODE. In turn, this change can be considered as a potent indicator of sandy desertification.

The primary objectives of this study were to: (1) explore soil factors and vegetation distribution along ODE; (2) analyze their relation with the environment; (3) interpret the difference in distribution among individual desert species during ODE degeneration; and (4) develop indicators for assessment of oasis health based on vegetation changes along ODE that can be easily be used by land managers.

Material and methods

Study site

This study was conducted during the summer season of 2002 at the Minqin Integrated Desert Control Experimental Station (MIDCES), located in the north-western China, 38°34´N, 102°58´E, in the southern edge of the Badain Jaran Desert, with a total area 1200 ha. The Minqin oasis lies in the lower reaches of the Shiyanghe River watershed of eastern end of the Hexi Corridor. The central area is surrounded in the west, north and east by the Badain Jaran Desert and is adjacent to the Tengger Desert with mobile, semi-mobile, and static dunes, including large areas of sparsely vegetated desert rangeland. The study area is characterized by arid continental monsoon climate of the temperate zone with a windy winter and spring. Average annual temperature is 7.6°C. Mean precipitation is 113.2 mm year^{-1}, with most of it occurring from July to September. The estimated potential evapotranspiration is about 2604.3mm. Zonal soil types in the area include gray-brown desert soil, gray desert soil and aeolian sandy soil. The total soluble salt content of water is 8-10g/L and groundwater is 17m deep. Irrigated agriculture depends on groundwater.

The site has not been grazed by livestock. The MIDCES was protected from human activities. The dominant plant species are *Nitraria tangutorum, Calligonum mongolicum, Haloxylon ammodendron, Agriophyllum squarrosum* and *Halogeton arachnoideus*.

Plant and soil measurements along ODE

At the MIDCES, 6 parallel sample bands along ODE were randomly selected. Three of these parallel sample bands were with relatively natural vegetation and the other 3 parallel sample bands were with relatively semi-natural vegetation. Along each of the transects, a quadrate of 10×10 m was marked at 50 m intervals in each sample band. In each quadrate the soil samples were taken (in bare ground, 0-50 cm depth) to measure soil moisture, organic matter and total nitrogen. Water potential of soil samples was measured with WP4 Dewpoint Potentia Meter before soil was processed for other analyses. The soil samples were sieved (2 mm) to eliminate the effects of aggregation by soil organic matter. Soil organic matter (weight %) was measured by loss on ignition and total nitrogen (weight %) was determined with an auto-analyzer after digestion with H_2SO_4 - salicylic acid - H_2O_2. The biomass estimation for every species was done in each sampled plot using regression equations (Wei et al., 2005). The coverage and density of every species were calculated based on the collected data.

Results

Soil water potential, organic matter and total nitrogen along ODE

No significant difference was found for these parameters between the two bands of the ODE based on two-way non-parametric analysis of variance. The results in the whole ODE showed that the soil water potential, organic matter and total nitrogen decreased along the ecotone, while the distribution tended to approach an inverted bell shaped curve (Fig. 1). High correlation was found among organic matter, total nitrogen and water potential ($p<0.001$, 0.01, 0.05, respectively).

Change in biomass along ODE

The total biomass distribution in the semi-natural band showed stronger variation than in the natural band (Fig. 2). Changes in total biomass were not significant in the semi-natural band while in natural band there was a decline along the ODE. Total biomass differed significantly ($p < 0.01$) between

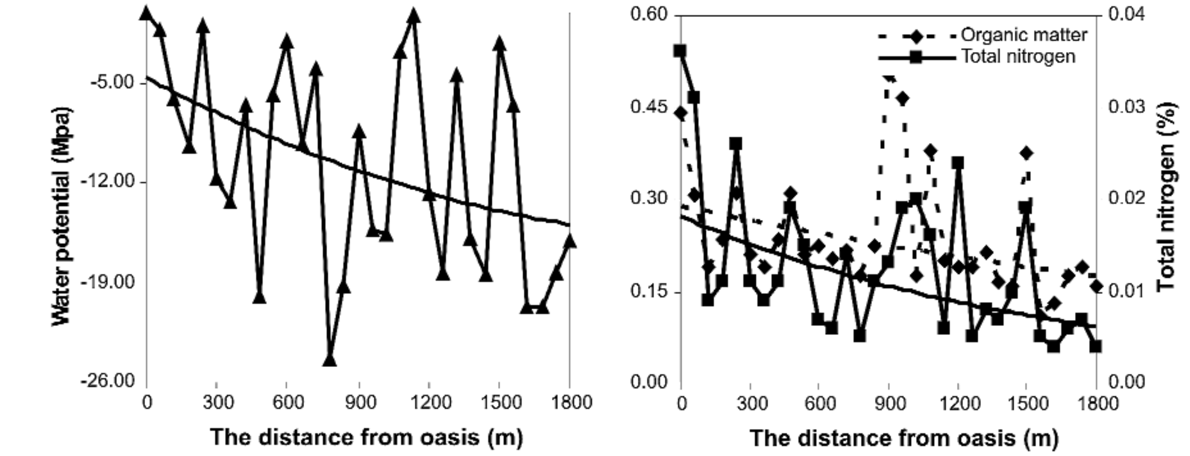


Fig. 1. The change in water potential (MPa), organic matter (%), and total nitrogen (%) of soil samples at 10-50 cm depth along the ODE.

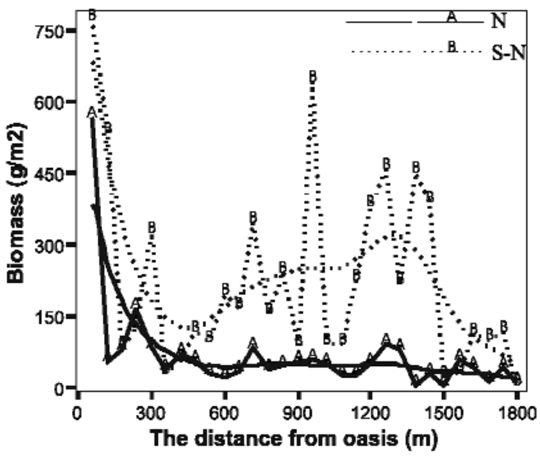


Fig. 2. The change in total biomass in dominant species in the natural and semi-natural bands along the ODE. N, natural band; S-N, semi-natural band.

the two sample bands because *H. ammodendron* was higher in semi-natural band. The best estimation of total live biomass in natural and semi-natural sample bands was 53 g/m^2 and 195 g/m^2, respectively. Shrubs and herbage biomass accounted for 86.73% and 0.80% respectively in natural area, and 96.87% and 0.34% in semi-natural area. This result indicated that shrubs were dominant in the study area.

Fig. 3 shows composition, distribution and change in above-ground and below-ground biomass along the ODE. In general, despite large differences in the total biomass between ecotone types, the only significant difference was between the desert vegetation types. Most of this difference could be attributed to the contribution of the *H. ammodendron* in the two bands (Fig. 3). In natural band, *N. tangutorum* is a dominant species in biomass followed by *C. mongolicum*, which is followed by *H. ammodendron*. However, in semi-natural band, *H. ammodendron* is dominant species, followed by *N. tangutorum*, which in turn is followed by *C. mongolicum*.

Fig. 3 shows that the below-ground biomass was more than the above-ground biomass of the dominant species. The root/crown ratio of *N. tangutorum*, *C. mongolicum*, and *H. ammodendron* in natural bands was 2.52, 0.93, 1.12, respectively, and these were not significantly different from the respective data for the semi-natural bands. Above and below-ground biomass for *N. tangutorum* and *C. mongolicum* declined along the two bands while no-significant trend in the of biomass variation for *H. ammodendron* was observed. In addition, the variation in *N. tangutorum* was stronger than in *C. mongolicum* and *H. ammodendron* in natural band and the variation in the below-ground biomass was stronger than above-ground biomass. The changes in *H. ammodendron* were stronger than *N. tangutorum* and *C. mongolicum* in the semi-natural band.

Difference in the change in cover and density between natural and semi-natural bands along ODE

The Fig. 4 shows the change in the coverage of dominant shrubs in the two bands along the ODE. The results indicate that *N. tangutorum* was the dominant species and it showed more strong change in coverage in the two bands; next dominant in coverage was *C. mongolicum* in the natural band and *C. mongolicum* and *H. ammodendron* in the semi-natural band. The next strong change was in *C. mongolicum* and this was followed by *H. ammodendron* in the two bands. However, the total coverage of dominant species in the two bands was non-significantly different. (The mean values were 12.90% and 11.94% in natural and semi-natural bands, respectively. The coverage with shrubs was 99.92%, and coverage with herbs was 0.08%). The coverage of *N. tangutorum* and *C. mongolicum* declined along the natural ODE. The coverage of *N. tangutorum* declined along the semi-natural ODE also, while the coverage of *C. mongolicum* and *H. ammodendron* showed a slightly increasing trend.

To test the statistical differences in these variables between the natural and semi-natural bands, we used two-way non-parametric analysis of variance. The difference in *H. ammodendron* was significant; in the semi-natural band the biomass, coverage and density were more than in the natural band ($p<0.001$). No significant difference between natural and semi-natural bands was observed for distribution of *N. tangutorum, C. mongolicum, A. squarrosum* and *H. arachnoideus* ($p>0.05$).

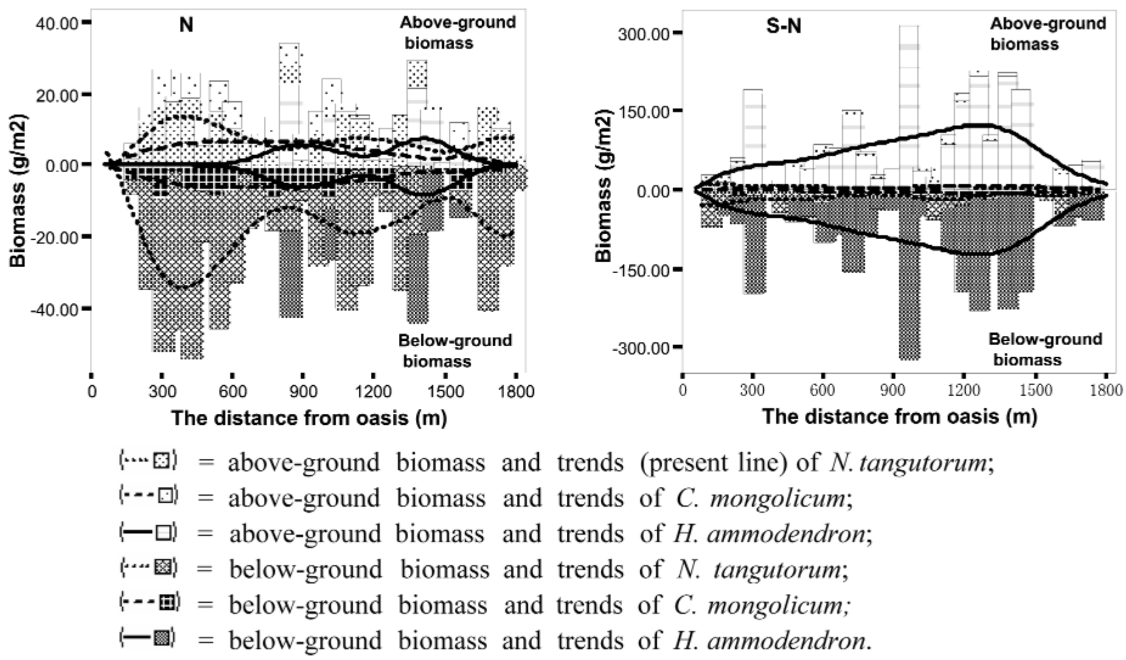


Fig. 3. Variations in the above-ground and below-ground biomass for dominant shrubs along the natural (N) and semi-natural (S-N) bands of the ODE.

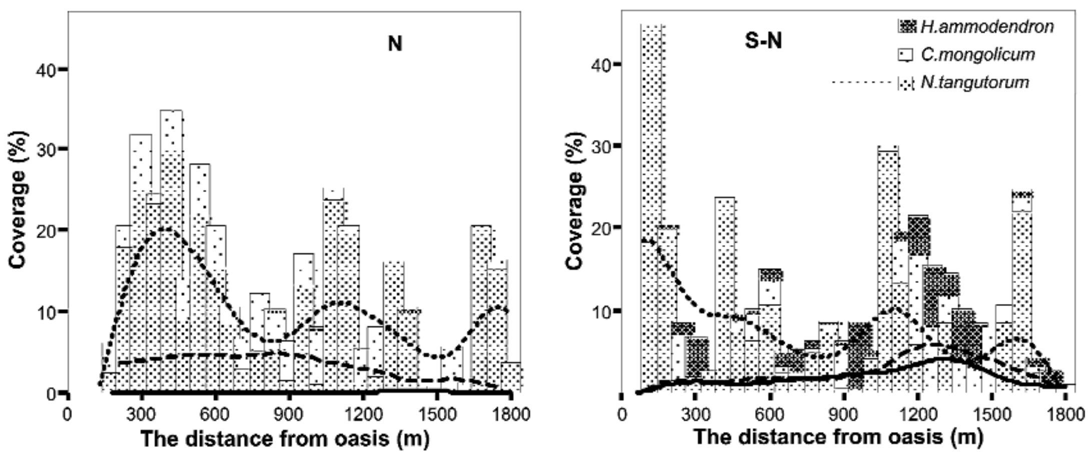


Fig. 4. Change in the coverage composition along ODE. N=natural band; S-N= semi-natural band.

Fig. 5 shows the trends of variations in density of dominant species along the ODE. The density of dominant species *N. tangutorum* and *C. mongolicum* was found to decline along ODE. The same trend was observed in *H. ammodendron* along the semi-natural ODE. However, the density of herbs showed different trends; there was a decline for *H. arachnoideus* and increase for *A. squarrosum* probably because of the difference in their demand for moisture. In addition, variations in the density of *C. mongolicum, A. squarrosum* and *H. arachnoideus* were stronger than of *N. tangutorum* and *H. ammodendron*.

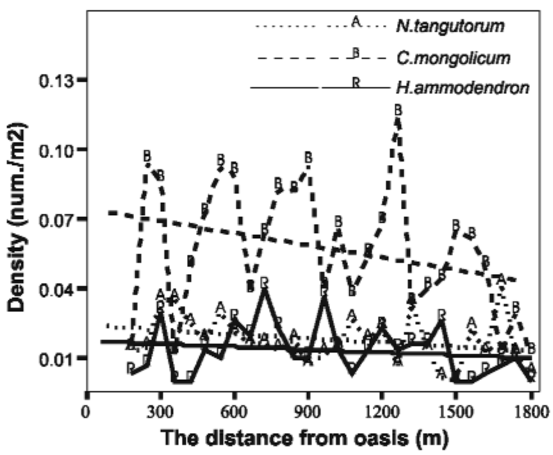
Discussion

Ecotones may be abrupt or gradual, with disturbance tending to increase the abruptness of the ecotone (Forman and Godron, 1981). Although water condition has been deteriorating because the groundwater had receded continuously to a depth of 17 m, our result shows abrupt distribution of soil water, organic matter and total nitrogen content along ODE. We think that there are two main reasons for the changes to occur in such short distances. One is the lower evapotranspiration near oasis due to oasis effect and the other is lateral infiltration with irrigation water.

Plant total biomass change was abrupt from oasis to the edge of desert along the two ODE (<300m in distance), where farmland confronts directly the desert. This was because the farmers had to reclaim land for producing more food to meet their growing needs due to the rapid population growth. In contrast, the plant total biomass, coverage and density decreased gradually from the edge of desert to desert (300-1800m) along the natural band ODE, while no trend was obvious along the semi-natural band ODE. Further analysis were undertaken to determine how the vegetation total biomass changed with change in soil moisture along ODE. Although Marissa and Venable (1993) argued that the spatial variation in the productivity of desert annuals can be substantially influenced by soil water availability, this study showed no-significant correlations between biomass and soil moisture (p=0.104), perhaps because the dominant shrubs absorbed water from the water table (Huang and Shen, 2000).

In conclusion, our study shows that vegetation structure and soil factors varied irregularly giving a spotty pattern along the ODE and got changed under human soil disturbance. Furthermore, the results showed that the ODE is a particular and typical small scale gradient environment. The results are consistent with the findings that the desert vegetation shows a gradient caused by the environmental gradient with water being the primary factor (Pan and Chao, 2003). The change in the biomass along ODE indicates a spotty patterns in our study. This result is supported by Hardenberg et al. (2001) who also reported such a pattern in biomass at relatively low precipitation. However, our results also imply strong irregular pattern among artificial vegetation spots. This may be because of greater competition in the high-biomass microhabitats (Guo and Wade, 1998).

(a) Shrubs



(b) Herbs

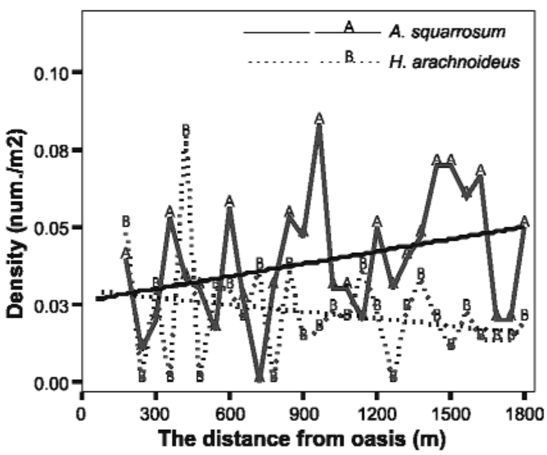


Fig. 5. Variations in density with trends and oscillation for dominant shrubs and herbs along the ODE. (a) Shrubs; (b) Herbs.

The dominant herbaceous species in our study are short-life form species, which depend on precipitation. Their biomass is low (the percentage of occupied total biomass was lesser than 0.3%) as also their coverage (lesser than 0.1% of the total). Very small precipitation in spring results in only slight contribution to management of sandy desertification. In addition the herbaceous species have no corresponding response to environmental changes of ODE from density. Great basin ecosystems are considered to be dominated by shrubs. Therefore, herbaceous species are not suitable for monitoring the stability and degree of sandy desertification of ODE.

Dominant *N. tangutorum* is natural species with spotty pattern while *H. ammodendron* and *C. mongolicum* are artificially introduced species. Our result showed that there was no-significant difference in the distribution of *N. tangutorum* and *C. mongolicum* but a significant difference in *H. ammodendron* (p<0.001). These results indicate that among the shrubs, *H. ammodendron* can use deep soil water, and *N. tangutorum* and *C. mongolicum* are apparently dependent on the water of upper soil layer (Yang and Gao, 2000). In addition, root/crown ratio in biomass of *N. tangutorum* is more significant than that of *H. ammodendron* and *C. mongolicum*. High below-ground biomass allocations can enhance the capacity of water uptake from soil. These are the advantageous characters for plants to survive long-term drought (Callaway et al., 1994; Wang et al., 2003). *H. ammodendron* is a huge shrub with high biomass per plant (11.69 kg) depending on groundwater and requiring more water than *N. tangutorum* and *C. mongolicum* (Huang and Shen, 2000). Therefore, it was hardly expanding since 50 years and was destroyed seriously in recent decades. It was more sensitive to environmental stress of groundwater decline than other dominant shrubs. An assessment of sandy desertification should be carried out to use individual plants that have different responses to environmental stress.

Sandy desertification is often assumed with the reduced level of plant growth (William et. al., 1990; Krogh et. al., 2002). In the overall study site, we only measured biomass, cover and density of dominant species because these were easily obtainable indicators and can be easily communicated to the public or the policy-makers. From the above experiment we developed several suggestions for early-warning indicators of ecosystem degradation and how to recover vegetation These are as follows: (a) Even though vegetation cover is a major factor as indicator for land degraded (Chen et al., 2000), our results indicate that the coverage and density in *H. ammodendron* showed smaller variation and slower trend for decline along the ODE and the density even showed some ascendance than *N. tangutorum* and *C. mongolicum*. Conversely, the degradation of *H. ammodendron* was most serious among dominant species at present. Consequently, total or individual biomass may be considered as better stable indicator to assess drought resistance of species and the degree of sandy desertification in ODE. This result is in agreement with McNaughton (1989) who pointed out the importance of annual aboveground net primary production (ANPP) as an integrative indicator of ecosystem functioning. (b) The significant difference in the change in biomass of dominant shrubs along ODE indicates that plant adapted to drought had smaller oscillation (Fig. 3). Thus spotty pattern of vegetation of C. *mongolicum* was the most stable uniform vegetation state, next was *N. tangutorum* and last was *H. ammodendron*. This indicates *C. mongolicum* and *N. tangutorum* are more suitable for stress environment than *H. ammodendron*. (c) Some artificial plants differed in gradient distribution to natural plants by showing smaller variation according to the previous study. However, *H. ammodendron* is showing high degeneration and it will be the first to be wiped out as the environment continues to deteriorate. Furthermore, natural vegetation spotty pattern should be preferred in restoration ecology at the study site. Moreover, *C. mongolicum* and *N. tangutorum* should be considered preferred species for achieving recovery.

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Health-related quality-of-life (QOL) levels and the recognition of desertification in the inhabitants of the Loess Plateau region of China

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Abstract

This study aimed to clarify health-related quality-of-life (HR-QOL) and the recognition of desertification in people living in the semi-arid Loess Plateau of China. HR-QOL was assessed by a three dimensional survey of general health perception, vitality, and general mental health using a 36-item short survey form (SF-36). The scores of general health perception were approximately the same for both the city and the village communities. The vitality and mental health scores were significantly lower for the women group in the village communities compared with the other groups. HR-QOL was significantly related to economic status in the village communities. The inhabitants of the village communities were more satisfied with their life situation than those of the city in spite of the economic gap between them. Levels of recognition of desertification were lower in the village communities than in the city.

Introduction

Desertification presents a serious threat in the semi-arid Loess Plateau of China. Anti-desertification policies such as the ‘Grain for Green’ project have been enforced by the government. Desertification is related to health status, quality of life, and the level of recognition of desertification among the inhabitants living there. However, there are currently very few studies that have examined this issue (Mu et al., 2006). This study aimed to clarify the health-related quality-of-life (HR-QOL) and recognition of desertification in people living in the semi-arid Loess Plateau of China.

Subjects and methods

In Yan'an City, Shanxi Province, we selected three city communities and four suburban farm village communities, considering the socio-economic and geometric situation of each. A questionnaire survey on HR-QOL, recognition of desertification, and economic status was carried out in August and September 2005. Subjects were heads (or deputies) of households in the communities selected. In the village communities, trained staff interviewed subjects according to the questionnaire. In the city communities, the staff distributed self-administered questionnaires to the subjects and collected them later.

HR-QOL was assessed by a 36-item short form (SF-36). The original SF-36 questionnaire includes 8 dimensions: body pain, general health perception, general mental health, physical functioning, social functioning, emotional role, physical role, and vitality (Ware et al., 1993). In this study, however, with the aim of keeping the questionnaire simple, only three dimensions (general health perception, vitality, and general mental health) from the SF-36 were investigated. The scoring of each dimension was performed according to the SF-36 scoring rules (Fukuhara et al., 2004).

The questions related to life satisfaction were worded as follows: Are you satisfied with 1) income; 2) housing conditions; 3) groceries for meal; 4) fuels for cooking and heating; and 5) human relationship with your friends and neighbors? The response choices were “definitely yes,” “mostly yes,” “don’t know,” “mostly not,” and “definitely not.” They were scored on a scale of 5 (definitely yes) to 1 (definitely no). The total scores on life satisfaction ranged from 25 to 5. The question related to the recognition of desertification was worded as follows: “Do you consider the problem of Chinese desertification to be serious?” The response choices were “very serious,” “not so serious,” and “not serious.” In addition, the total household income in 2004 was asked of each household in the questionnaire. The annual income per person was calculated as the total household income divided by the number of family members.

The groups were compared using a t-test and analysis of variance. A chi-square test was used to assess differences between proportions. Moreover, Pearson’s and Spearman’s rank correlation coefficients were used for the estimation of correlations. A probability value of <0.05 was accepted as statistically significant.

Results

Table 1 shows the characteristics of the study population. There were a total of 195 responses from subjects in the city communities and 248 responses from the village communities. Thus a total of 443 subjects were investigated. The response rates were estimated at 86% and 100% in the city and village communities, respectively. Two thirds of the subjects were men, and the mean age was 47.6 and 44.2 years in the city and village community groups, respectively. In addition, educational achievement was significantly different between the two groups.

Table 1. Characteristics of study population

	City		Village	
	n	%	n	%
Gender				
Men	126	64.6	164	66.1
Women	69	35.4	84	33.9
Age (years)				
20~39	84	43.5	89	36
40~59	75	38.9	133	53.8
60~80	34	17.6	25	10.1
Mean±SD	44.76±13.81		44.15±11.71	
Education (Year)				
0~84	82	4.9	243	97.9
9~	145	75.1	5	2.1

Table 2 shows the average annual income per person for the seven communities. The average annual incomes of the city communities (A, B, C) ranged from 6,336 to 8,649 Yuan, while those of the village communities (E, F, G, H) ranged from 1,720 to 3,907 Yuan. Thus, the average annual income of the city communities was higher than that of the village communities.

Table 2. Population and average annual income per person in city and village groups in 2004

		Population		Income (Yuan)
		n	%	Mean±SD
City	A	50	11.3	7210±3161
	B	97	21.9	8649±3796
	C	48	10.8	6336±5034
	Total	195	44.0%	7735±4088
Village	E	59	13.3	3092±2266
	F	59	13.3	1720±1180
	G	65	14.7	2256±1386
	H	65	14.7	3907±2119
	Total	248	56.0%	2760±1973

Table 3 shows the HR-QOL results, including general health perception, vitality, mental health, life satisfaction, and recognition of desertification, by gender and age in the city and village communities. The scores of general health perception were approximately the same between the city and village communities, with the scores tending to decrease with age. The scores of vitality were significantly lower in the village communities compared to those of the city. The vitality and mental health scores were significantly lower among the women in the village communities compared to the other groups. The scores of life satisfaction were significantly higher in the village communities than in the city communities. The proportions of persons who answered “very serious” on the problem of Chinese desertification were significantly lower in the village communities than in the city communities.

Table 4 shows the correlations of HR-QOL, life satisfaction, and recognition of desertification with the characteristics of the study subjects. The scores of general health perception, vitality, and general mental health were significantly correlated with economic status in the village communities. In the city communities, only the vitality scores were correlated with economic status.

Discussion

A large number of health-related quality-of-life evaluation methods have been developed during the past three decades. The SF-36 was designed for use in clinical practice and research, health policy evaluation, and general population surveys (Ware et al., 1993). Further, the SF-36 is one of the most frequently used generic measurements of HR-QOL (Ohsawa et al., 2003). In the present study, the HR-QOL of inhabitants living in the semi-arid Loess Plateau of China was assessed by a three dimensional survey of general health perception, vitality, and general mental health (based on SF-36). General health perception was approximately the same between the city and village communities. The vitality and mental health scores were significantly lower for the women group in the village communities when compared with the other groups. These findings may be related to the social conditions of women in the village communities. HR-QOL was found to be significantly related to economic status in the village communities. We suggest that the increase of income related to anti-desertification policies and other socio-economic factors improved the HR-QOL levels of inhabitants in the village communities of the semi-arid Loess Plateau of China.

The inhabitants of the village communities had a more satisfied life situation than those of the city in spite of the economic gap between them. Thus, life satisfaction was not determined by income. These findings on life satisfaction are consistent

Table 3. HR-QOL including general health perceptions, vitality, mental health, life satisfaction, and recognition of desertification by gender and age group in the city and village communities

	Age group	City		Village	
		Men	Women	Men	Womena
General health	20~39	64.02±18.49	60.15±16.87	64.88±15.82	60.30±16.12
perceptions[a)]	40~59	59.27±17.19	53.13±16.19	57.73±16.71	53.31±14.21
Mean±SD)	60~80	46.00±17.58	48.43±25.12	48.53±18.73	33.67±16.69
	Total	58.87±18.85	56.23±17.86	58.76±17.30	55.24±16.59
Vitality[a)]	20~39	65.76±12.62	61.13±12.67	59.38±15.95	58.59±12.55
Mean±SD)	40~59	60.90±15.06	62.50±14.16	59.47±11.09	51.56±13.80
	60~80	60.23±11.50	57.14±19.24	57.89±13.15	44.79±17.42
	Total	62.82±13.59	61.21±13.89	59.26±12.87	54.44±13.93
Mental health[a)]	20~39	64.13±12.84	63.59±12.59	60.42±14.69	58.25±10.41
Mean±SD)	40~59	58.62±13.94	64.38±13.05	59.42±10.62	53.75±10.91
	60~80	57.95±17.23	61.43±16.26	60.26±10.47	53.33±9.83
	Total	60.82±14.35	63.65±12.99	59.81±11.89	55.90±10.65
Life satisfaction[b)]	20~39	14.42±3.68	13.30±4.86	15.58±3.51	15.93±3.41
Mean±SD)	40~59	14.13±4.95	15.83±3.85	16.89±2.31	14.86±2.84
	60~80	15.18±3.85	16.00±3.61	16.74±2.77	15.00±3.69
	Total	14.45±4.22	14.55±4.51	16.48±2.81	15.34±3.21
Recognition of	20~39	67.3	74.2	43.5	37.5
desertification[c)]	40~59	68.2	95.8	55.2	38.9
	60~80	81.8	71.4	36.8	16.7
	Total	70.4	82.3	49.7	36.6

a) Score: 0~100; b) Score: 5~25; c) %

Table 4. Correlation of HR-QOL including general health perceptions, vitality, mental health, life satisfaction, and recognition of desertification with the characteristics of the study subjects

	City				Village			
	Gender	Age	Education	Income	Gender	Age	Education	Income
General health perceptions	-0.068	0.297***	0.203***	-0.049	-0.097	0.300***	0.117	0.163*
Vitality	-0.056	0.188**	0.177*	0.250**	0.170**	-0.056	0.169**	0.197**
Mental health	0.097	0.185*	0.026	0.097	0.160*	-0.026	0.117	0.183**
Life satisfaction	0.011	0.147*	0.000	0.202**	0.182**	0.109	-0.014	0.219**
Recognition of desertification	-0.123	-0.061	0.168*	-0.069	0.131*	-0.041	-0.098	-0.067

*$p<0.05$ **$p<0.01$ ***$p<0.001$

with other studies (Li et al., 1995). On the other hand, level of recognition of desertification was lower in the village communities than in the city communities. Generally speaking, recognition levels among inhabitants are related with anti-desertification activities, and therefore environmental education may be needed in order to improve recognition levels in the village communities.

The numbers of subjects and communities were limited in the present study. It is therefore difficult to extrapolate the findings of this study to the general population in the semi-arid Loess Plateau of China.

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Meat production for self-consumption by nomadic herders in the Gobi Desert region of Mongolia

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Abstract

A field study was conducted to investigate meat production for domestic use in the Gobi Desert region. A total of 42 nomadic families were selected from the semi-desert (FG1) and the semi-mountainous (FG2) areas. Sheep and camels were dominant in FG1, goats and cattle were dominant in FG2, and horses were prevalent in nearly all the families. The number of animals per family was greater in FG1. In general, sheep were chosen, instead of goats, for slaughtering. The animals in large herds tended to be slaughtered frequently. In FG2, the numbers of slaughtered sheep and goats were similar; horses were not generally slaughtered; camels were slaughtered in nearly all of the studied families, and the number of camels was the greatest of all the animals slaughtered in both groups. There was no difference in the total number of animals slaughtered per annum between the two groups. Strong seasonality differences by animal types or family groups were found with regard to slaughtering: the large animals were slaughtered only in the winter, from November to December; the herders irregularly slaughtered sheep and goats during the period from April to June, and they constantly slaughtered during the period from July to October; the FG1 families slaughtered sheep more frequently throughout the year than did the FG2 while the FG2 families slaughtered more cattle than FG1. Overall, the results showed the adaptation of herders to the differences in topography and herd size, their adaptation to meat quality by animal types, their economic strategies, and their intent to enrich their diets.

Introduction

Mongolian herders use open natural pasture throughout the year for carrying sheep, goats, cattle, horses and camels. The cattle in this paper include yak and the hybrid cattle, as the Mongolian statistics usually do. The biomass of natural pastures is maximum in early autumn, and it decreases gradually until the following spring (Enkhamgalan, 1995). Milk and meat are the two major foodstuffs in the nomadic area, and their production has a large seasonality, closely related to the pasture biomass. The major milking season is during summer and autumn, and milk is processed into many types of products, such as butter, cheese and yogurt. On the other hand, the main slaughtering season is during late autumn and early winter when animals are at their heaviest weight and the maximum air temperature in the day falls to freezing point. All types of animals are slaughtered during this time, and the meat for year-round consumption is prepared. Some of the meat is frozen and consumed during cold seasons; the remainder is freeze-dried and consumed during warm seasons (Yamasaki, unpublished, 1995). Sheep and/or goats are slaughtered during warm seasons, also. Beside, it is known that small stocks are slaughtered occasionally in summer, e.g. when they hold a large party.

The total carcass meat production in 1994 was 90.3 kg/capita, with sheep, goat, horse, cattle and camel meat accounting for respectively 47, 8, 10, 32 and 3% of the total production (State Statistical Office of Mongolia, 1996). This is highest amount amongst all the Asian countries (FAO, 2005). However, the information on annual and seasonal amounts of meat production and consumption of herder families is not available. Moreover, the relationship between annual and seasonal slaughtering of different types of animals types and the herd size of the individual families who migrate to the different topographies has not been determined. Therefore, a field study was conducted to determine the timing and amount of meat production by animal types for two herder family groups located in different topographic conditions in the Gobi desert of Mongolia, where the five types of animals are herded and slaughtered for domestic consumption. The seasonal patterns in the amount of meat consumed by animal types and the kind of meat processing done by the two groups of the studied families were also determined.

Material and methods

Study site

The Bulgan district (area 7,360 km2) in the north-western part of Omnogobi province (area 165, 000 km^2) was selected for the study. The Omnogobi is located in the central-southern part of Mongolia, bordering the People's Republic of China for 800 km. This province has the characteristics typical of the Gobi Desert: the annual precipitation is only 50 to 120mm; the vegetation type is steppe-desert or desert; the dominant livestock are goats and camels, although five types of animals are grazed. Mountains over 2,000m high mark the southern border of Bulgan.

The Bulgan area can be fairly evenly divided into northern and southern parts, according to its topographical differences. Features of the northern part are little slope in 1,000-1,200 m heights, sand or sandy soil with complex but sparse vegetation types dominated by legume, lily, grass, and goosefoot families. Conversely, the features of the southern part are gentle or rapid slope in 1,200-1,900 m heights from the center of the Bulgan up to the mountains with a simple but dense vegetation structure dominated by grass and lily families. The herders in both areas conduct annual migration starting from their winter-spring base camps, where thermal stalls with storm walls are prepared. They conduct the migration only in the area where their base camps are settled (Yamasaki et al., 1996). Hence, the herders' families in the district can also be divided into northern and southern groups. The herders in both family groups have adapted to the local topographic conditions, e.g., they have developed fodder supplementation techniques for coping with the deficiency of the forages production during cold seasons from the vegetation around their camping sites (Yamasaki and Ishida, 2004).

Research methods

Field study was conducted from 20 February to 22 March, 1995. Forty-two families were selected randomly across Bulgan, and they were separated into two groups: FG1, 20 families migrating in the northern area; and FG2, 22 families migrating in the southern area. Livestock structures of the studied families up to December, 1994 were collected from the statistical data of the Bulgan. The number of family laborers and the number of animals slaughtered each month from April 1994 to March 1995 were determined by talking to the people. A family laborer was defined as a member who could work constantly in animal husbandry; members less than four years old were excluded, as were the students living away from their families and the aged and sick members who could rarely work. The slaughtered animals included both those the families had carried and those they had purchased. The numbers of different types of animals were calibrated using either sheep head or the following formula: sheep: goats: cattle: horses: camels = 1.0: 0.7: 6.8: 7.5: 12.0. The sheep head (hereinafter "head", for short) was based on the animals' carcass meat weights (20.6 kg/head), which were calculated from the data published by the State Statistical Office of Mongolia (1996). The data on the livestock structure and the number of slaughtered animals were expressed on per family laborer basis. The slaughtered animals' ratio was calculated by the division of the number of slaughtered animals by the herd size in each family. The data of families which did not herd all the animals were not used to determine the ratio. The frequency, which is defined as the number of family-slaughtered animals divided by the number of studied families, was determined as was the carcass meat weight for each month.

Chi-square test and t-test were used, as appropriate, for comparing the different characteristics in the two family groups (FG1 and FG2), and for making comparison between the animals or the months in each family group. Minitab software version 14 was used for statistical analysis.

Results

Herd structure

The average number of family laborers was 5.0 in FG1 and 4.1 in FG2, but the difference was not significant (p>0.1) (Table 1). Most families in both groups carried four to five types of animals, including at least sheep, goats and horses. Significantly more cattle were carried in FG2, and camels in FG1 (p<0.001-0.01). The FG1 families herded more sheep and camels, but fewer goats and cattle than FG2 (p<0.001-0.05). Sheep and camels were dominant in FG1, goats and cattle were dominant in FG2, and horses were prevalent in nearly all families in both groups. In FG1, the number of camels was the greatest of all the animals (p<0.05). Camels contributed more than half of the total (100 heads in 187 total heads, 53%), followed by horses (20%) and sheep (12%). On the other hand, more cattle (32%), horses (30%) and goats (25%) were carried than sheep (9%) and camels (4%) in FG2 (p<0.05). The total number of herd animals tended to be greater in FG1 (187 heads) than in FG2 (130 heads) (p<0.1), largely because of the difference in the camels' herd sizes between the two groups.

Table 1. Number of laborers and families carrying each nomadic animal, and herd structure of the studied herders' families corresponding to the topographic differences in the Gobi Desert of Mongolia in December, 1994.

	Family group	
	FG1	**FG2**
No. of studied family	20	22
Labor/family (number of persons)	5.0±0.6	4.1±0.1
Family with animals (number of families)		
Sheep	20a	21 a
Goats	20a	22 a
Cattle	12 b	21** a
Horses	20a	22 a
Camels	20***a	9b
Animals/family/member (mean±SEM number of sheep head)		
Sheep	23±4* bc	12±2b
Goats	16±2c	33±5**a
Cattle	11±4c	42±13*a
Horses	37±6b	39±7a
Camels	100±19***a	5±2c
Total	187±26	130±18

; p<0.05, **; p<0.01, *; p<0.001 in the same row. a, b, c differ from each other with p<0.05 in the same column.*

Annual number of slaughtered animals

The studied families had already finished the slaughtering of animals at the time of the present visit. Some of the results with regard to slaughtering numbers corresponded to the herd structure of the family groups: sheep and goats were slaughtered in nearly all families, including one FG2 family that had not carried sheep and had purchased it from other herders; more sheep and fewer goats and cattle were slaughtered in FG1 than in FG2 families (p<0.05-0.1) (Table 2). On the other hand, only half of the families in both groups slaughtered horses; the number of slaughtered horses in both groups was not statistically different, but the number of slaughtered horses in FG2 was lower (p<0.05) than that of the other animals in the group.

Table 2. Number of family-slaughtered animals and number of slaughtered animals per family laborer during April 1994 and March 1995, corresponding to the topographic differences in the Gobi Desert of Mongolia

	Family group	
	FG1	**FG2**
No. of studied family	20	22
Families slaughtering animals (number of families)		
Sheep	19ab	22a
Goats	18ab	22a
Cattle	7c	19** a
Horses	11c	10b
Camels	16bc	19a
Slaughtered animals/family labor (number of sheep head ,% in total)		
Sheep	2.2±0.4† a	1.4±0.2b
Goats	1.1±0.2b	1.7±0.2†b
Cattle	0.7±0.4b	1.7±0.3*b
Horses	1.0±0.3b	0.8±0.2c
Camels	3.5±0.7a	3.2±0.6a
Total	8.5±1.0	8.7±1.0
Ratio of slaughtered animals in the herd (%)		
Sheep	9.7±1.2a	12.8±1.2†a
Goats	10.2±2.4a	7.9±1.9 a
Cattle	7.4±4.2ab	13.5±5.0a
Horses	2.4±0.7 b	4.6±2.3 a
Camels	5.5±1.7 ab	35.3±13.0†a
Total	5.6±0.7	8.5 ±1.0*

*** , * and † show significant difference at p<0.01, 0.05, and p<0.10, respectively, in the same row; [a, b, c]differ from each other with p<0.05 in the same column.*

Most of the FG2 families, including the families which had not carried them, also sl aughtered camels; the number of slaughtered camels in both groups was the largest (p<0.05) of the five types

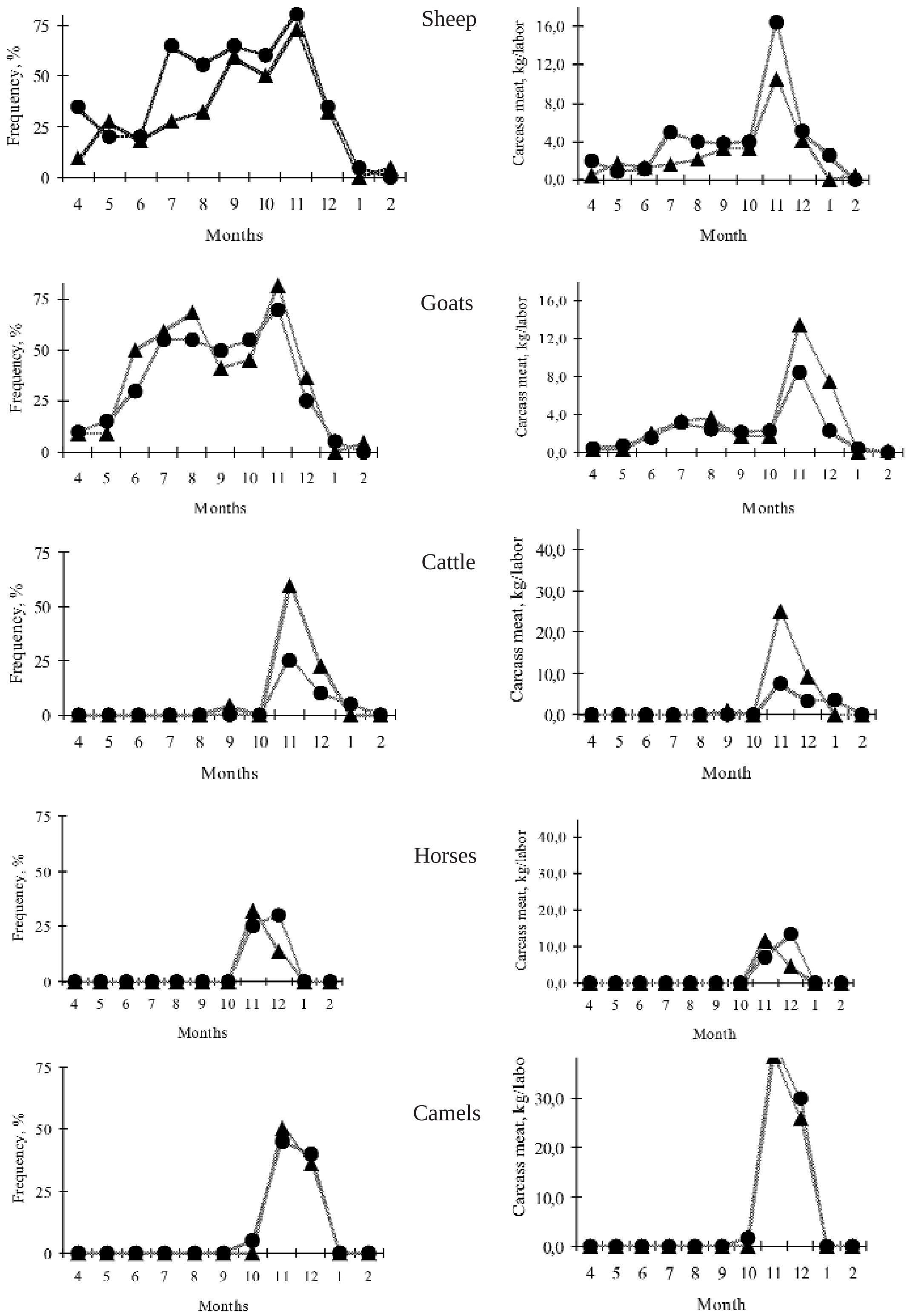

Fig. 1. Frequency of herders' families which slaughtered animals and the carcass meat weight of slaughtered animals per laborer corresponding to the topographic differences of the families (circle = FG 1; triangle = FG 2) during the period from April 1994 to March 1995 in the Gobi Desert in Mongolia. The frequency was determined based on the number of household that slaughtered or had planned to slaughter any animals in March, 1995. Letter a, b, c, d show significant difference at $p<0.05$ among the values in the FG1. Letters p, q, r, s show significant difference at $p<0.05$ among the values in the FG2. The significance of differences of the values between FG1 and FG2 are shown as follows: * at $p<0.05$; ** at $p<0.01$; * at $p<0.001$. In case of no asterisk the difference is statistically not significant or it has not been tested statistically.**

of animals. The numbers of slaughtered sheep and goats were not significantly different from each other in FG2 ($p=0.053$). In addition, there was no difference ($p>0.1$) in the total number of slaughtered animals between FG1 (8.5 head) and FG2 (8.7 head).

The ratio of slaughtered animals, defined as the number of slaughtered animals divided by the herd size was computed for only those households that carried each animal. Data in Table 2 show that the ratio was the highest in sheep and goats, intermediate in cattle and camels, and lowest in horses in FG1 ($p<0.05$). In FG2, the ratio of goats (7.9%) and horses (4.6%) tended to be lower ($p<0.1$) than that of the other animals. Both family groups slaughtered 5.6% (FG1) to 8.5% (FG2) animals of their total herd sizes for their consumption, and the ratio was higher ($p<0.05$) in FG2 than in FG1. The ratio of sheep and camels in FG2 tended to be higher ($p<0.1$) than that in FG1.

Seasonal diversities of meat production and animal slaughtering

The primary slaughtering time of every type of animal was November in both family groups (Fig. 1). When the families could not finish it in November, they either continued slaughtering in December, or they waited until February of the following year. The large animals, including cattle, horses and camels, were hardly ever slaughtered during the period from April to October. On the other hand, the small animals, sheep and goats, were slaughtered during spring and autumn, too. In April and May, only a few sheep and goats were slaughtered by a few families. These numbers increased in June, reached a plateau during the period of July to October, and peaked in November, although the plateau is not clear in some cases, and the height was different by family groups and animals. The proportion of families which slaughtered sheep or goats was usually more than 50% from July to October. Therefore, in contrast to large animals, sheep and goats were constantly slaughtered at the households during summer and autumn. Notwithstanding this, certain specific differences by animal and family group were found: more FG1 families slaughtered sheep in April and July than did FG2 families ($p<0.05$); more sheep were slaughtered in July in FG1 than in FG2 ($p<0.05$); the numbers of families and sheep in FG1 were usually not less than those in FG2 throughout the year; more FG2 families slaughtered more cattle in November than did FG1 ($p<0.05$); in the case of horses and camels, the peak timing of the slaughtering was extended to December. Especially in the case of horses in FG1, more families slaughtered more animals in December, although there were no significant differences from the numbers in November.

Discussion

Annual amount of meat production and consumption

Total herd size, which would be equivalent to the stock of meat, tended to be larger in FG1 than in FG2. But there was no significant difference between the total number of slaughtered animals per family laborer in both groups ($p>0.1$). For the convenience in the estimation of meat consumption by the herders, the number of slaughtered animals in the studied families and the carcass meat yield (20.6 kg/head) was multiplied, and it was determined that one laborer produced annually about 180 kg carcass meat. But there are several points which would indicate that the annual consumption must be lower: The annual amount of carcass meat production/consumption per capita in the country in 1994 was reported to be half of the above amount (State Statistical Office of Mongolia, 1996); family members who could not work constantly in the present study were excluded from the number of laborers; students, who usually lived apart from their families during the school terms, needed to bring meat to school for their food, and they consumed meat during vacations, and the like. On the other hand, the consumption amount would be greater in rural areas, where herders graze their animals, than in the urban areas. Therefore, the actual amount should be considered as less than 180 kg. It can roughly be estimated as more than 100 kg/person/year in the studied families, and as 120-150 kg/adult/year or more than 10 kg/adult/month.

Adaptation to topographic conditions, and economic strategy

The reason that the annual number of slaughtered animals partially reflected the herd structure of the family groups is that the large animal herds would be more readily chosen for slaughter in an effort to enlarge the herd size or to increase the possession of the families (Table 1-3). It is the adaptation of herders to their topographic condition that accounts for the animals chosen for slaughter because the herd size or structure reflected the topographic condition in which the herders were migrating. On the other hand, the slaughtering situations did not fully reflect the herd structures. One of the factors might be the herders' economic strategy in the open market. Besides its suitability for processing as dried meat, camels' carcass meat per kg was the cheapest of the five types of animals. Therefore, camels, the most dominant animals in the area, were most popularly slaughtered to reach the meat demand, not only in the FG1 but also in the FG2 families. Economically strategic slaughtering was also found in the results of the comparison between sheep and goats. The goats produce high value wool, known as cashmere. One kg of cashmere, the amount combed from three billy goats, had a value as high as US$40. Therefore, the herders avoided slaughtering the high-value animal, as seen especially in the data for FG2 (Table 2 and Fig. 1), and they wanted to slaughter sheep instead of goats. A drastic rise in the number of goats occurred during the 1990s: the goat population in 2000 had increased up to 222% of that in 1990, though the number of sheep had remained steady (106%) (FAO, 2005). The change was caused by the strategic slaughtering, observed at the studied households, which represented the majority of herders' families across Mongolia.

Seasonality of meat production and consumption corresponding to meat quantity and quality

The frequency and number of slaughtered animals in each month also reflected the herd size, especially in sheep and cattle, e.g., the frequency and amount of mutton production in FG1 was not less than in FG2; more than twice the number of families slaughtered cattle and produced more than double the amount of meat in FG2 than in FG1 (Fig. 1). On the other hand, the reason that the results did not partially reflect the herd structure would need to be discussed more from the points of seasonality of meat production/consumption and meat quality.
The differences in the meat quality are traditionally known by the herders, partially by the kind of 'warming' effect the meat might have on the person consuming it. They classify the meat quality into three, i.e. warm, cool and medium. Sheep and horse meat is considered as having the 'warm' effect, goat and camel meat the 'cool' effect, and cattle meat the 'medium' effect. Only the 'cool' and 'medium' quality is suitable for processing into dried meat. In addition, in contrast to the small stocks such as sheep and goats, the horse is a large stock. Once slaughtered, the horse meat must be consumed during winter and early spring because its quality is 'warm'. Thus, horses were not slaughtered in about the half of the studied families, and the average number of horses slaughtered was less than that of the other large animals (cattle and camels). The quality of horse meat might also affect the timing of the slaughter in FG1 families, which migrate in the low land where the temperatures are comparably high and therefore might chose to delay the slaughtering of horses than the other animals, and as compared to the time when FG2 families slaughtered their horses.

The amount of meat consumption per family was estimated by animal, season and type of meat - fresh or dried - based on the previous study (Yamasaki, unpublished). The following seasonality of meat consumption was found: the total amount of monthly consumption was high in the cold season and low in the warm season; dried meat was consumed mainly during the period from April to June; but fresh meat accounted for approximately 40% of monthly meat consumption during the period from July to October, and the increase in the amount of fresh meat increased the monthly meat consumption, as compared with that during the previous three months; camel meat contributed constantly to consumption throughout the year; horse meat contributed to increase in the amount of monthly meat consumption during the cold season. *Hawar* in Mongolian usually means 'spring.' It also means 'deficiency'; which might be a reflection of low amount of items such as milk and meat in the diets of the Mangolians. Figure 1. clearly shows the deficiency in consumption during spring, the families consume comparably smaller amount of meat, which is mostly dried.

Enrichment of diets

Most of the families slaughtered four to five types of animals (Table 2); even in FG1 families, in which the camel occupied more than 50% of the total herd size, the camels made up less than 50% of the total number of slaughtered animals; the herd size of the cattle in FG2 was very large, as compared with the number of slaughtered animals; not only sheep but also goats were slaughtered, even in FG2 families which carried fewer goats as compared with FG1; sheep and goats were constantly slaughtered from July to October in both family groups. The reason for these results may be that the herders may have wanted to enrich the variety of foodstuffs and the types of meat. The taste and smell of the meats differ by animal and by processing (fresh or dried). And the slaughter of sheep and goats in the spring also contributed to enriching life or easing suffering during the spring season.

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Theme: Application of new technology and crop improvement for dry areas

Effects of different tillage and rotation on crop performance

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Abstract

Both tillage and rotation affect crop growth and yield. Farmers in Iran traditionally use conventional tillage (moldboard plow followed by disc harrow) to grow their crops. Such system not only requires high energy input, but also causes long-term soil physical degradation and is time consuming. This study was conducted on a silty clay loam soil to determine the effect of tillage systems on the agronomic performance of winter wheat (*Triticum aestivum* L.), sorghum (*Sorghum vulgare* L.) and clover (*Trifolium alexandrinum* L.), grown in rotation, in southwest Iran. Tillage treatments comprised (a) conventional tillage (CT) involving moldboard plowing followed by disc harrowing, (b) reduced tillage (RT) involving disc plowing followed by disc harrowing, and (c) no tillage (NT) in which crop was sown directly in the untilled soil. Soil sampling was done before planting and after harvest to a depth of 30 cm in 4 intervals. Infiltration rate and soil bulk density were determined. Wheat grain yield and clover dry matter yield were measured. Wheat yield was not affected significantly by different tillage systems. Clover dry matter yield was significantly higher in RT (7.35 Mg ha^{-1}) as compared to CT (5.93 Mg ha^{-1}) and NT (5.12 Mg ha^{-1}) treatments. The results from the second year rotation showed no significant differences between tillage treatments on wheat, but the yield of wheat following clover was significantly greater than that following sorghum.

Introduction

Wheat, clover and sorghum crops in the arid regions of Iran are generally grown using conventional tillage systems, which involves moldboard plowing followed by disc harrowing. Tillage systems could affect both soil physical properties and crop production. Soil physical properties and water-use efficiency have always been a major concern in crop production under arid regions. The conventional tillage system not only needs a high energy input but also results in soil physical degradation (Asoodar, 2001; Barzegar et al., 2004). Reduced and no-tillage systems on the other hand are effective in improving soil properties and improving crop yields. However, the response to reduced tillage and no tillage depends on the climatic conditions and soil factors.

Although the effect of tillage systems on different crops has been studied around the world (e.g. Beyaert et al., 2002; Asoodar and Desbiolles, 2003), but the influence of tillage systems on clover and sorghum yield in rotation with winter wheat has rarely been studied. Katsvario et al. (2002) and Willoughby et al. (1997) indicated that moldboard plowing resulted in the greatest infiltration rates among various tillage systems. Many scientists have reported greater bulk density for no-tilled soil compared to soils receiving conventional tillage. Similarly, infiltration rate has been shown to increase in reduced tillage because of higher organic matter concentration and earthworm activity, which in turn affected crop yields.

Legumes, such as clover, with the faculty of symbiotic N fixation, are known to improve soil nitrogen status and thus benefit wheat production on soils poor in soil nitrogen. A few studies have examined the effect of different varieties of clovers, grown either as a cover crop to control weeds (Abdin et al., 2000) or as a soil enriching leguminous crop, on nitrogen uptake and growth of a succeeding winter wheat crop (Kumar and Goh, 2002). Although the yield increase of wheat after clover has been shown, the influence of different tillage treatments on the performance of the crops grown in rotation on irrigated lands is seldom studied. In arid regions there exists a need to reduce rates of soil degradation without adversely affecting the yield of crops. The objectives of this study were to compare the influence of different tillage systems on soil physical properties and crop performance and examine the interaction of tillage treatments with crop rotation in affecting the yield of winter wheat.

Materials and methods

The experiment was conducted at Ramin Agricultural University Research Station (48°53'E and 31° 35'N, average altitude 30 m), 30 km northeast of Ahwaz Iran. The soil was silty clay loam, which is representative of a large area of arable land in Khuzestan Province in Iran. The average annual temperature is 23°C with the highest monthly temperature of 34°C in July and the lowest of 11°C in January. The cropping sequence at the experimental site, over at least the last 25 years, was winter wheat and summer fallow and sometimes maize was also grown.

A randomized block designs was used with four replications. The tillage treatments consisted of conventional tillage (CT), reduced tillage (RT) and no tillage (NT). In the CT treatment moldboard plowing to the 25 cm depth was followed by two-time disk harrowing to a depth of 10 cm. The RT treatment consisted of disc plowing to a depth of 15 cm followed by disc harrowing to a depth of 10 cm. Two two-year rotations were tested. These were ‘wheat-sorghum-wheat’ and ‘clover-wheat’. Experimental plots (24 in all) were 20 m long and 7 m wide and 3 m apart. The site was tilled and sown to winter wheat (*Triticum aestivum* L.), and berseem clover (*Trifolium alexandrinum* L.) on 1 December 2002 and sorghum (*Sorghum vulgare* L.) was sown as a summer crop after wheat was harvested and as a rotation treatment for the first year. Wheat was sown in all the plots in the second year (1 December 2003) to study the effects of tillage and crop rotation on wheat grain yield. Depth of sowing was 5, 3 and 4 cm for wheat, clover and sorghum respectively. The row spacing for all crops was 18 cm. Wheat and clover were each flood irrigated six times during the crop growth. Sorghum was sown during summer periods and harvested before winter wheat cultivation.
Wheat from 1m row length in three rows within each plot was harvested in early June 2003. The clover biomass of each plot was measured four months after sowing, using a 1 m frame at three random locations per plot (Barzegar et al., 2004). Three intact soil cores were taken from the soil layers down to the 30 cm depth with a 10-cm diameter steel core sampler.

The bulk density of the soil at three stages of wheat growth, namely tillering, flowering and after harvest was studied. In case of clover plots it was done after harvesting the clover. Infiltration rate was measured for each plot before sowing, before grain filling stage and after harvesting by using the twin-ring method.

The data were analyzed using the SAS statistical package for analysis of variance. All differences reported significant in the text are at the $P<0.05$ probability level unless otherwise stated. The least significant difference (LSD) was calculated only when the analysis of variance showed that F-test was significant.

Results and discussion

Soil characteristics

Selected physical and chemical properties of the site just prior to the start of the experiment are given in Table 1. The soil texture was silty clay loam with a clay content of 34-35%. The electrical

Table 1. Selected chemical and physical properties of soil at different depths before the start of the experiment.

Soil layer (cm)	O.M ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	N (%)	P ($mg\ kg^{-1}$)	K	BD ($Mg\ m^{-3}$)	Clay ($g\ kg^{-1}$)	Silt	Sand
0-5	12.1	3.3	7.6	0.10	15.4	192	1.5	354	538	108
5-10	10.0	2.1	7.7	0.08	16.2	165	1.6	336	520	144
10-20	9.5	2.0	7.8	0.10	9.3	117	1.6	358	510	132
20-30	9.0	2.2	7.8	N/A	6.1	118	1.6	348	512	140
STD	3.4	1.2	0.2	0.03	3.5	43	0.06	36	22	30

OM, organic matter; EC, electrical conductivity; BD, bulk density; STD, standard deviation of mean conductivity ranged from 1.2 to 3.3 dS m^{-1}. N, P and K contents of soil were 0.08 to 0.10%, 6.1 to 16.2 and 117 to 192 mg kg^{-1}, respectively, depending on the depth.

The organic matter concentration for all tillage treatments (data not shown) for both crops measured after harvesting was generally higher than before cultivation. The organic matter concentration in different soil layers of NT, except for the upper soil layer, was significantly higher compared to RT and CT. Analysis of variance of data indicated that the effect of both tillage ($p<0.05$) and depth ($p<0.01$) on organic matter were significant. Our results are consistent with other reports (Lal et al., 1994) that showed a higher organic matter concentration in no or reduced tillage as compared to full tillage. The soil bulk density, measured at three stages of wheat growth, (data not shown) was not significantly different among tillage treatments. Similar results were obtained in clover plots after harvesting (data not shown). Lal et al. (1994) and Hill (1990) reported that tillage with the moldboard plow generally resulted in a lower bulk density during the early stages of crop growth. Our results are consistent with Blevins et al. (1983) who showed no differences in bulk density among tillage systems used for corn production. Katsvario et al. (2002) reported some physical properties of a 6-year tillage, crop rotation and management system. They indicated that tillage and crop rotation had no significant effect on soil bulk density.

Infiltration rate was greatest in the CT treatment for both wheat and clover (Fig. 1). Soil loosening in the CT treatment probably contributed to the increased infiltration rates. It is not clear why field infiltration rate was more in the CT treatment when soil bulk density did not differ among tillage systems.

Crop results

The yield of wheat (data not shown) in the first year was not affected by tillage treatments while the clover yield was significantly affected (Fig. 2). Clover yield was significantly higher with reduced tillage (Fig. 2) than with NT and CT. Clover biomass under NT treatment contained the highest nitrogen content whereas the highest phosphorus content was under RT (Table 2). Potassium contents of clover biomass under NT and CT were less than under RT and might be related to the yield difference observed.

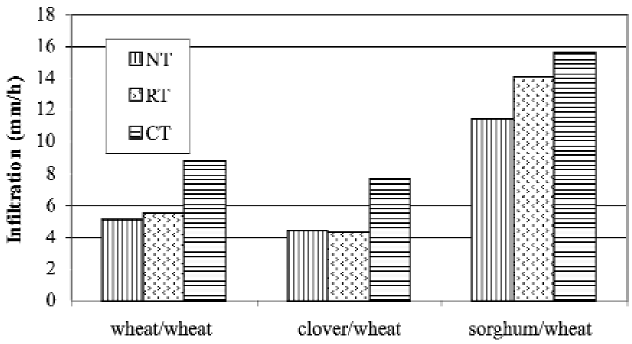

Fig. 1. Infiltration rate after 2 years of crop rotation, measured after wheat.

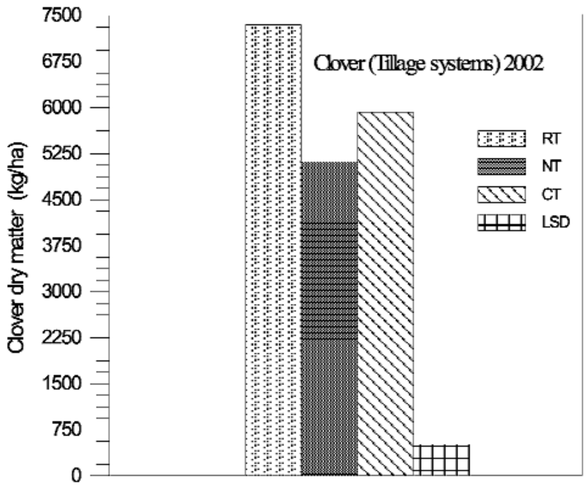

Fig. 2. Clover yield as affected by tillage.

Table 2. N, P and K content of winter wheat and clover biomass

	Wheat			Clover		
Tillage	**N (%)**	**P (g kg^{-1})**	**K (%)**	**N (%)**	**P (g kg^{-1})**	**K (%)**
NT	1.5	2.7	1.4	2.8	2.4	2.4
RT	1.7	3.4	1.6	3.0	3.4	2.6
CT	1.5	3.2	1.7	2.9	2.9	2.3
LSD 0.05	0.1	0.6	0.2	0.1	0.6	0.4

NT, no tillage; RT, reduced tillage; CT, conventional tillage

In the second year, all plots were sown to winter wheat to study the effect of both tillage and rotation. No-till and reduced tillage produced the same amount of wheat grain yield compared to the other tillage treatments (Fig. 3). Halvorson et al. (2000) compared the grain yield of winter wheat under different tillage systems in a dryland region and indicted that no-till could produce higher grain yield compared to CT and minimum tillage. Although the dry matter of weeds were not measured in our study, one explanation for non-significant results obtained for tillage treatments could be greater incidence of weeds in the NT treatment. Young et al. (1994) indicated that the success of no tillage has usually been limited largely because of the lack of effective weed control. Our results revealed that nitrogen content of above ground tissues of wheat crop under NT was greater than other tillage treatments (Table 2). However, the difference was not substantial and therefore no major effect on biomass and grain yield or distribution pattern of assimilates into spikes, was detected.

Our results indicated that the winter wheat under CT gave the highest yield, but this was not statistically significant. Similar results were reported by Halvorson et al. (2001). Wheat production was however affected by crop rotation. Wheat yield was significantly higher when wheat followed clover (CW) compared to other crops. Wheat yield was the lowest when wheat followed sorghum crop (SW) as shown in Fig. 4.

No till resulted in the highest wheat yield after sorghum, but it was not significantly different from other tillage treatments. The higher yield of wheat under the second year of rotation under no tillage treatment might be due to the higher amount of organic matters that was available under this treatment.

Conclusion

No tillage and reduced tillage treatments improved or maintained wheat and clover yields compared to conventional tillage, suggesting that these can be considered as appropriate tillage systems for wheat and clover production in the semi arid region.

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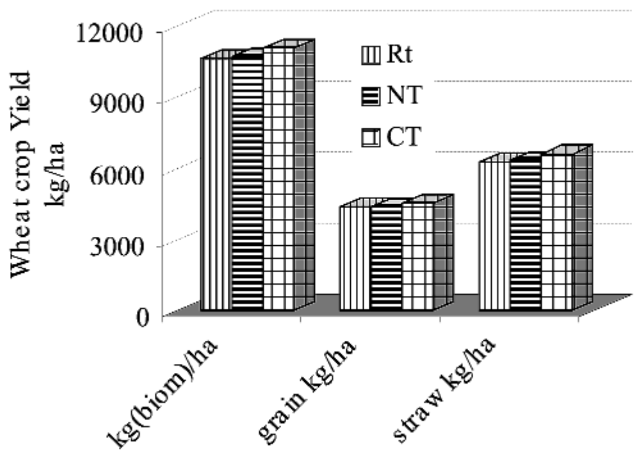

Fig. 3. Wheat crop harvested after 2 years of rotation.

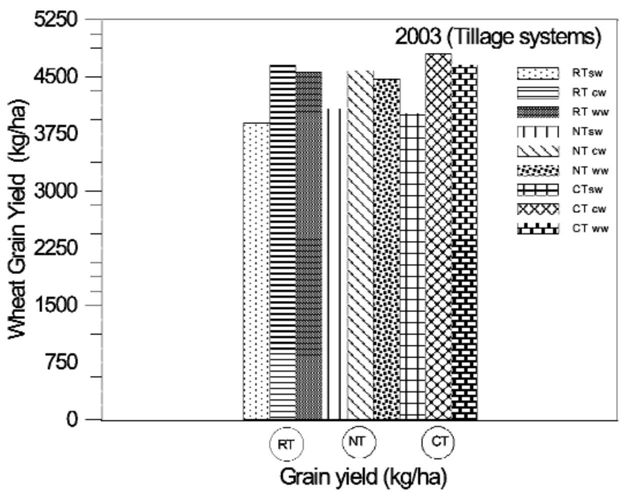

Fig. 4. Effect of crop rotation on wheat grain yield under different tillage systems.

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Influence of supplementary irrigation and variety on yield and some agronomic characters of rapeseed and mustard under rainfed conditions in northern Syria

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Abstract

West Asia and North Africa (WANA) region is short of edible oil and depends mainly on imports for meeting its domestic needs. Import bill exceeds 3 billion US dollars per annum. Rapeseed and mustard crops, which are fast gaining area in the western world for the production of good quality oil, are grown on a very limited scale in this region, mainly in Ethiopia and Pakistan. Introduction of rapeseed and mustard in other parts of WANA will greatly help in increasing local production of edible oil. The rainfed cropping in the WANA region occurs during the cool and wet winter season, from October to May. Crop yields are low because rains are often inadequate and erratic. Use of small amount of supplementary irrigation (SI) can, however, result in more acceptable yields. This field study was conducted for three years at Tel Hadya, Syria, to asses the effects of SI on seed yield of some cultivars of rapeseed and mustard being evaluated for introduction in this dry Mediterranean region. SI treatments included rainfed, 50 % SI, and 100 % SI. Seed yields varied with seasonal rainfall and its distributiont. Yield increased with SI over rainfed treatment, but the differences were not significant. Data also showed that in high rainfall season the effect of SI was little.

Introduction

The use of rapeseed (*Brassica rapa, B. napus)* and mustard *(B. juncea*) seed oils has grown faster than of any other oilseed crop in the period from 1981 to 2000. These crops have become the third most important edible oil source after soybean and oilplam. Over 14% of the world's edible oil supply now comes from rapeseed and mustard. The brassica seeds on extraction normally yield more than 40% oil, on a dry weight basis, and the resulting meal contains 38 to 44% high quality protein (Downy and Robbelin, 1989). The meal of low glucosinolate varieties is now utilized as a high protein feed for livestock and poultry.

Rapeseed and mustard can be cultivated in the cooler regions and at higher elevations in subtropical areas and as a winter crops in the more temperate zones, mainly because of their ability to germinate and grow at low temperatures. According to the FAO (1997), the major brassica producing countries, based on area, are India (about 7 mha), China (7 mha), Canada (5 mha) and Northern Europe (2 mha). The area is also growing in the USA.

West Asia and North Africa (WANA) region is short of edible oil and depends mainly on imports for meeting its domestic needs. Import bill exceeds 3 billion US dollars per annum. In the WANA region only Ethiopia and Pakistan have some area under these crops. Morocco and Turky tried the crop but the area did not develop (Beg, 1994). There is need for identifying appropriate brassica cultivars and production technology for different regions in WANA. Iran started efforts to introduce these crops in the last two decades. In 1999, the area was 30,000 ha. In 2002-03 the area became 120,000 ha. The research conducted on these crops in Iran jointly with ICARDA from 1991-94, recently reported by Beg et al.(2003), provides ample evidence that these crops can be successfully grown in the Mediterranean region with winter climate same as in Syria and produce economical yields. Since much of the WANA region has harsh climate and rainfed crops depend on winter rains, the crop productivity is highly variable because of variability in the rainfall.

Experiments were therefore conducted to find out if the perfromance of these crops could be improved under the dry Mediterranean environments by using supplemental irrigation.

Materials and methods

This study was conducted for three years, from 1994 to 1996, at Tel Hadya, Syria, the main research station of ICARDA, on a fine clay soil (montmorillonitic, thermic Calcixerollic Xerochrept) with a pH of 8.0. The area receives winter rain, as is usual with the Mediterranean climate, from end of October to May. Long time average rainfall is 325 mm. Rainfall was 312.9 mm in 1994-95, 404.9 in 1995-96 and 433.7 mm in 1996-97. Effective rains in the first two years were received in the first week of November, and in the end of October in the 3rd year. The monthly total precipitation and monthly mean maximum and minimum temperatures observed during the three cropping seasons are given in Table 1.

The experiment included three cultivars, 'Shiralee' (*B. napus*), 'Cutlass' (*B. juncea*) and 'Rex' (*B. rapa*) and three irrigation regimes, rainfed, 50 % supplemental irrigation (SI), and 100 % S1. Experiment was conducted in a split-plot design with varieties in the main plots and water regimes in subplots. Treatments were replicated three times. Plot size was 1.5 by 12 m, with 5 rows 30 cm apart. Seed rate was 8 kg/ha. Plant to to plant distance was 2-2.5 cm. Fertilizer was applied at sowing @ 50 kg/ha phosphate and 40 kg/ha N. Top dressing was done of 60 kg/ha N in the middle of February.

Seeding was done with a small plot planter on 7 Nov 1994, 21 Oct 1995 and 5 Nov 1996. Germination occurred on 18, 3 and 16 Nov in the three respective years.

The SI treatments were given before the wilting point was reached. Irrigation was applied by drippers which discharged water at 7 liter/hour.
Plots were hand-weeded when necessary. The crop matured by the end of May. Harvesting was done using small plot cereal combine. Plot at each end was trimmed at harvesting to avoid border effects.

Data were recorded on total biological yield, grain yield, both determined from an area of 14 m^2, leaf area, days to 50 % flowering, 200-seed weight, and harvest index. Data were analysed using Mstat statistical analysis system.

Results and discussion

The main effects of various factors on different crop atruibutes are given in Table 2. There was a trend for increase in yield because of supplemental irrigation. Yield was also higher in the year when rainfall was higher. 'Shiralee' yielded the highest and 'Cutlass' the lowest. The analyses of variance, however, showed that these effects were statistically nonsignificant except for the effect of varieties on some characters. All the interactions were also not significant.

Table 1. Growing season rain and temperature at Tel Hadya Syria 1994-1997 and long time average.

Precipitation (mm)											
Year	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**Total**
1994-95	1.3	15.7	98.1	45.1	42.4	16.5	24.5	48.3	19.5	1.5	312.9
1995-96	0.0	10.3	68.3	35.5	73.7	45.0	137.0	32.2	2.9	00	404.9
1996-97	22.9	35.3	17.4	92.5	46.8	24.8	76.3	111.7	6.0	00	433.7
Long time average	0.5	24.8	50.0	52.2	62.8	57.3	39.3	25.6	16.5	2.7	332.4

Maximum and minimum temperatures (°C)										
Year	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
Maximum										
1994-95	37.3	30.3	17.8	9.6	12.2	16.5	18.9	23.1	31.6	35.7
1995-96	34.3	28.3	17.2	12.4	11.2	14.4	15.8	20.6	32.2	35.6
1996-97	33.1	26.1	20.1	15.2	12.0	12.9	15.3	20.0	31.9	34.8
Minimum										
1994-95	19.9	14.8	7.4	1.6	3.7	2.7	3.4	6.9	11.5	18.6
1995-96	18.0	10.5	4.6	2.0	3.3	4.3	6.6	6.7	12.3	17.6
1996-97	17.1	11.0	7.1	7.3	2.6	-1.0	2.2	6.3	11.6	17.7

Table 2. Average differences in various attributes of rapeseed and mustard as affected by season, varieties and irrigation levels.

Attributes	1994-95	1995-96	1996-97	S.E
		Average effect of seasons		
Days to 50 % flowering	169	172	171	0.6
200-seed-weight in g	0.48	0.41	0.39	0.03
Leaf area in cm^2/6 pl	636	679	899	59.5
Harvest index (%)	17	16	16	1.14
Seed yield in kg/ha	580	683	669	47.3
		Average effect of varieties		
	Cutlass	**Shiralee**	**Rex**	**S.E**
Days to 50 % flowering	175	167	171	1.3
200-seed-weight in g	0.361	0.513	0.410	0.03
Leaf area cm^2/6 plants	993	596	626	143.5
Harvest index (%)	16	18	16	2.0 6
Seed yield in kg/ha	502	771	659	105.7
		Average effect of SI		
	100% SI	**50 % SI**	**Rainfed**	**S.E**
Days to 50 % flowering	173	170	170	0.8
200-seed-weight in g	0.427	0.413	0.444	0.01
Leaf area cm^2/ 6 plants	797	738	680	81.0
Harvest index (%)	18	16	16	0.79
Seed yield in kg/ha	582.14	632.39	717.12	80.7

Perhaps the timing of supplemental irrigation and amount use was not appropriate to result in significant improvements in the yield. Weather conditions, particularly the low average minimum temperatures (Table 1) might have constrained crop growth so that it could not benefit fully from the supplemental irrigation. It might have also resulted in an uneven growth in different parts of the experimental field, thus leading to increased error estimates so that the difference in treatment effects failed to reach the level of significance. This is particularly evident from the data on the yield in the two way table for cultivar and supplemental irrigation (Table 3).

Table 3. Rapeseed and mustard seed yield as affected by varieties and supplementary irrigation (SI), average over the three years.

Cultivars	Supplimental irrigation		
	Rainfed	**50% SI**	**100% SI**
Cutlass	476	476	556
Shiralee	647	802	862
Rex	623	618	712
Vx SI SE+/-		139.9	

Conclusions

The study provides some evidence that yield of rapeseed-mustard increases with SI. The effects were however not significant. The timing and the amount of supplemental irrigation need to be firther studied so that optimum practice for supplemental irrigation could be developed.

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Effect of drought stress on yield, yield components and relative water content in rapeseed (Brassica napus L.) cultivars

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Abstract

The effect of drought stress in the generative-growth period on agronomical and physiological characteristics in rapeseed (*Brassica napus* L.) cultivars was studied in a field experiment at Seed and Plant Improvement Institute, Karaj in 2002/3. There were two factors. Irrigation at two levels (a. irrigation after 80 mm evaporation from class A pan as control and b. drought stress created by no irrigation from stem elongation stage until physiological maturity) was the main plot treatment and ten spring cultivars, 'Ogla', '19-H', 'Hyola 401' (Canada), 'Hyola 401' (Safiabad), 'Hyola 401' (Borazjan), 'Hyola 420', 'Syn-3', 'Option 500', 'Hyola 308' and 'Quantum' were the sub- plot treatment in a single split plot design. Agronomical and physiological characteristics were studied. Results showed that water stress during the generative phase had adverse effect on growth, yield and yield components but the differences were significant only for seeds per pod and 1000-seed weight. The oil content decreased by 3.3% and oil yield by 18.6% in drought-stress condition, but the decreases were not significant. Cultivar differences were significant for most of the attributes. Among the ten cultivars, Syn-3, 19-H, Hyola 420, Hyola 401 (Canada) and Hyola 401 (Borazjan) produced more seed yield than the others, while Hyola 308 had the lowest seed yield. The decrease in relative water content in leaf was more in sensitive varieties. The amount of proline in leaves reflected the degree of stress but it was not related to drought-stress tolerance. On the basis of the results it is concluded that Syn-3, 19-H, Hyola 420, Hyola 401 (Borazjan) and Hyola 401 (Canada) cultivars, with higher stress tolerance index (STI), could produce greater seed yield both under good and limited moisture supply conditions.

Introduction

The rapeseed/canola crop (*Brassica napus* L.) is the world's third most important edible oil source and its importance continues to increase (Downey, 1990). Canola crops integrate well in the wheat-based cropping system, because they provide a disease break for cereal crops, allow rotation of chemical pesticides, and diversify farm income. In addition, the canola oilseed meal is a good source of protein for animal feed. Canola has become a major oilseed crop in the cropping areas in Iran in recent years. The area sown to canola in Iran reached 70,000 ha in 2001-02 (Shirani-Rad and Dehshiri, 2002).

Canola is relatively poorly adapted to drier environments and more generally to years with substantially lower than average rainfall (Wright et al., 1995). Seasonal temperature and rainfall patterns indicate that a combined temperature and water stress usually occurs in spring-seeded annual crops during their reproductive stage. Drought stress can reduce crop yield by affecting both source and sink for assimilates. Plant response to abiotic stresses depends on the developmental stage. Seed yield potential in *Brassica* crops depends on the event occurring prior to and during the flowering stage (Mendham and Salisbury, 1995), because the reproductive period is most susceptible to the abiotic stresses.

Canola has indeterminate growth habit. It, therefore, exhibits substantial recovery from the stress (Mendham and Salisbury, 1995). Angadi et al. (2004), comparing drought stress effect at various stages of crop development, found that earlier the stress occurrence the greater was the opportunity for the crop to recover. Studies on the effect of soil drying on seed yield and seed quality in rapeseed (*Brassica napus* L.) grown in sandy and loamy soils in lysimeters in the field showed that under low evaporative demand (2-4mm day^{-1}) seed and oil yields were not significantly influenced by soil drying, but under high evaporative demands (4-5 mm day^{-1}) early drought during the vegetative and the flowering stage or late drought during the pod filling stage decreased the seed and oil yield on sandy soil (Jensen et al., 1996).

Several reports have emphasized that the generative growth period (flower bud formation until seed filling stage) is the most sensitive period to drought in rapeseed/canola (Hashem et al., 1998). In drought stress condition, source limitation for seed yield can arise from reduced photosynthesis and from rapid development of storage organs such as seeds. Abiotic stress at a later stage of reproductive growth can result in source limitation for seed yield by inducing the shedding of leaves and/or by hastening the crop maturity. Angadi et al. (2004) reported that rapeseed cultivars that had less pods in drought-stress condition had high seed size.

Several physiological characters that can contribute to continued growth under water stress have been identified. With most plants, the maintenance of growth and function depends on maintaining a higher water content in the protoplasm. This is because many important physiological processes such as leaf enlargement, stomatal opening and photosynthesis are directly affected by a reduction in leaf water potential and relative water content (RWC). In order to facilitate crop genetic improvement for drought tolerance it is important to understand the mechanisms involved and to develop suitable methodologies for their measurements. Osmotic adjustment, i.e. a net increase in solute leading to a lowering of osmotic potential, is one of the main mechanisms whereby crops can adapt to limited water availability. The solutes that accumulate during osmotic adjustment include sugars, amino acids, organic acid, proline and glycinebetaine (Good and Maclagan, 1993).

Osmotic adjustment (OA) – the lowering of cell osmotic potential by energy dependent solute accumulation as water potential falls – increases the tolerance of some crops to drought.

Indian mustard (*B. juncea*) maintained higher leaf turgor pressure and longer leaf area duration and thereby achieved greater dry weight and seed yield under terminal drought than canola (Wright et al., 1996). Study on the influence of soil water deficit on solute accumulation in expanded and expanding leaves of canola (*B. juncea* line PI-81792) showed that three genotypes expressed similar magnitude of OA in response to drought, compared with a 2 fold higher OA in expanding leaves than in fully expanded leaves (Ma et al., 2004). Drought induced change in OA of expanded leaves of all genotypes were largely due to the accumulation of nitrate, soluble sugars and proline. In expanding leaves, K^+ accumulation was significant as was proline, whereas nitrate and soluble sugars were less important than in expanded leaves. Proline was hardly detected in well watered plants, but sharply increased in leaves of drought affected plants in direct proportion to the magnitude of OA. Proline may thus be a suitable 'marker' for OA in juvenile *Brassica* plants because, of all the solutes measured, praline concentration was directly proportional to the magnitude of OA across cultivars and leaf types (Ma et al., 2004).

The objective of this study was to test the response of canola varieties commonly grown in Iran to water stress during reproductive growth in the field. We aimed to determine the change in seed and oil yield of canola in response to drought stress as affected by changes in the yield attributes; examine the physiological responses to drought stress in terms of leaf relative water content with leaf osmotic potential; and identify cultivar differences in drought tolerance and their ability for osmoregulation under stress by measuring proline content in leaf tissue.

Material and methods.

The study was conducted during the winter season on the experimental field of the Seed and Plant Improvement Institute, Karaj, Iran, from September 2002 to June 2003. Weather conditions are shown in Table 1. The total rainfall in the

Table 1. Monthly weather data for the 2002-2003 growing season at Karaj.

Year and month	Temperature (°C)		Rainfall	Relative humidity
	Max.	Min.	(mm)	(%)
2002				
October	29/3	15/6	0/3	30/75
November	18/4	7/8	9/3	49/80
December	7/2	0/5	106/4	69/60
January	8	-1/0	2/7	59/12
February	8/6	0/6	35/3	65/10
March	11/3	2/2	42	63/10
2003				
April	16/7	7/0	78/7	58/50
May	22/9	9/5	11/1	46/90
June	28/6	13/9	16/6	43/40

growth period was 302.4mm.The highest rainfall was in December and the lowest in September.

The experiment was conducted in a split-plot design with four replications. In the main plots were the two irrigation levels (regular irrigation after 80mm evaporation from Class A pan as control, and drought stress from stem elongation stage until physiological maturity by withholding irrigation in this period). In the subplots were ten spring cultivars of rapeseed, 'Ogla', '19-H' , 'Hyola' 401(Canada)', 'Hyola 401(Safiabad)', 'Hyola 401 (Borazjan)', 'Hyola 420', 'Syn-3', 'Option 500', 'Hyola 308' and 'Quantum'.

Before sowing the experimental crop, the soil was adequately fertilized with N and P fertilizers as per the soil test. For early weed control, Trifluralin was applied at 2 L/ha and incorporated in the top soil with a small garden tiller. Each plot was 5 x 1.2 m in size and contained four rows of rapeseed at 30cm distance. Planting was done on 29 September 2002 and the crop emerged in October. Following the seedling emergence, plots were thinned to a stand of about 90-110 plant/m^2. Plots were hand-weeded as needed throughout the experiment.

Water was applied at 10 to 15 day intervals in the control (irrigated) plots; the amount of water applied was equal to 80% of the cumulative evaporation. A total of four irrigations were given. The total amount was 320 mm. The rainfall was 302 mm. Thus the control plots received a total of 622 mm water. On the other hand, plots having drought treatment, did not receive any irrigation after plants reached stem elongation stage (stage 2.03 in the growth stage key) until physiological maturity (stage 6.9). Thus, these plots received only 102 mm water in two irrigations and the total water (rain + irrigation) for drought stress treatment plots was 422 mm.

The plants were harvested on 12 and 16 Jun 2003. Two harvest dates were needed because of the difference in crop maturity associated with the treatments. At harvest, the plants were cut at ground level, pods and seeds counted, and the oven-dry mass of seeds and remainder of the plant determined. At maturity, four plants from each treatment were harvested and the number of pods per plant measured. Pods were then removed to determine the number of seeds per pod, 1000-seeds weight, total dry mass, seed and straw yields. Two thousand seeds were counted and weighed to determine seed weight for each cultivar. Oil yield was calculated from seed yield and the oil concentration data. Seed oil content was measured by low-resolution, continuous-wave nuclear magnetic resonance on seed dried at 105°C for 6h.

Proline content of the leaf tissues was determined 231 days after sowing (DAS). Five fully expanded leaves from each plot were selected and frozen in liquid nitrogen. The content of proline in leaves was determined using a Spectrometer (L340 model, Hitachi, Japan) and expressed in mmol/g fresh weight of leaf.

For determining the relative water content (RWC), five young and fully expanded leaves that were at the same height on the stalk from the soil, were sampled 239 DAS (between 11 and 12 AM). Leaves were immediately weighed to determine fresh weight (FW). They were then floated on distilled water for 4h at 22°C under dim light. The turgid weight (TW) was then determined. The samples were then dried for 24h at 80°C to determine the dry weight (DW). The relative water content was determined as follows:

$$RWC = \frac{FW - DW}{TW - DW}$$

For the evaluation of the drought tolerance of the cultivars, the stress intensity (SI) of the environment was first calculated as given below:

$$SI = 1 - \frac{Y_{\bar{s}}}{Y_{\bar{p}}}$$

where Y_s and Y_p are mean yield of the ten cultivars under drought-stress treatment and normal irrigation treatment, respectively. Then, the stress tolerance index (STI) was calculated for each cultivar as follows:

$$STI = \frac{Y_s . Y_p}{(Y_{\bar{p}})^2}$$

where Y_s and Y_p are seed yields of a cultivar in drought stress and normal irrigation conditions, respectively, and $Y_{\bar{p}}$ is the mean yield of all the varieties in normal irrigation.

The data were subjected to analysis of variance (ANOVA). Means were compared using Duncan's Multiple Range Test (DMRT) at 5% level of probability where the F-test was significant.

Results and discussion

Leaf RWC and proline content

The ANOVA results showed that the irrigation and cultivars had a significant ($p< 0.01$) effect on RWC, whereas the interaction of irrigation and cultivars was not significant. Drought stress reduced the mean RWC from 80.60% to 76.60%. The highest mean RWC was in Hyola 420 with 81.15% and the lowest in Hyola 308 with 75.50% (Table 2).The highest RWC was in Hyola 420 in normal irrigation (82.82%) and the lowest was in Hyola 308 in the drought-tress condition (72.81%).

Both irrigation treatments and cultivars had a significant effect on praline content in leaves ($p<$ 0.01). The interaction effects were also significant ($p< 0.01$). Proline was present in the tissues of plants under normal irrigated treatment too, but in drought-stress condition it increased. Drought stress caused an increase in proline content from 11.98 to 90.60 (mmol/g.f.w). The highest content of proline was in Hyola 308 and the lowest in Option 500. The interaction effects showed that the highest content was in Hyola 308 under drought-stress condition and the lowest in Hyola 401(Safiabad) in normal irrigation ((Table 3). Deepak and Wattal (1995) showed that water stress at flowering in rapeseed decreased chlorophyll content and under severe stress there was concomitant increase in NO_3 and free proline pools in leaves. With an increase in stress intensity, leaf water potential, RWC and leaf area declined significantly. In our study the highest proline content and the lowest RWC were under drought-stress condition. For example, Hyola 308 and Ogla, with the 225.10 and 217.50 mmol/g.f.w proline, had the lowest RWC (72.81 and 73.63%, respectively) under drought- stress condition (Table 3).

Yield attributes

All yield attributes (pod/plant, seed/pod, 1000)-seed

Table 2. Mean values over two irrigation treatments for yield attributes, yield and some physiological parameters of 10 cultivars. Means followed by different letters in a column are significantly different at p< 0.05

Cultivars	Pods/plant	Seeds/pod	1000-seed weight (g)	Seed yield (kg/ha)	Straw yield (kg/ha)	Oil (%)	Oil yield (kg/ha)	Proline content (mmol/g.f.w)	RWC (%)
Ogla	167.6cde	17.8d	4.05b	3248cd	1158oab	47.41a	1531bcd	112.2b	76.14ef
19-H	250.1a	23.5ab	4.14ab	3909ab	1296oab	46.47abc	1815abc	33.4f	77.85d
Hyola 401 (Can.)	148.9de	21.4bc	4.40ab	3686abc	1325oa	47.85a	1765abc	19.4g	79.48bc
Hyola 401 (Safi.)	146.2e	19.2d	4.46ab	3438bcd	1219oab	47.36a	1629abcd	19.8g	77.29de
Hyola 401 (Bora.)	188.3bc	25.1a	4.21ab	3679abc	1298oab	46.98ab	1735abc	52.9c	80.79ab
Hyola 420	197.0bc	25.2a	4.04b	3793abc	1329oa	47.76a	1824ab	50.2c	81.15a
Syn-3	210.1b	24.7a	4.34ab	4093a	1371oa	46.60ab	1904a	44.8d	80.68ab
Option 500	185.3bcd	17.9d	4.48a	3212cd	11420ab	47.61a	1532bcd	19.1g	78.50cd
Hyola 308	161.2cde	19.7cd	3.65c	2876d	1037ob	44.53c	1294d	121.4a	75.50f
Quantum	164.6cde	19.1d	4.11ab	3248cd	11500ab	44.96bc	1462cd	39.5e	78.62cd

weight) were significantly ($p<0.01$) affected by cultivars; irrigation-treatment effect and interaction effect of the two factors were significant only for seeds/pod. The highest number of pods/plant (250.1) was in 19-H and the lowest one (146.2) in Hyola 401 (Safiabad) (Table 2). Although irrigation had no significant effect on pods/plant, drought stress declined this attribute from 190.3 to 173.60. It appears that the rainfall in spring, which coincided with the flowering in all cultivars, prevented the abscission of regenerative organs and finally prevented any major reduction in the pods/plant.

Drought stress caused a decline in mean value for seeds/pod, from 23.90 to 21.20. The highest mean number of seeds/pod was in Hyola 420 and the lowest in Ogla (Table 2). The highest number of seeds/pod was in Hyola 401 (Borazjan) in normal irrigation and the lowest in Ogla under drought-stress condition (Table 3). Hyola 420 had the highest number of seeds/pod (25.13) in stress condition. It seems that this cultivar was better adapted to drought condition, whereas Ogla was highly susceptible. The drought stress reduces the photosynthesis and therefore, it results in reduced transfer of assimilates from leaves for seed formation in drought condition.

ANOVA results showed that irrigation and cultivar had significant effect on 1000-seed weight ($p<0.05$ and $p<0.01$, respectively). Drought declined the 1000-seed weight from 4.37g to 4.01g. The highest 1000-seed weight was in Hyola 401 (Borazjan) under normal irrigation and the lowest was in Hyola 308 in drought-stress condition (Table 2). Reason for decline in the 1000-seed weight with drought could be the same as for the number of seeds/pod mentioned above. It seems that in this study, the plant could not compensate the reduction of assimilates with remobilization.

Seed and straw yield

The ANOVA of seed yield showed that only cultivar effect was a significant ($p< 0.01$). The highest and the lowest mean yields were in Syn-3 and Hyola 308, respectively (Table 2). Drought stress reduced the mean seed yield slightly, from 3824.6 kg/ha to 3211.7 kg/ha, but this was not significant. Although the interaction was not significant between the two treatment variables, the highest seed yield was in 19-H and Syn-3 under normal irrigation and the lowest in Hyola 308 under drought condition (Table 3). It seems that Hyola 308 has a high susceptibility to drought.

Table 3. Interaction of cultivars and irrigation on seed yield, oil content and some physiological characters in *Brssica napus*. Mean values followed by different letter in the column are significantly different at $p<0.05$.

Irrigation Treatment (I)	Cultivars (V)	Seed yield (kg/ha)	Oil content (%)	Proline content (mmol/g.f.w)	Leaf RWC (%)
Normal irrigation	Ogla	3521	47.82	6.829lm	78.18
	19-H	4519	46.70	6.653lm	80.72
	Hyola 401 (Canada)	4033	48.44	14.55jk	81.06
	Hyola 401 (Safiabad)	3950	48.64	6.436m	79.61
	Hyola 401 (Borazjan)	3948	47.95	11.50klm	82.44
	Hyola 420	4175	49.71	20.93hi	82.82
	Syn-3	4444	47.72	12.13kl	82.50
	Option 500	3240	47.83	13.81jk	79.66
	Hyola 308	3104	44.76	17.69ij	78.65
	Quantum	3313	45.86	9.277klm	78.77
Drought stress	Ogla	2975	47.01	217.5b	73.63
	19-H	3300	46.24	60.18f	74.97
	Hyola 401 (Canada)	3340	47.27	24.23h	77.90
	Hyola 401 (Safiabad)	2925	46.08	33.12g	74.97
	Hyola 401 (Borazjan)	3410	46.01	94.39c	79.85
	Hyola 420	3410	45.81	79.51d	80.33
	Syn-3	3742	45.47	77.58d	78.87
	Option 500	3183	47.39	24.49h	77.33
	Hyola 308	2648	44.30	225.1a	72.81
	Quantum	3183	44.06	69.80e	76.92
IxV interaction	NS	NS	NS	S	S

Reduction of seed yield (16%) was related to reduction in the number of seeds/pod (11.3%), pod/plant (9%) and 1000-seeds weight (8.24%).

In this study, proline content was not related to drought tolerance. Hyola 308, with the highest content of proline (225.15 mmol/g.f.w) in drought stress, had the lowest seed yield (2468 kg/ha) (Table 3). The cultivars that could maintain their RWC at high level produced high seed yield, as seen in the case with Hyola 401(Canada), Syn-3, Hyola 401(Borazjan) and Hyola 420. Their respective RWC was 77.90 , 78.87, 79.85 and 80.33, and the respective seed yields 3340, 3742, 3410 and 3410 kg/ha (Table 3).

The ANOVA showed that none of the treatment variables and their interaction had any significant effect on straw yield. The drought stress slightly declined the straw yield from 12862 to 11787 kg/ha. The highest straw yield was in Syn-3, Hyola 420 and Hyola 401 (Canada) (13710, 13290 and 13250 kg/ha, respectively) and the lowest one (10370 kg/ha) was in Hyola 308 (Table 2). The highest straw yield was in Syn-3 in normal irrigation and the lowest in Hyola 308 in drought condition (Table 3). Reduction of straw yield was related to reduction of growth characteristics such as plant height, number of lateral branches and leaf area.

Oil content and yield

Results of ANOVA showed that only the cultivar had significant effect on oil percentage ($p< 0.01$). The highest oil content was in Hyola 401(Canada) and the lowest in Hyola 308 (Table 2). Drought stress caused little decline in the oil content. The highest oil content was in Hyola 420 under normal irrigation treatment and the lowest in Quantum under drought-stress condition (Table 3), although these differences were not significant. In drought-stress conditions, accelerated ripening of plants reduces the synthesis of proteins and oils from the photosynthates coming to the seeds. Also, drought stress reduces net photosynthesis which finally translates in to reduced oil production in the seeds.

Assessment of cultivars for their drought tolerance

Drought stress from stem elongation stage until physiological maturity gave an stress intensity (SI) index of 0.1602. To assess response to this level of drought stress, the stress tolerance index (STI) of each cultivar was computed. Syn-3, 19-H, Hyola 420, Hyola 401 (Canada) and Hyola 401(Borazjan) had the highest STI values, 1.1367, 1.0194, 0.9734, 0.9208 and 0.9204 because they had the highest seed yield in this condition. On the other hand, Hyola 401 (Safiabad), Quantum, Ogla and Option had the STI of 0.7898, 0.7161 and 0.7055 and thus formed the moderate tolerance group. Hyola 308 with the STI of 0.5119 had the highest susceptibility to drought stress.

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Crop water productivity a strategy for sustainable development in drylands

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Abstract

The countries located in arid and semiarid environment suffer water shortage and thus face the challenge to produce more food from less water. This challenge can however be met by increasing the crop water productivity (CWP). Based on experiments in last ten years, it was found that the range of CWP of wheat in Iran was higher than that reported by FAO earlier. The CWP of corn in the area in north-west of country was higher than that reported by FAO while it was less in the areas located in south-west of the country. The prevailing wide range of CWP (0.65-2.07 kg m^{-3} for wheat and 0.33-2.19 kg m^{-3} for maize) opens scope for organizing and increasing the agricultural productions with less water resources. The variability of CWP can be ascribed to (i) climate, (ii) cropping calendar, (iii) irrigation water management (irrigation scheduling, deficit irrigation, etc), and (iv) soil fertility management. The study has shown that the management of the cropping based on the prevailing climatic conditions is the most appropriate strategy. Another important conclusion was that CWP can be increased significantly if irrigation is reduced by introducing deficit irrigation.

Introduction

The growing population in the developing world will result in considerable increase in the demand for food. Simultaneously, in view of increasing water scarcity and environmental concerns, the arid and semi-arid areas the world face the challenge of producing more food with less water. This goal can however be achieved only if appropriate strategies are taken for water savings and for more efficient water uses in agriculture. One important strategy is to increase the productivity of water (Molden, 1997; Molden et al., 2003). Crop water productivity (CWP) is defined as the physical or economic output per unit water applied to the crop (e.g. kg m^{-3} or \$ m^{-3}). A higher CWP results in either the same production from less water resources, or a higher production from the same water resources, so this is of direct benefit for other water users. De Wit (1958) was among the first to use this concept and he expressed the water use efficiency in kg crop production per m^3 of water transpired.

Molden (1997) introduced the broader term of water productivity for analysis of water use at different levels of aggregation. Kijne et al. (2003a) gave an overview of the work on WP since the introduction of this concept. The definition of WP is scale and user dependent. Molden et al. (2003) referred to this problem as ‘‘which crop and which drop”. The total dry or fresh biomass or harvested product can be used as the numerator in this relationship either in physical or economic terms and the transpiration (T), evapotranspiration (ET), amount of irrigation water, water input in different scale, etc. can be used as denominator. Often it is not stated explicitly whether the fresh or dry yield is used as the numerator (e.g., Tuong, 1999; Droogers et al., 2000; Chen et al., 2003; Li et al., 2004).

Kijne et al. (2003b) provide several strategies for enhancement of CWP by integrating varietal improvement and better resources management at plant, field and agro-climatic level or basin level. Examples of options and practices that can be taken at plant level include improving crop tolerance to drought and salinity through breeding or reducing non-transpiration part of water use, transpiration without reducing production or to increase production without increasing transpiration. At field level the options include increasing the harvest index, applying deficit irrigation, adjusting the planting dates and tillage to reduce evaporation and to increase infiltration. At agro-ecological level the options include water reuse and spatial analysis for maximum production and minimum ET.

Iran is situated in one of the most arid regions of the world. The average annual precipitation is 250 mm and of this 179 mm of rainfall is directly evaporated. Thus 71% of precipitation is lost due to evaporation. The annual potential evaporation of the country is between 1500 and 2000 mm. The altitude varies from -40m to 5670m above the mean sea level and it has a pronounced influence on the diversity and variation of the climate. Although most parts can be classified as arid to semi-arid, the country, however, enjoys a wide range of climatic conditions. Both latitude and altitude also have a major influence on climatic conditions in different regions. This is reflected in the spatial variation of annual precipitation which ranges from 50 mm in the central desert in the southeast and 1600 mm in southern coast of the Caspian Sea.

Various studies have been made on water use and yield relationship of specific crops, on specific locations, with specific cultural and water management practices in Iran. This paper summarizes the results of field experiments conducted over 5 years to improve water productivity and to find plausible values for the relationship in two major staple crops of Iran, namely, wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.).

Methodology and database

A total of 10 field experiments were conducted in 5 locations of Iran (Karaj, Orumieh, Mashhad, Dezful, and Esfahan) by the Agricultural Engineering Research Institute of Iran. Five experiments were conducted on maize, one each at the above five locations. Another five experiments were conducted on wheat. Of these, 3 were in Mashhad, one each in Karaj and Orumieh. All experiments were conducted at experimental stations and covered a vide range of climates, cropping calendar, irrigation, fertilization, soils, cultural practices, etc. In all the experiments the crop water requirements (ETc) were computed based on Penman-Monteith model (Allen et al., 1998), which is reported to be applicable for the region. The amount of irrigation water applied (I) in the experiments was based on the different fraction of ETc, and ranged from deficit to over irrigation.

The CWP was defined as the marketable crop yield (Y_{act}) per unit (I):

$$\text{CWP (kg/m}^3\text{)} = Y_{act} \text{ (kg) / I (m}^3\text{)} \qquad (1)$$

When considering this relation from a physical point of view, one should consider transpiration only. The partitioning of evapotranspiration in evaporation and transpiration in field experiments is, however, difficult and therefore not a practical solution. Moreover, evaporation is always a component related to crop specific growth, tillage and water management practices, and this water is no longer available for other usage or reuse in the basin. As the purpose of this research is to find plausible CWP ranges under farm management conditions, all measured CWP values of an experiment are included in the database.

Yield (Yact) is defined as the marketable part of the total above ground biomass production. In our study the total grain yield of wheat and maize is considered. Siddique et al. (1990) investigated CWP of old and new wheat cultivars and found that older cultivars had lower CWP values due to lower harvest index. No significant difference in total biomass production between the old and new cultivars was found (Tuong, 1999). Thus, the results of experiments older than 5 years were excluded to minimize the influence of older varieties with lower harvest index and longer growth period.

Although CWP is a key element in long-term and strategic water resources planning, the actual and practically feasible values are hardly understood. The most complete international work so far is compiled by Doorenbos and Kassam (1979), who used crop yield response factors (k_y) for relating the actual marketable crop yield, Y_{act} (kg/ha), and the actual seasonal crop water consumption by evapotranspiration, ETact (m^3/ha). The problem with the standard 'FAO 33-approach' is that the maximum yield ought to be known, which differs for given cultural practices. This implies that Yact = f (k_y, $Y_{potential}$, ET_{act}, $ET_{potential}$) is not straightforward, although it is often applied in absence of alternative expressions.

Results and discussions

The values of CWP ranged between 0.1-2.7 kg m^{-3} for both maize and wheat (Fig. 1 and Fig. 2). Also, the maximum number of CWP observations occurred in the same range of CWP (1.1-1.3 kg m^{-3}) for both crops. To exclude extreme values, the range of CWP was determined by taking the 5 and 95 percentiles of the cumulative frequency distribution of dataset (Table 1).

Wheat had a large number of experimental points (*n* = 255) compared to maize (*n* = 53). CWP of wheat ranged between 0.57 and 1.89 kg m^{-3}. Doorenbos and Kassam (1979) gave a lower range of 0.8–1.0 kg m^{-3} (see Table 1). The maximum CWP of wheat at different sites resulted in the following site ranking: Mashhad > Karaj > Orumieh.

The maximum CWP of maize was measured in Mashhad under deficit irrigation, while the maximum crop yield was measured in Karaj (8903 kg/ha). CWP of maize ranged between 0.34 and 2.34 kg m^{-3} (Table 1). The maximum CWP value of 1.6 kg m^{-3} given for maize by Doorenbos and Kassam (1979) (Table 1) was exceeded in 3 out of 5 data sources and was equal with that in Mashhad. The maximum value of CWP was measured in Orumieh (2.88 kg/m^3), under full irrigation, where crop yield and I were 15900 kg and 8150 m3, respectively. The maximum I was measured at Dezful (32558 m^3) where the maximum CWP was 0.45 kg m^{-3}. Maximum CWP of maize measured in experimental sites followed the order: Orumieh > Mashhad> Esfahan > Karaj > Dezful.

The correlation between Y_{act} and I was not straightforward as often assumed. The *r*-squared values for both the crops were low; the correlation was higher for wheat (r^2 = 0.50) than maize

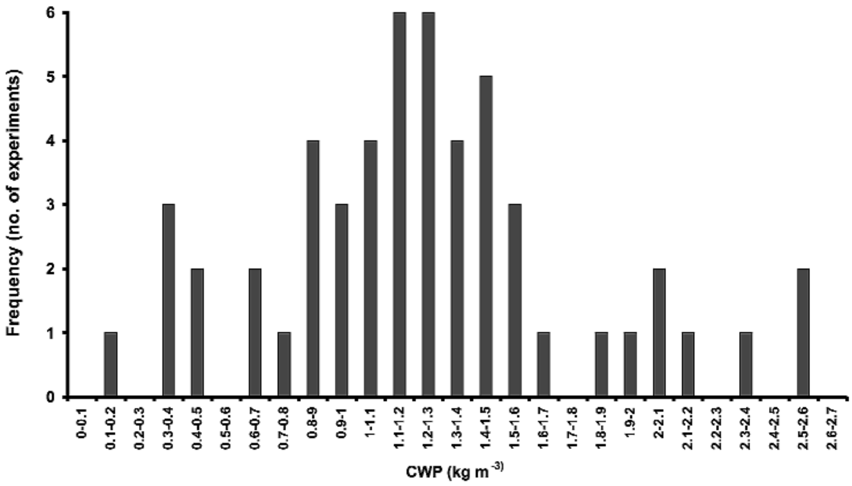

Fig. 1. Frequency of maize water productivity (CWP) per unit irrigation water applied (n=53).

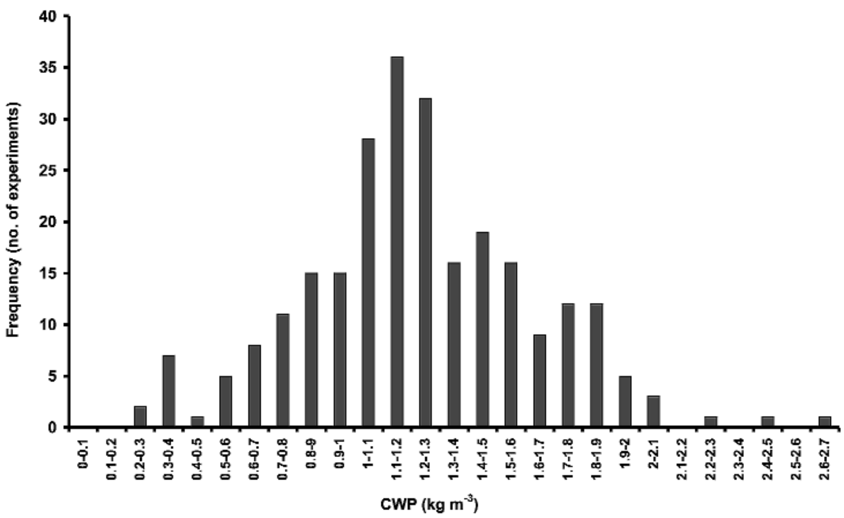

Fig. 2. Frequency of wheat productivity (CWP) per unit irrigation water applied (n=255).

($r^2 = 0.32$). Accordingly, Y_{act} (I) functions are only locally valid and cannot be used in macro-scale planning of agricultural water management. The broad range of CWP observed (Table 1) may be because of many factors that influence the soil-plant-water relationship, climate, irrigation water management, and soil management being the most effective ones.

Influences of climatic parameters on the relation between photosynthesis and transpiration have been described by several workers (De Wit, 1958; Bierhuizen and Styler, 1965; Tanner and Sinclair, 1983). Tanner and Sinclair (1983) found an inverse relationship between vapor pressure deficit of the air and CWP. As the vapor pressure deficit generally decreases when moving away from the equator, CWP is expected to increase with the increase in the latitude. This proposition is confirmed by Zwart et al. (2004). We found similar results for wheat water productivity (Fig. 3); the WP decreased with decrease in the latitude. Orumieh, with highest latitude, showed the highest wheat water productivity of 1.75 kg m^{-3}.

Influences on CWP of irrigation water management, such as different aspects of deficit irrigation, irrigation scheduling, supplemental irrigation, etc., have been reported in literature (e.g., Oktem et al., 2003; Zhang et al., 1998; Yazar et al., 2002; Kang et al., 2000; Sharma et al., 1990). Deficit irrigation practices have been researched to quantify the effect on yield and to find optimum CWP values. Figure 4 shows CWP of wheat and Figure 5 of maize plotted against the irrigation water applied in various experiments and demonstrate how CWP can be increased while simultaneously saving water by reduced irrigations. According to our database, optimum values for CWP are reached at approximately 300 and 600 mm for wheat and maize, respectively. Wheat water productivity (Fig. 4) in Orumieh was less than that in other areas for any amount of irrigation water, while the maize water productivity there (Fig. 5) was higher. CWP of maize in Dezful showed the lowest value as compared to other sites. Irrigation water applied for maize in Dezful was almost 60-200% higher compared to other experimental sites.

Based on these results we suggest the need for some changes in cropping pattern of wheat and maize cultivation in the region covered in this

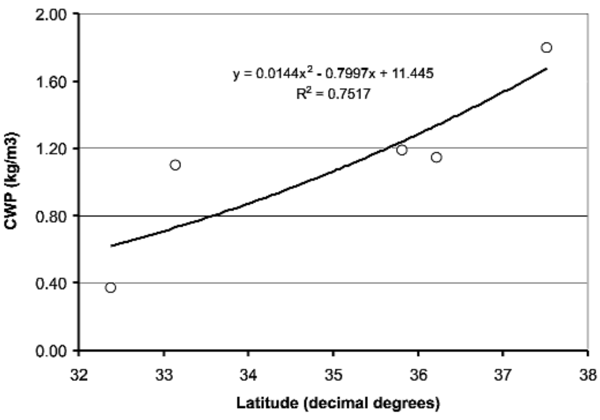

Fig. 3. Relation between latitude and average crop water productivity.

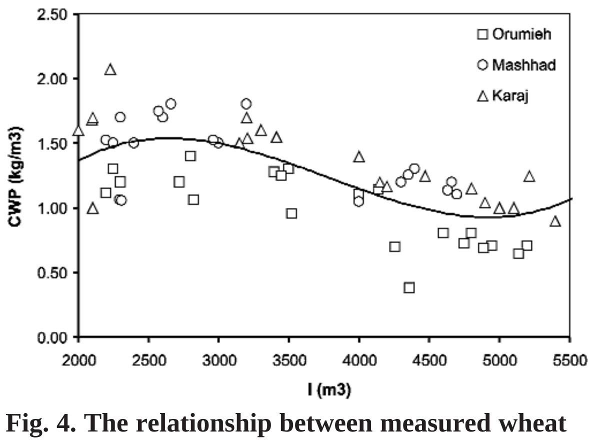

Fig. 4. The relationship between measured wheat water productivity (CWP) and amount of irrigation water applied.

Table 1. Range of measured wheat and maize crop water productivity (CWP) (kg/m^3)and the benchmark values of CWP according to "FAO 33" (Doorenbos and Kassam, 1979) and statistical values of data sets.

Crop	*n*	CWP-range "FAO33"	CWP-range[a] "this research"	Minimum	Maximum	Mean	Median	S.D.
Wheat	255	0.8–1.0	0.57–1.89	0.23	2.65	1.23	1.19	0.41
Maize	53	0.8–1.6	0.34–2.34	0.20	2.55	1.25	1.20	0.50

[a] *Defined as the 5 and 95 percentiles of the entire range.*

study to improve CWP and save water, namely, replacing maize in Dezful and wheat in Orumieh with crops with higher water productivity. We also recommend, based on our results, that deficit irrigation should be applied for wheat production, as has also been recommended by Zhang and Oweis (1999) for durum wheat production in northern Syria. The saved water can be used to irrigate new land rather than to achieve maximum yield with low CWP. Maximum water productivity will often not coincide with the interest of farmers whose aim is a maximum land productivity or economic profitability. There is need for a shift in irrigation water management and basin water allocation to move away from 'maximum irrigation-maximum yield' strategies to 'less irrigation-maximum CWP' policies.

Conclusions

The range of crop water productivity (CWP) for both wheat and maize was large (0.1-2.7 kg m^{-3}) which was mainly ascribed to climate, irrigation water management, cropping calendar, although some other variables might also prevail. Maximum CWP of wheat and maize in our study was higher than that indicated in the FAO classification. Maize water productivity in Dezful was 2-3 times smaller than that in other experimental sites. Therefore, change in regional cropping pattern can be effective in improving CWP at the country level. Plants are more efficient in water use when they are subjected to some water stress. It is therefore concluded that to achieve optimum CWP in water scarcity regions, it would be desirable to irrigate wheat with less water than what is currently applied. Wheat water productivity was decreased when irrigation water applied was more than 300 mm. The wide range in CWP observe suggests that agricultural production can be maintained with less water resources provided the new water management practices are adopted. Moreover, average CWP increased with increase in the latitude and this is likely to be related to change in the vapor pressure deficit with latitude.

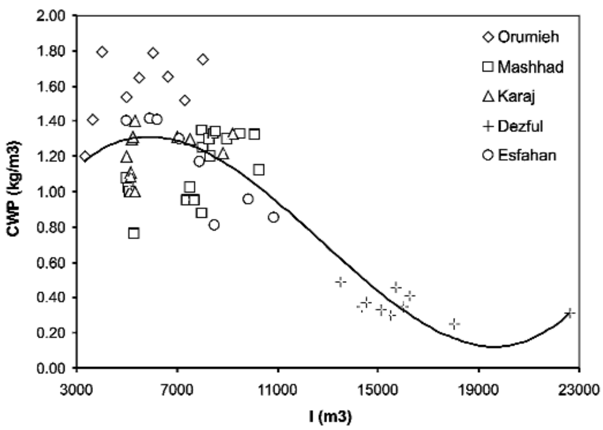

Fig. 5. The relationship between measured maize water productivity (CWP) and amount of irrigation water applied.

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Long-term effects of fertilizer and water availability on cereal yield and soil chemical properties in northwest China

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Abstract

Wheat (*Triticum aestivum* L.) - and corn (*Zea mays* L.) - rotation system is important for the food security in northwest China. Grain yield and water-use efficiency (grain yield / estimated evapotranspiration, ET) trends, and changes in soil properties during a 24-year rainfed fertilization experiment in Pingliang, Gansu, China, were recorded. Mean wheat yields for the 16-yr period ranged from 1.29 Mg ha^{-1} for the unfertilized plots (CK) to 4.71 Mg ha^{-1} for the plots that received annually manure (M) with inorganic nitrogen (N) and phosphorus (P) fertilizers (MNP). Corn yields for the 6-yr period averaged 2.29 and 5.61 Mg ha^{-1} in the same treatments. Yields and WUEs declined with year except under CK and MNP treatments for wheat. Wheat yields for the N and M declined an average of 77 and 81 kg ha^{-1}yr^{-1}, but the decline of 57 kg ha^{-1}yr^{-1} for the NP was similar to that of 61 kg ha^{-1}yr^{-1} for the treatment receiving straw and N annually and P every second year (SNP). Likewise, the corn yields and WUEs declined significantly for all treatments. Grain yield estimated ET relationships were linear with slopes ranging from 0.5 to 1.27 kg ha^{-1}m^{-3} for wheat and 1.15 to 2.03 kg ha^{-1}m^{-3} for corn. Soil organic C, total N, and total P gradually increased with time except under CK, in which total N and total P remained unchanged but C and available P decreased. Soil available P also decreased in the N treatment. Soil available K declined rapidly without application of straw or manure. The greatest C increases of about 160 mg kg^{-1} yr^{-1} occurred in SNP and MNP treated soils, suggesting that long-term additions of organic materials could increase water-holding capacity which, in turn, improved water availability to plants and arrested grain yield decline, and sustained productivity.

Introduction

Northwest China is a vast, semi-arid area with average annual precipitation ranging from 300 to 600 mm. More than 90% of the cropland in this area receives no irrigation. The main crops are wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.), which are periodically rotated. There are about 1.3 million ha of wheat and corn rotations in the Loess Plateau region of northwest China. This cropping system produces about 40% of the local food needs (Fan and Song, 2002), and has emerged as the most important system for food security in this dryland region (Xing et al., 2001). Generally, three or more years of continuous wheat are followed by two or more years of continuous corn. In a typical system where winter wheat follows corn, wheat is seeded immediately following corn harvest. In all other combinations, land is fallowed between crops to store water in the soil for the subsequent crop. The fallow periods between crops range from none for wheat following corn to 9 months for corn following wheat, and from about 3 months for wheat following wheat to 6 months for corn following corn. Shangguan et al. (2002) reported that fallow efficiency (FE), expressed as soil water accumulation divided by precipitation received during the fallow periods, for the area was about 35 to 40%. The importance of storing soil water during fallow periods for increasing grain yields of subsequent crops has been supported by many dryland studies including those in the

US Southern Great Plains by Johnson (1964) and Musick et al. (1994) and in the China Loess Plateau by Shangguan et al. (2002).

Rational fertilization and management of soil fertility are among the most important measures to improve grain yield and water use efficiency (WUE, grain yield per unit of seasonal evapotranspiration in kg ha^{-1} m^{-3}) toward a sustainable crop production required to meet the food demand of the region's growing population. The importance of soil fertility to optimizing WUE has long been recognized (Power et al., 1961; Viets, 1962; Stewart, 1989; Cai et al., 2002). Therefore, maintenance of soil fertility will be essential to improve and sustain grain yields. Soil organic matter (SOM) will be critical to this goal because it directly and indirectly affects various chemical, physical, and biological soil properties that are related to plant behavior (Vanlauwe et al., 2001; Merckx et al., 2001; Zhang and He, 2004). Challenges for dryland farming in northwest China are low WUE resulting from low SOM and low soil fertility (Zhang et al., 1997; Zhu, 1984). Organic carbon in the surface layer of this region is generally < 5.8 g kg^{-1} (Xing et al, 2001) because low quality manure is applied at rate of 30 Mg ha^{-1} and crop residue is usually taken out from field for feed or fuel. Farmyard manure (not pure manure but a mixture with soil) and inorganic fertilizers are widely applied as a crucial approach for both improved soil properties and efficient water use for crop production (He and Lin, 1992).

Long-term experiments are invaluable for assessing cropping system effects on soil properties, grain yield and WUE, and risk management (Regmi et al., 2002; Dawe et al., 2000; Camara et al., 2003). Many long-term experiments have been used to test effects of fertilization on grain yield and soil properties (Jenkinson, 1991; Mitchell et al., 1991; Sandor and Eash, 1991; Brown, 1991; Bhandari et al., 2002; Zhu, 1997; Wang et al., 2002), but few continuous long-term studies are available from northwest China. Therefore, preliminary fertilizer recommendations, which need further calibration through multi-year field experiments, were provided based on studies within a short period of time. The long-term experiment reported here began in 1979, and is the longest running annual cropping system experiment in the Loess Plateau. The study aimed to (1) examine grain yield and WUE trends for wheat and corn in annual cropping systems under long-term organic and inorganic fertilization; and (2) monitor long-term effects of fertilization on soil properties.

Materials and methods

Experimental site

A long-term permanent plot experiment has been conducted since April 1979 at the Gaoping Agronomy Farm, Pingliang, Gansu, China. The site is in the central part of the Shizi highland plateau (35°16' N, 107°30' E, 1254 m altitude). Its dark loess soils are classified as Calcarid Regosols (FAO/UNESCO, 1988) with an average soil organic matter (SOM) of 9.1 g kg^{-1}, corresponding to about 5.3 g kg^{-1} of soil organic carbon (SOC). Soil texture in the 0-20 cm depth is silt loam (sand 231 g kg^{-1}, silt 433 g kg^{-1}, and clay 336 g kg^{-1}) with a bulk density of 1.30 Mg m^{-3}. Analysis of soil samples taken from the experimental area in October 1978 indicated that the top 15-cm of soil had a pH of 8.2, SOC content of 6.2 g kg^{-1}; total N (TN) of 0.95 g kg^{-1} (Black, 1965); total P (TP) content of 5.7 g kg^{-1} (Murphy and Riley, 1962); available P (AP) of 7.2 mg kg-1 (Bray and Kurtz, 1945); and available K (AK) of 165 mg kg^{-1} (Shi, 1976). SOM was analyzed by the Walkley-Black (WB) procedure (Allison, 1965) and the value divided by 1.724 to estimate SOC in g kg^{-1} that was converted to Mg ha^{-1} of SOC for given depth assuming a bulk density of 1.30 Mg m^{-3}. Groundwater level remained at a depth of about 80 m below soil surface for the duration of the study.

Under average climatic conditions, the area has an aridity index (P/PET: precipitation / potential evapotranspiration) of 0.39 and receives 540 mm precipitation, about 60% of which occurs from July through September. May through June is the driest period for crop growth and light precipitation is common during December and January. The mean monthly maximum and minimum temperatures for the wheat-growing period (October-June) are 21.1°C and –12.9°C, and 24.2°C and 8.1°C for the corn-growing season (April-September). The study area is representative of a typical rain-fed farming region.

Experimental design and treatments

The experiment began in 1979 with a corn crop on land that had been cropped to corn the previous year. There was one crop each year. Six fertilizer treatments were arranged in a randomized complete block design with three replications. Corn was grown in 1979 and 1980, wheat from 1981 through 1984, corn in 1985 and 1986, wheat from 1987 through 1990, corn in 1991 and 1992, wheat from 1993 through 1998, soybean [*Glycine max*(L.) *Merr.*] in 1999, sorghum [*Sorghum bicolor* (L.) *Moench*] in 2000, and wheat in 2001 and 2002. Data for the 16 years of wheat and 6 years of corn are presented in this paper (Table 1).

The experimental area covered 0.44 ha. Each plot was 16.7 m by 13.3 m with a buffer zone of 1.0 m in between two plots. The six treatments were 1) CK, unfertilized, 2) N, nitrogen fertilizer annually, 3) NP, N for nitrogen and P for phosphorus fertilizers annually, 4) SNP, straw (S) plus N added annually and P fertilizer added every second year, 5) M, farmyard manure added annually, and 6) MNP, farmyard manure plus N and P fertilizers added annually. Urea and superphosphate were the N and P sources, and were broadcast applied at rates of 90 kg N ha^{-1} and of 30 kg P ha^{-1}, respectively. Manure was added at rate of 75 Mg ha^{-1} (wet weight). Deep plowing of approximately 23 cm was performed in July after wheat harvest or in October after corn harvest except for the years in which wheat followed corn. In those years, shallow disk tillage was done after corn harvest and wheat was seeded immediately.

Generally, the farmyard manure was a mixture of about 1:5 ratio of manure to loess soils so its nutrient content was quite variable from year to year. The N, P, and K contents of the manure mixture taken in 1979 were 1.7, 6.8, and 28 g kg^{-1} in dry weight, indicating that manure is very low in N,

Table 1. Growing season precipitation (GSP), potential evapotranspiration (PET), estimated seasonal evapotranspiration (ET) and crop water stress index (CWSI=1-ET/PET), drought index (DI), and year type classified by DI values in the long-term (1979-2002) rainfed fertilization experiment.

Years	GSP (mm)	ET (mm)	PET (mm)	CWSI	DI†	Year type
			Winter wheat			
1981	191	191	1096	0.83	1.83	dry
1987	316	316	965	0.67	0.74	dry
1995	206	249	1190	0.79	1.58	dry
2001	282	282	1006	0.72	1.07	dry
1982	170	405	966	0.58	0.08	normal
1988	367	431	887	0.51	-0.40	normal
1993	380	380	862	0.56	-0.08	normal
1994	290	397	980	0.59	0.14	normal
1996	297	369	932	0.60	0.24	normal
1997	197	339	941	0.64	0.50	normal
1998	270	397	899	0.56	-0.08	normal
2002	289	433	917	0.53	-0.30	normal
1983	412	553	804	0.31	-1.85	wet
1984	364	502	810	0.38	-1.36	wet
1989	267	436	746	0.42	-1.10	wet
1990	324	472	843	0.44	-0.92	wet
			Corn			
1986	309	333	1099	0.70	1.57	dry
1992	354	374	935	0.60	0.60	dry
1979	380	494	1075	0.54	0.00	normal
1991	340	444	1011	0.56	0.21	normal
1980	553	569	1000	0.43	-1.09	wet
1985	465	550	967	0.43	-1.08	wet

† DI is defined as $(CWSI_i - \overline{CWSI})/\sigma$, where $CWSI_i$ and $\overline{CWSI}$ are crop water stress index for individual and average year for 16-yr wheat and 6-yr corn, and σ is standard deviation for CWSI. Dry, normal, and wet year refers to $0.5<DI<2$, $-0.5\leq DI\leq<0.5$, and $-2<DI<-0.5$, respectively.

and high in P and K. Although the specific amounts of nutrients added with manure each year were not determined, an application of approximately 75 Mg ha^{-1} (wet weight) supplied roughly 40 kg N ha^{-1}, 200kg P ha^{-1}, and 840 kg K ha^{-1} annually to crops. For SNP treatment, 3.75Mg ha^{-1} of wheat straw approximately 10 cm in length was returned to the soil prior to plowing, and phosphorus fertilizer was added with the straw every second year. There was very little wheat straw or corn residue on the other treatments because all crops were harvested at the ground level and removed from the plots before thrashing the grain. The SNP treatment was the only one that had residue returned to the plots. The carbon (C) content of the straw was 42.9% so there was approximately 1.6 Mg C ha^{-1} added each year to the SNP treatment.

Winter wheat (cultivars 'Qingxuan 8271', 'Longyuan 935', and 'Ping 93-2') was seeded in rows 14.7 cm apart at rates of 165 kg ha^{-1} on about 20 September each year when wheat followed wheat, and in early October when wheat followed corn. Corn hybrid 'Zhongdan 2' was seeded about 20 April each year that corn was grown by hand in hills every 33 cm in rows 66.5 cm apart. About 3 weeks after seeding, corn plants were thinned to one plant per hill. Later, if tillers developed, they were removed to avoid competition with the main stem. Hand weeding was done to manage the weeds and plant protection measures were applied when needed. Crops were harvested manually close to the ground. Grain yields were determined by harvesting 20, and 40 m2 areas in the center of each plot for wheat and corn, respectively. Grain samples were air-dried on concrete, threshed and oven-dried at 70°C to a uniform moisture level, and then weighed.

Soil sampling and analysis

Eighteen soil samples of three replicates of six treatments were collected annually during 1979 through 1991 and 1996 through 1998, 15 d after harvest. Each sample was a composite of three random 2-cm-diameter cores per plot. A 5-cm internal diameter auger was used to sample the 0 to 15-cm soil depth to determine the effect of fertilizations on soil nutrient contents by the methods listed earlier. The entire volume of soil was weighed and mixed thoroughly and a sub-sample was taken to determine dry weight. The fresh soil was mixed thoroughly, air-dried for 7 days, sieved through a 2.0-mm sieve at field moisture content, mixed, and stored in sealed plastic jars for analysis. Representative sub-samples were drawn to determine TN, TP, AP, AK, and SOM by the methods listed earlier. TP, AP, and AK were not determined in the samples taken in 1996.

Seasonal evapotranspiration and crop water stress index

Monthly precipitation was measured using a rain gauge at a weather station close to the experimental farm, and potential evapotranspiration (PET) was derived simultaneously from 255-200 Class 'A' Evaporation Pan located on the station (FAO, 1998). Generally, seasonal evapotranspiration (ET) values are calculated by summing seasonal soil water depletion amounts with the growing season precipitation (GSP) amounts. For this study, soil water amounts at seeding and harvest were not measured so ET values could not be determined for each plot. However, ET amounts were estimated by assuming fallow efficiency (FE) values based on reported studies and authors' experience (USDA, 1974; Freebairn and Glanville, 1994; Shangguan et al., 2002; Xing et al., 2001; Nielsen et al., 2002). Therefore, estimated seasonal ET amounts were calculated by: ET = (FE $\times$ fallow season precipitation) + (GSP, growing season precipitation). Surface runoff was not considered because individual plots were surrounded with border dikes. Drainage was assumed negligible because of semiarid conditions. In this assumption, mean FE values used were 35% for the 3-month fallow period when wheat followed wheat, 30% for the 6-month fallow period when corn followed corn, and 25% for the 9-month period when corn followed wheat. A null FE value was assumed when wheat followed corn because there was no fallow period and the corn generally had used most or all of the plant available soil water. Although these FE values are somewhat arbitrary, we think they provide reasonable estimates of water used from stored soil water and allow estimates of seasonal ET values. For the 24-year study, there were 16 wheat crops and 6 corn crops. Three of the wheat crops followed corn and one followed sorghum (calculations for sorghum were same as for corn), and 12 wheat crops followed wheat. Of the six corn crops, three followed corn and three followed wheat.

The methodology used resulted in all fertilizer treatments having the same amounts of seasonal ET. Although in reality there were probably some differences, the amounts are believed relatively small because water was generally limiting so all treatments extracted most or all of the plant available water from the soil profile. Viets (1962), in his classic review on fertilizers and the efficient use of water, stated that under arid and semiarid conditions fertilizers often had no effect on ET. Huang et al. (2003) showed little or no differences in seasonal ET values for various fertilizer treatments during a 15-year study in Shanxi Province relatively with similar soil and climatic conditions to those in our study.

The crop water stress index (CWSI) is defined as being equal to 1 – (ET/PET) (Jackson et al., 1988; Olufayo et al., 1996) and was used in this study to assess the relationship between it and crop grain yield. Mean seasonal CWSI values for wheat and corn each year were calculated using estimated seasonal ET and derived PET from the weather station. A CWSI value of 1 would indicate full water stress and a value of 0 would indicate no stress. In this study, WUE was expressed as grain yield divided by estimated ET. At the same time, assuming that the 24 years of record closely represent the climate of the region, probability values, expressed by the relative frequency from the 24 years (1979 to 2002), of 75%, 50%, and 25% for CWSI and ET in the above four annual cropping systems, were calculated based on monthly PET records and estimated ETs, respectively. Therefore, grain yields corresponding to these probabilities can be predicted by using the functions of ET and CWSI related to grain yield as presented in this study.

Data analyses

Analysis of variance (ANOVA) for the randomized complete block design was done to determine main and interactive effects of treatment and year on wheat and corn grain yield and WUE using PROC GLM (SAS Inst., 1991), and the fertilization treatment by year mean square was used as the error term to test for treatment and year effects in the 16 yr wheat and the 6 yr corn. There were significant interactions between treatments and years so means separation tests for 16 yr wheat and 6 yr corn were not conducted. One-way ANOVA was therefore made for individual years, and mean separation tests among fertilizer treatments were conducted using the least significant difference (LSD) procedure at the 0.05 probability level only when F was significant. Linear regression analyses were done using each plot data to determine trends (slopes) of grain yield and WUE and using composite soil data from three replicate plots to assess trends of various soil parameters over the years. Linear regression analyses were also used to identify the impact of seasonal ET, and CWSI on both wheat and corn grain yield. The P values (Pr>t) of the slopes were used to test whether the observed changes were significantly different from 1.

To analyze further treatment effects on grain yield in response to years with different rainfall, drought index (DI), defined as $CWSI_i – CWSI)/\sigma$, where $CWSI_i$ and $CWSI$ are crop water stress indexes for individual and average year for wheat and corn, and σ is standard deviation for CWSI, was calculated. Xing et al. (2001) used DI to distinguish among wet (–2<DI<-0.5), normal (–0.5≤DI≤0.5) and dry (0.5<DI<2) years.

Results and discussion

Crop water stress index

There were large differences in the amounts and distribution of growing season precipitation (GSP), fallow period intervals, and PET and CWSI values for the various annual cropping systems (Table 1). For the 16 yr of wheat, the average GSP, estimated seasonal ET, PET, and CWSI values were 289 mm, 384 mm, 928 mm, and 0.57, respectively. The CV values were 24.9%, 24.5%, 12.0%, and 24.6%, respectively. The highest CWSI value was 0.83 in 1981 when the seasonal ET was only 191 mm and the PET was 1096 mm. This was the year with the lowest amount of seasonal precipitation during the wheat growing season, and also a year when wheat was seeded immediately following corn. The lowest CWSI was 0.31 when wheat followed wheat in the wet year of 1983. During that year, seasonal ET was 553 mm and the PET was 853 mm. The calculated drought index (DI) values for the 16 yr of wheat ranged from –1.85 to 1.83 (Table 1). Four years, 1981, 1987, 1995 and 2001, had DI values ranging from 0.74 to 1.83, and were classified as dry, with an average CWSI of 0.75. Four years, 1983, 1984, 1989 and 1990, were wet with DI values ranging from –0.92 to –1.85 with an average CWSI of 0.39. The remaining 8 years of wheat, 1982, 1988, 1993, 1994, 1996, 1997, 1998 and 2002, were classified as normal years with DI values ranging from –0.40 to 0.50 and an average CWSI of 0.57.

For the 6 yr of corn, the GSP, ET, PET, and CWSI values were 400, 461, 1015 mm, and 0.54, respectively. The CVs were 23.0%, 20.6%, 6.1%, and 18.8%, respectively. The highest and lowest CWSI values for corn, 0.70 and 0.43, occurred in 1986 and 1980 (and 1985), respectively, when corn followed corn. The estimated ET for 1986, the dry year, was 333 mm compared to 569 mm for 1980, the wet year (Table 1). The difference in PET values, however, was only 65 mm to 935 mm compared to 1000 mm. The DI values for the 6 yr of corn ranged from -1.09 in 1980 to 1.57 in 1986. Two years, 1986 and 1992, were classified as dry. Two years, 1979 and 1991, were classified as normal and the remaining two years, 1980 and 1985, were classified as wet. The mean CWSI values were 0.65, 0.55, and 0.43 for the dry, normal and wet years, respectively. The DI values were 0.60 and 1.57 for the dry years, -0.00 and 0.21 for the normal years, and -1.09 and -1.08 for the wet years.

From data in Table 1, it is worthy of note that if an exceptional dry year of 1981 was not included, the estimated ET for 15 yr of wheat had declined with amounts of 6.8 mm per year at the 0.04 probability level. For 6 yr of corn, the estimated ET declined at amounts of 10.8 mm per year at the 0.1 probability level. This indicated that water stress gradually increased for both wheat and corn crops over the years.

Grain yield

Statistical analyses of the 16 yr of wheat grain yields and 6 yr of corn grain yields showed that fertilization treatments impacted grain yields significantly, but grain yields were still highly influenced by precipitation and its interaction with fertilization, which was represented by high significant effect of years in the ANOVA (Table 2). For each year, there were significant effects due to treatments using LSD (data not shown) for both wheat and corn. Grain yields in fertilized plots were generally higher than those in the unfertilized control (CK) plots. Grain yields for wheat and corn were consistently highest in the MNP treatment and lowest in the CK treatment (Fig. 1).

The average grain yields of wheat for the 16 growing seasons were 1.29, 2.36, 3.54, 4.15, 3.87, and 4.71 Mg ha^{-1} for the CK, N, M, SNP, NP, and MNP treatments, respectively (Table 2). During the study period, the wheat yield declined with time except CK and MNP treatments (Table 2), indicating grain yield when manure was added with the chemical fertilizers could arrest the grain yield decline, and low yield without any nutrients added fluctuated highly at coefficient of variation (CV) of 40% among years. In the NP and SNP treatments, the grain yield declines of 57 and 61 kg ha^{-1} yr^{-1} were significant at the 0.05 probability level, but mean yield for the SNP treatment was 7% higher than the NP treatment. In contrast, the N and M treatments showed grain yield reductions of 77 and 81 kg ha^{-1} yr^{-1} that were significant at 0.01 probability level and accounted for 16 to 20% of the yield variability. Although these differences in grain yield reduction were similar, the N only treatment had a CV of 55% that was the highest among all treatments. The M treatment CV was only 35% and was close to the CV of 28% found in the MNP treatment that showed the greatest stability of all treatments. These results indicated that depletion of other nutrients limited wheat yield. In addition, grain yield differences between treatments were also influenced by how dry or wet the growing season was (Fig. 1). For the 4 years classified as dry by the DI, the CK had an average grain yield of only 0.60 Mg ha^{-1} compared to 1.75 Mg ha^{-1} for the 4 years classified as wet. In comparison, an average yield for the N only treatment was 0.86 Mg ha^{-1} for the dry years and 4.22 Mg ha^{-1} for the wet years. The yields of the N treatment were still low in the normal and wet years when compared to treatments receiving fertilizer P in addition to N or when organic materials were added, but they were much higher than the CK treatment. The MNP treatment produced the greatest yields and averaged 3.1 Mg ha^{-1} for the dry years and 6.2 Mg ha^{-1} for the wet years. These results show the importance of adequate soil fertility even in the dry years because the average yield of wheat from the MNP was about 5 times higher than the yield of the CK for the same years (Fig. 1).

Table 2 Grain yield and water use efficiency (WUE) changes, significance of yield and WUE change (P>t) over years, linear regression coefficient (R2), and analysis of variance (ANOVA) in a long-term (1979-2002) rainfed fertilization experiment in Pingliang, Gansu, China.

Treatment (T)	Wheat								Corn							
	Grain yield				WUE				Grain yield				WUE			
	Mean†	Change	P>t‡	R^2	Mean	Change	P>t	R^2	Mean§	Change	P>t	R^2	Mean	Change	P>t	R^2
	Mg ha^{-1}	Mg ha^{-1} yr^{-1}			Kg ha^{-1} m^{-3}	Kg ha^{-1} yr^{-1}			Mg ha^{-1}	Mg ha^{-1} yr^{-1}			Kg ha^{-1} m^{-3}	Kg ha^{-1} yr^{-1}		
Control	1.29 (40 %)	-0.021	0.0935	0.07	0.32 (26%)	-0.003	0.1766	0.04	2.29 (52%)	-0.185	0.0001	0.66	0.47 (36%)	-0.028	<0.0001	0.70
N	2.36 (55%)	-0.077	0.0054	0.16	0.57 (38%)	-0.014	0.0036	0.17	3.02 (45%)	-0.186	0.0006	0.54	0.63 (29%)	-0.027	0.0002	0.60
NP	3.87 (34%)	-0.057	0.0382	0.08	0.99 (18%)	-0.007	0.049	0.06	4.75 (32%)	-0.250	0.0004	0.56	1.00 (14%)	-0.030	0.0001	0.62
SNP††	4.15 (30%)	-0.061	0.0234	0.11	1.08 (16%)	-0.008	0.034	0.09	4.75 (29%)	-0.160	0.005	0.40	1.02 (9%)	-0.010	0.0177	0.30
M	3.54 (35%)	-0.081	0.0014	0.20	0.91 (16%)	-0.014	<0.0001	0.33	4.39 (38%)	-0.181	0.0018	0.46	0.94 (20%)	-0.017	0.0009	0.51
MNP	4.71 (28%)	-0.050	0.1054	0.07	1.22 (12%)	-0.004	0.2298	0.03	5.61 (35%)	-0.249	0.0021	0.46	1.19 (16%)	-0.026	0.0008	0.52
LSD (0.05)	0.067				0.019				0.148				0.032			

ANOVA	Grain yield			WUE			Grain yield			WUE		
	d.f.	F	P>F	d.f.	F	P>F	d.f.	F	P>F	d.f.	F	P>F
Year (Y)	15	31.78	<0.0001	15	6.59	<0.0001	5	58.01	<0.0001	5	19.31	<0.0001
T	5	111.52	<0.0001	5	123.36	<0.0001	5	40.46	<0.0001	5	64.55	<0.0001
Y×T	75	24.94	<0.0001	75	19.73	<0.0001	25	13.74	<0.0001	25	8.43	<0.0001

† A mean grain yield of 16 yr of wheat.

‡ Probability value for testing slopes (yield change) different from 1 was calculated using each plot data by years.

§A mean grain yield of 6 yr of corn.

Values in parentheses are coefficient of variance.

†† A 3.75 Mg ha-1 straw plus nitrogen (N) added annually and phosphorus (P) added every second year.

Farmyard manures, a mixture of manure with loess soil (1:5).

Like wheat grain yields, corn grain yields were also significantly influenced by treatments, and the mean yields for the 6 yr were 2.29, 3.02, 4.39, 4.75, 4.75, and 5.61 Mg ha^{-1} for the CK, N, M, SNP, NP, and MNP treatments, respectively. However, unlike wheat, the corn yield declines over that period were highly significant for all treatments, and the declined amounts ranged from 181 to 250 kg ha^{-1} yr^{-1}, much higher than in wheat. These declines explained 40 to 66% of the yield variability that were also substantially greater than those for wheat (Table 2). The yield declines for the CK, N, and M treatments did not differ, but yield declines increased by 32% for the N treatment and 92% for the M treatment compared to the CK. The yield decline for NP was similar to that for MNP.

These obvious yield declines for wheat and corn were likely due to both negative changes in soil characteristics and precipitation variation. As suggested earlier, the water stress gradually increased for both crops because the estimated ET showed a downward trend that resulted in an upward trend in CWSI. The years of 1984 for wheat and 1985 for corn were wet, and the highest yields were on the MNP plots. Grain yields were 7.0 Mg ha^{-1} for wheat and 7.9 Mg ha^{-1} for corn. These comparable yields suggest that N likely became limiting for corn growth. The yield changes for dry, normal, and wet years were similar to those of wheat, but the year effect was greater for corn (Fig. 1).

More importantly, the average wheat yield for the 16yr in the SNP treatment was 0.28 Mg ha^{-1} higher than that in the NP treatment. There was no difference, however, for corn yield between these two treatments, and the yield decrease in the SNP was only 160 kg ha^{-1} yr^{-1} that was smallest among all the treatments. Both wheat and corn yields from the

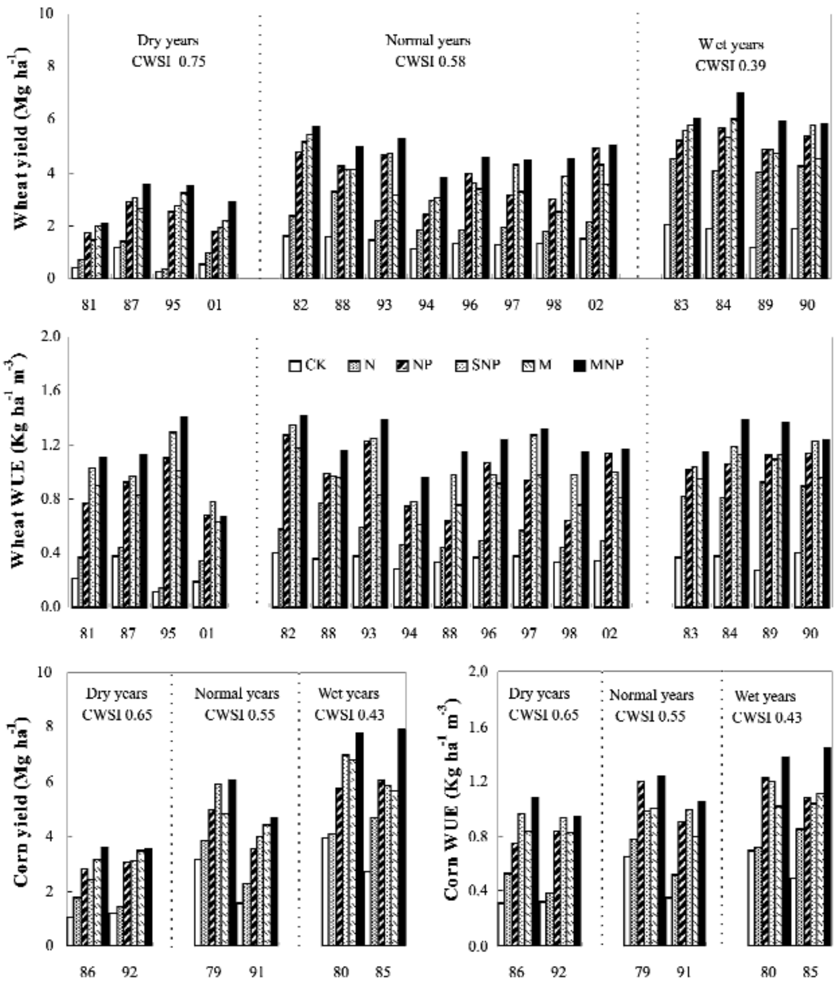

Fig. 1. Changes of grain yield and water use efficiency (WUE) in a long-term (1979 to 2002) rainfed fertilization experiment. CWSI is crop water stress index (1-ET/PET), where ET is estimated seasonal evapotranspiration for wheat and corn, and PET is potential evapotranspiration.

Table 3 Fitted linear slopes and y-intercepts for the relationship between grain yield and estimated seasonal ET in a long-term (1979-2002) rainfed fertilizer experiment in Pingliang, Gansu, China.

Treatment	Wheat†				Corn‡			
	Slopes	***P*>t §**	**y-Intercepts**	**R^2**	**Slopes**	***P*>t**	**y-Intercepts**	**R^2**
	Kg ha^{-1} m^{-3}		Mg ha^{-1}		Kg ha^{-1} m^{-3}		Mg ha^{-1}	
CK	0.0051	<0.001	-0.657	0.85***	0.0115	<0.001	-3.003	0.79***
N	0.0127	<0.001	-2.523	0.82***	0.0134	<0.001	-3.128	0.86***
NP	0.0124	<0.001	-0.884	0.74***	0.0184	<0.001	-3.745	0.94***
SNP	0.0115	<0.001	-0.269	0.73***	0.0139	<0.001	-1.640	0.93***
M	0.0112	<0.001	-0.769	0.74***	0.0145	<0.001	-2.306	0.93***
NPM	0.0125	<0.001	-0.097	0.80***	0.0203	<0.001	-3.759	0.94***

† A 16-year wheat yield data for each treatme nt was used.
‡ A 6-year corn yield data for each treatment was used.
§ Probability value for testing slopes different from 1.
******* *Linear regression coefficient (R^2) significant at the 0.001 probability level.*

M treatment were consistently higher than the N treatment. These results clearly showed a positive impact of annual application of organic materials such as straw and manure on these dryland crops. However, it is not clear whether the impact was due to improved water relationships resulting from increased soil organic matter or improved fertility.

Water use efficiency

The linear regression between grain yield and estimated ET were statistically significant for both wheat (16 yr) and corn (6 yr) for all treatments (Table 3). The linear regression coefficients (slopes) ranged from 1.15 to 1.27 kg ha^{-1} m^{-3} for wheat and from 1.34 to 2.03 kg ha^{-1} m^{-3} for corn across treatments except for the CK, in which the slopes were 0.51 and 1.15 kg ha^{-1} m^{-3}, respectively. The slopes for the CK were low presumably because plant nutrients were often more limiting than water for crop production. The slopes for the fertilized wheat plots in this study were similar to the value of 1.22 kg ha^{-1} m^{-3} reported by Musick et al. (1994) for wheat grown in the semi-arid US Southern Great Plains. The slope values for the fertilized corn plots were close to the values of 2.05 kg ha^{-1} m^{-3} reported by Musick and Dusek (1980) and 1.53 kg ha^{-1} m^{-3} by Tolk et al. (1998) in the US High Plains.

WUE values varied greatly between crop years and treatments and ranged from 0.12 kg ha^{-1} m^{-3} for unfertilized wheat in the dry year of 1995 to 1.42 kg ha^{-1} m^{-3} for the plot fertilized with NPM in the normal year of 1982 (Fig. 1). Similarly, values ranged from 0.31 kg ha^{-1} m^{-3} for unfertilized corn in the dry year of 1986 to 1.44 kg ha^{-1} m^{-3} for the NPM treatment in the wet year of 1985. Similar to the ANOVA results for grain yields, WUE values of both crops were significantly affected by treatments, years, and their interactions (Table 2). For each year, effects of the fertilized treatments were statistically significant as assessed by LSD (data not showed). Average WUE values for the 16 yr of wheat were 0.32, 0.57, 0.91, 0.99, 1.08, and 1.20 kg ha^{-1} m^{-3} for the CK, N, M, NP, SNP, and MNP treatments, respectively. For the 6 yr of corn, WUE values averaged 0.47, 0.63, 0.94, 1.0, 1.02, and 1.19 kg ha^{-1} m^{-3} for the respective treatments. In all years, the MNP had the highest WUE value, the CK had the lowest value, and the N only treatment was lower than all treatments other than the control. Compared to yield data, CVs for WUE values were consistently low for all treatments, nearly half of those for yield, showing their relative stability from year to year. For wheat, when both M and NP were used simultaneously, it is particularly noteworthy that lowered grain yields during dry years did not coincide with substantially lowered WUE values (Fig. 1). Moreover, the increased yields during normal and wet years could not be attributed to increased WUE as much as in the dry years. Similar findings occurred for corn in the dry and wet years.

The wheat WUEs over years also declined with lapse of time except the CK and MNP treatments. For corn, WUE declined linearly and the change was significant in all treatments (Table 2). The relative decline in WUE was greater for corn than for wheat.

For the SNP and MNP, mean WUE values for four dry wheat years were 1.02 and 1.17 kg ha^{-1} m^{-3}, and for two dry corn years were 0.95 and 1.01 kg ha^{-1} m^{-3}, respectively. The WUE values for these two treatments were consistently higher than those for other fertilized treatments, indicating that the combination of NP and organic materials resulted in the most efficient use of water.

Crop water stress and grain yield

Grain yields were also strongly correlated with CWSI values for both wheat and corn (Figs. 2 and 3). The declining linear regression slopes ranged from 3.2 to 8.7 Mg ha^{-1} per unit increase in CWSI for wheat, and from 9.7 to 18.2 Mg ha^{-1} for corn across all treatments. During the 24-year study, CWSI values ranged from 0.31 to 0.83. The downward slope was almost double for corn as compared to wheat, suggesting that corn is more sensitive.

Grain yields of both wheat and corn increased as CWSI values decreased, but this differed with treatments. The greatest yield increases occurred with the MNP and NP treatments, followed closely by the SNP and M and N. The yield increase for the CK was constrained by lack of nutrients so increased available was not utilized efficiently.

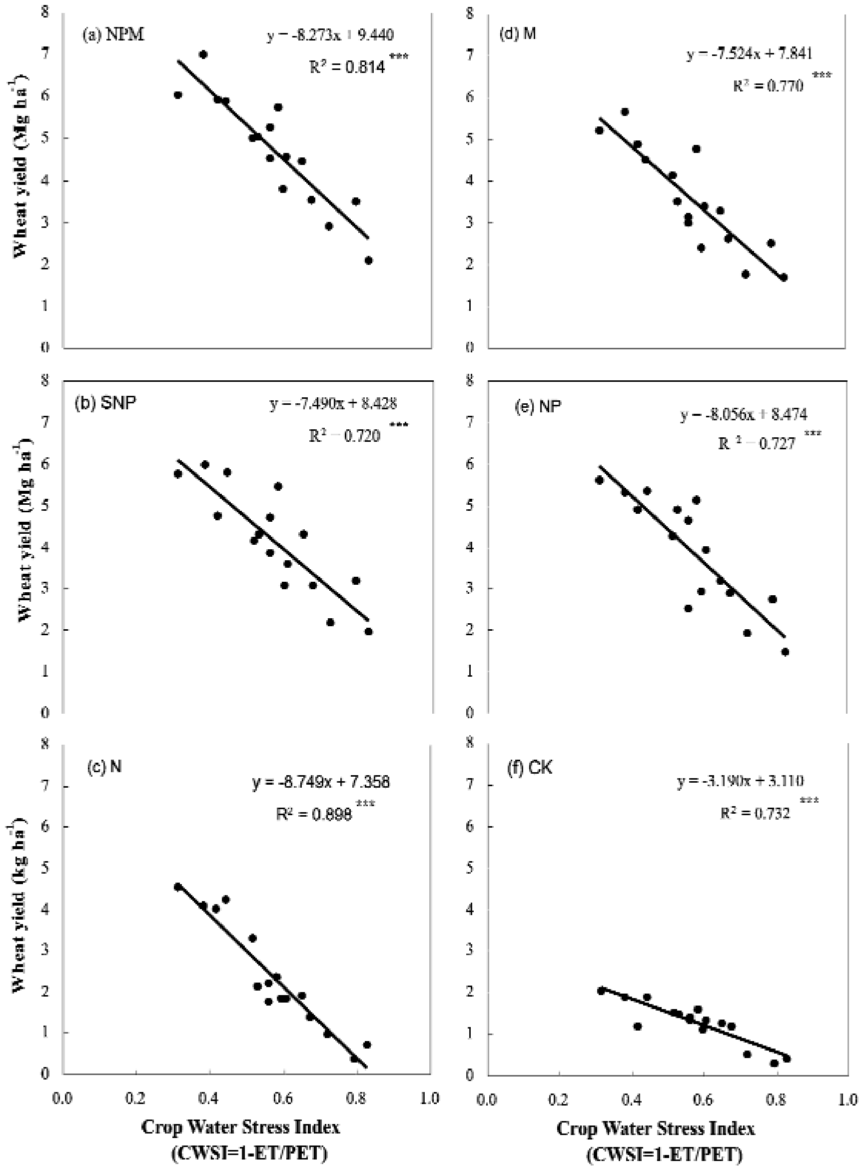

Fig. 2. Relationship between wheat grain yield and crop water stress (CWSI) in a long-term rainfed fertilization experiment. A CWSI value of 1 or 0 would indicate full stress or no stress. * Linear regression coefficient (R^2) significant at 0.001 probability level.**

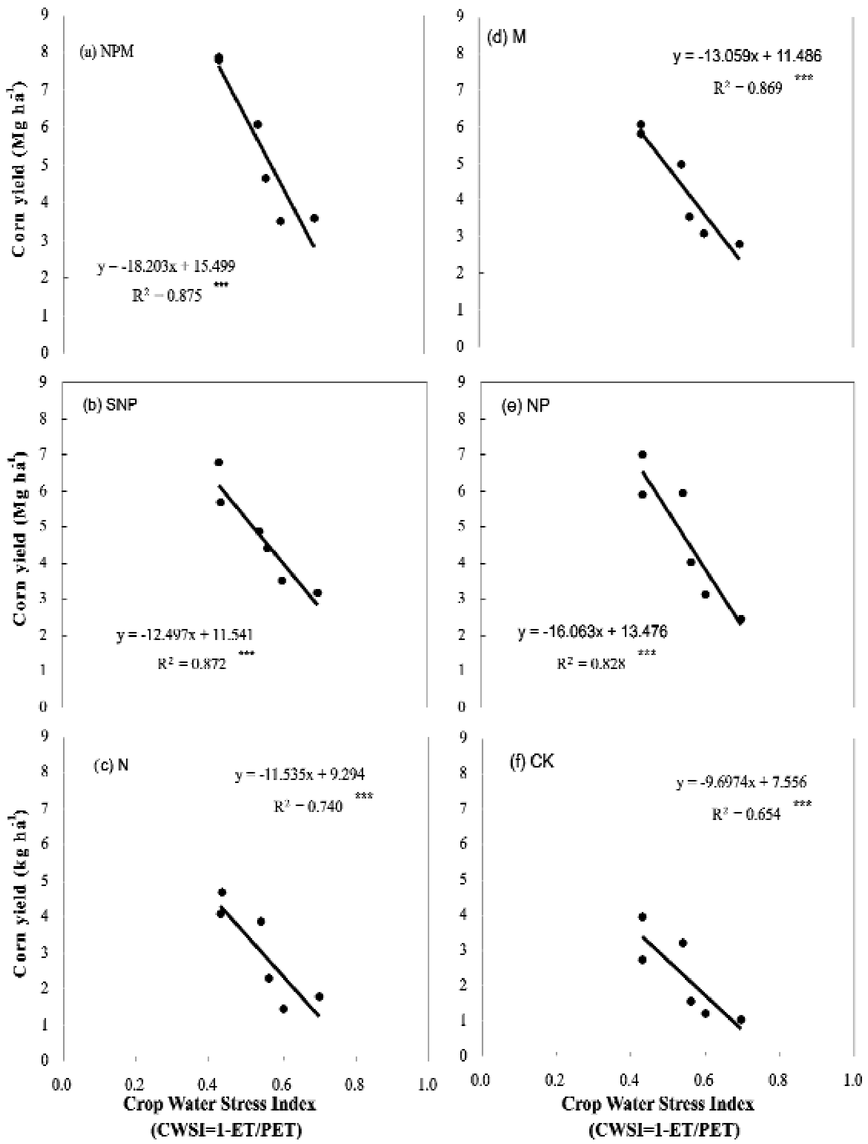

Fig. 3. Relationship between corn grain yield and crop water stress (CWSI) in a long-term rainfed fertilization experiment. A CWSI value of 1 or 0 would indicate full stress or no stress. * Linear regression coefficient (R^2) significant at 0.001 probability level.**

Data (Fig. 2 and 3) showed that grain yields of both wheat and corn were < 1 Mg ha^{-1} when CWSI value was >0.68 for the CK, and >0.72 for the N. For similar CWSI values, wheat yields were > 3 Mg ha^{-1} for the MNP and SNP, and corn yields were about 2.5 Mg ha^{-1}. This clearly illustrates the importance of adequate soil fertility even when water is limiting. In the driest year in which wheat was grown, even when the CWSI values approached 0.83, yields were still about 2 Mg ha^{-1} for the fertilized treatments (MNP and SNP), but only 0.4, and 0.7 Mg ha^{-1} for the CK, and N treatments, respectively.

Grain yield predication based on probabilities of ET and CWSI

Dryland farming is greatly impacted by variations in amount and distribution of seasonal precipitation, making risk assessment a necessary and important farm decision tool. The ET and CWSI probabilities of producing various amounts of wheat and corn grain for different cropping sequences and different fertility treatments are shown in Figures 4 and 5, respectively. The results suggest that, for example, when wheat follows wheat, there is a 50% probability that the CWSI during the growing season will

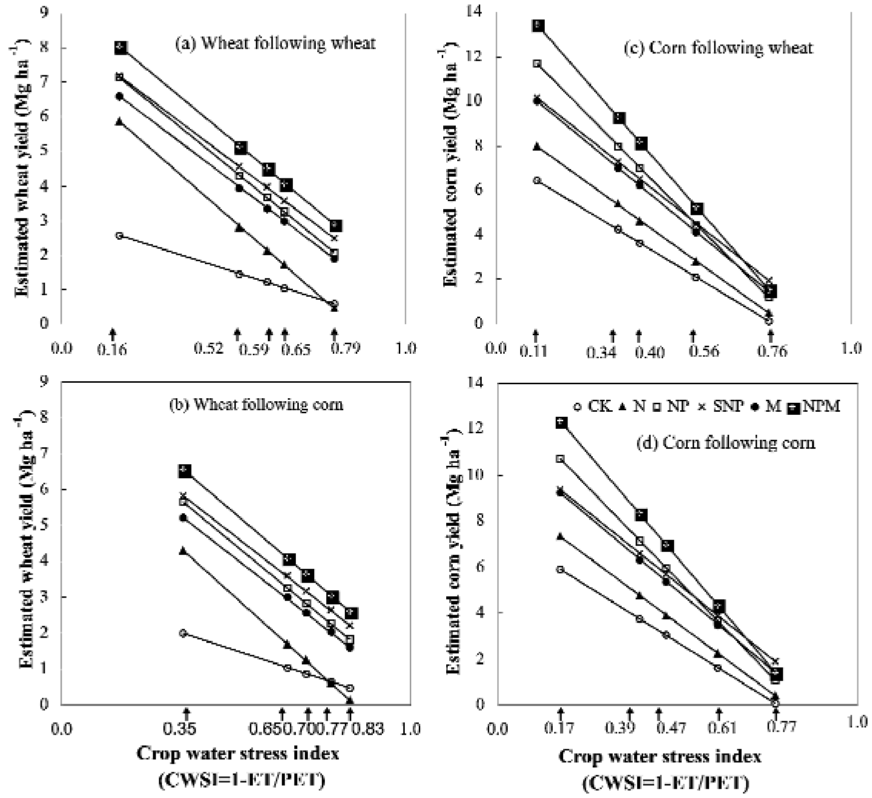

Fig. 4. Estimated grain yield for different cropping systems based on probabilities of crop water stress index (CWSI) and grain yield-CWSI relationships.

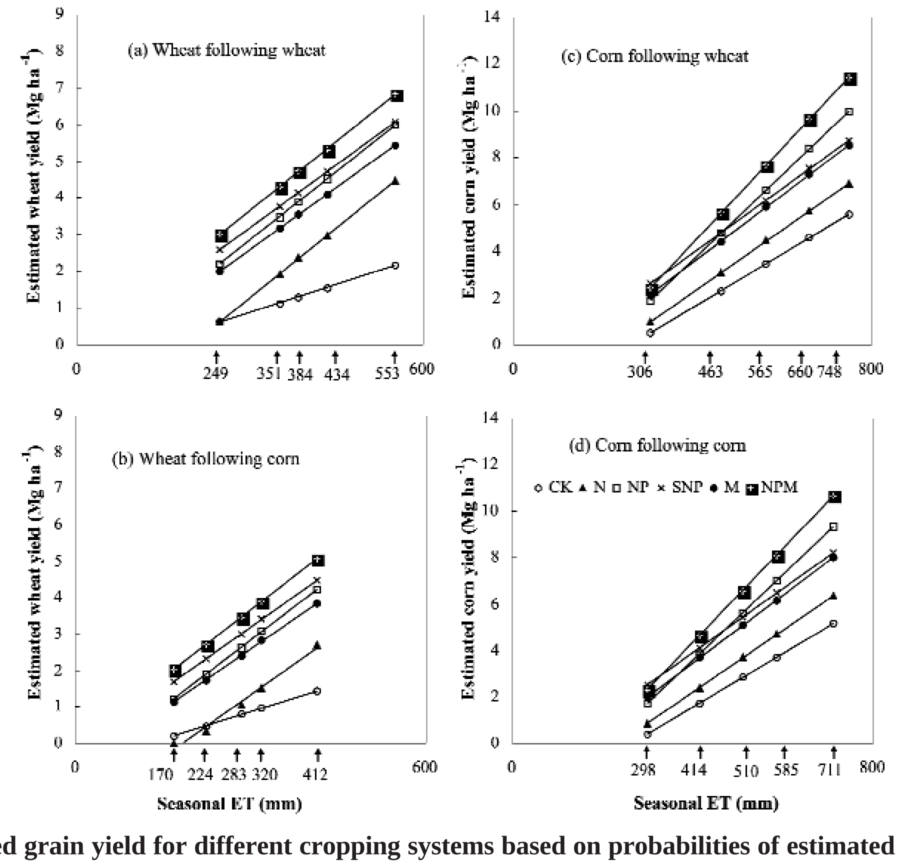

Fig. 5. Estimated grain yield for different cropping systems based on probabilities of estimated seasonal evapotranspiration (ET) and regression function of grain yield to estimated ET.

be 0.59 or less and the estimated grain yield for a control area will be about 1.2 Mg ha^{-1} or more (Fig. 4). In contrast, for an area of high fertility like the NPM plot, the grain yield would be expected to be about 4.5 Mg ha^{-1} or more. For the same treatments, there is a 75% probability that the CWSI will be 0.52 or less and the yield of the control would be about 1.4 Mg ha^{-1} or more, but a high fertility area would likely yield about 5.1 Mg ha^{-1} or more. The lowest wheat yields would be expected when wheat follows corn because there is essentially no fallow period for storing soil water. In that case, there is a 50% probability that the CWSI will be 0.70 and the grain yield of wheat will not be more than about 1 Mg ha^{-1}, but even in this case, a high fertility area would be expected to yield about 3.6 Mg ha^{-1}. This reinforces the need for adequate soil fertility management for reducing risk and maintaining production in dry years. Figure 5 shows similar trends when estimated seasonal ET values are considered rather than CWSI values.

The CWSI values and seasonal ET amounts shown in Figures 4 and 5 were calculated using the 24 years of weather records and the fallow efficiency assumptions discussed earlier. If actual

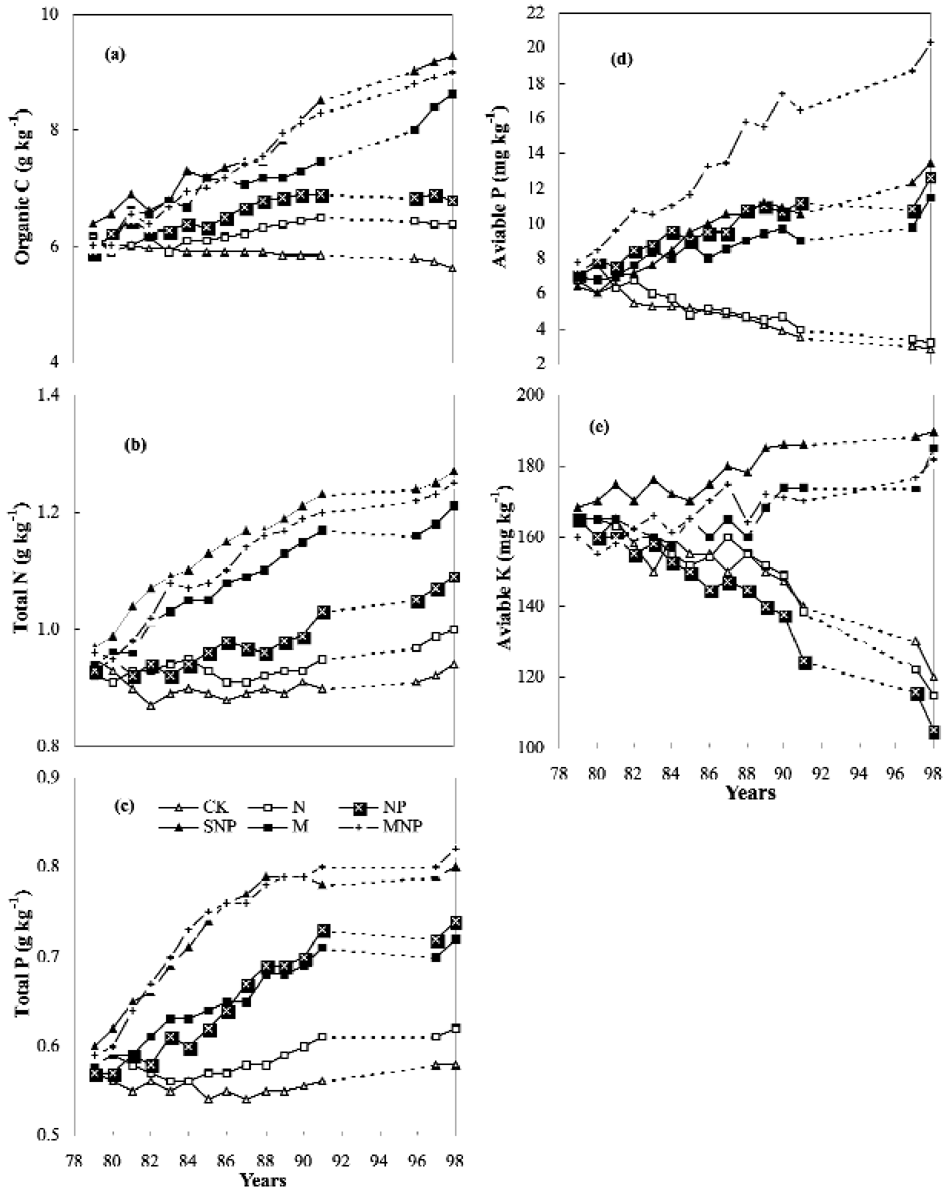

Fig. 6. Trend changes of soil fertility in long-term fertilizers experiment in Pingliang, Gansu, China. Data showed here were continuous from 1979 through 1991 and 1996 through 1998; soil samples for 1992 -1995 were not analyzed (Dashed lines), and total P, available P, and available K for 1996 were not determined except total N and soil organic matter.

plant available soil water amounts at seeding time are known, they should be used along with probabilities of seasonal precipitation to possibly improve the risk assessment.

The results clearly show that wheat following wheat, corn following corn, and corn following wheat are all well adapted systems for the Loess Plateau of China. The risk of low yields when wheat follows corn is considerably greater because of limited stored soil water, but even this sequence is fairly dependable when soil fertility and soil organic matter are maintained at a high level.

Soil organic carbon and total nitrogen

Levels of SOC and soil TN were greatly affected by the various treatments during the study period. From 1979 to 1998, SOC concentrations increased for all treatments except the CK, but the greatest increase occurred for MNP, SNP and M that received organic materials (Fig. 6). Slopes values in Table 4 indicated that 165.0, 157.3, and 118.7 mg C kg^{-1} yr^{-1} were added each year for the MNP, SNP, and M treatments, respectively. The NP and N treatments also increased SOC levels but at much lower rates of 44.3 and 20.9 mg C kg^{-1} yr^{-1}, respectively. SOC decreased in the CK plots at 18.3 mg kg^{-1} yr^{-1}. Taking the soil bulk density as 1.30 Mg m^{-3} in 15 cm-depth, the annual rates of C increase in the three treatments receiving annual organic matter additions compare favorably to values of 0.2 to 0.3 Mg C ha^{-1} yr^{-1} for fertilized maize reported by Lal (2000) for western Nigeria, and 0.31 Mg C ha^{-1} yr^{-1} reported by Jenkinson (1991) for the 157-year study at Rothamsted. In the SNP treatment, this would suggest that about 15% of the total C added was converted into SOC each year. Based on a literature review in semiarid regions, Rasmussen and Collins (1991) concluded that soil organic C levels typically increase at a rate of 10 to 25% of the amount of added C. These findings show that the combination of organic and inorganic fertilization enhanced the accumulation of SOC and maintained the highest productivity and WUE, consistent with many other studies in the world. It was deduced that SOC amounts increased at a rate of about 0.30 Mg ha^{-1} yr^{-1} when the manure or straw was added to the soil in combination with NP fertilization. At this rate, the SOM amounts of the surface 15 cm of soil can be increased about 0.4% in 25 years.

Similarly, TN concentrations increased over the life of the study except in the CK treatment, in which it remained fairly stable. Slopes (Table 4) ranged from 3.6 mg kg^{-1} yr^{-1} for the N only treatment to 15.6 mg kg^{-1} yr^{-1} for the MNP treatment. N accumulation was higher when manure or straw was added along with NP fertilizers. This may have been partially due to a slow release of N from manure and straw, resulting in smaller losses of N as suggested by Bhandari et al. (2002). In addition, the MNP and SNP treatments produced higher amounts of crop biomass and therefore might have had more extensive root systems that may result in increased N levels. The consistent SOC and TN trends illustrate the importance of long-term additions of organic materials to soil for maintaining SOC and sustaining land productivity.

Table 4. Slopes of the linear regression vs. time for each soil property, significance of soil properties change *(P*>t values) in a long-term rainfed fertilization (1979-2002) experiment in Pingliang, Gansu, China.

Treatments		Soil properties†				
		SOC	TN	TP	AP	AK
Control	Slope (mg kg^{-1} yr^{-1})	-18.3	0.7	0.6	-0.20	-2.06
	P value	< 0.001	0.519	0.354	< 0.001	< 0.001
N	Slope (mg kg-1 yr-1)	20.9	3.6	1.9	-0.22	-2.44
	P value	0.006	< 0.001	0.013	< 0.001	< 0.001
NP	Slope (mg kg-1 yr-1)	44.3	8.41	0.1	0.25	-2.95
	P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SNP	Slope (mg kg-1 yr-1)	157.3	14.6	10.4	0.38	1.18
	P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
M	Slope (mg kg-1 yr-1)	118.7	13.5	7.5	0.19	0.98
	P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
NPM	Slope (mg kg-1 yr-1)	165.0	15.6	11.6	0.67	1.18
	P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

† SOC, soil organic C; TN, Total N; TP, Total P; AP, Available P; AK, Available K.

Wheat yields for the NP, MNP, and SNP treatments for different years were analyzed in relation to estimated seasonal ET (mm) and SOM (Mg ha-1 to 15 cm-depth based on soil bulk density of 1.30 Mg m^{-3}) to gain some insight regarding the effect of SOM. All of the selected treatments received the same amount of NP fertilizer but the SOM was considerably higher in the MNP and SNP plots than in the NP plots (Fig. 6). Grain yield (Mg ha^{-1}) was related to estimated ET and SOM as follows:

$$Yw = -1.538 + 0.0124ET + 0.0429SOM$$

(R^2=0.77, n = 30, P < 0.001)

where *Yw* = grain yield of wheat, *ET* = mm seasonal evapotranspiration, and SOM = %SOC× 1.724. The ET coefficient 1.24 kg m^{-3} is similar to values found by Musick et al. (1994). The SOM contribution of 42.9 kg ha^{-1} is, however, larger than the 15.6 kg ha^{-1} that Bauer and Black (1994) found for Typic Agriborlls in the US, but similar to the 40.7 kg ha^{-1} reported by Martin et al. (1999) in the semi-arid Argentine Pampas. The increased grain yield with increasing SOM in this study is perhaps a combination of increased soil fertility and of increased soil physical properties that improved WUE. This would imply that a decline in SOM will result in decreased yields as a consequence of both loss of fertility and decreased soil water holding capacity that, in turn, reduce water availability to plants.

It was hypothesized that perhaps the grain yields and WUEs of the MNP treatments would increase with time as SOM increased, but this could not be detected. Although the causes of yield decline are not separated from weather effect and SOM increase, gradual increase of water stress might be a major reason, and low input of N and declining soil fertility should be of much concern. As discussed earlier, about 130 kg N ha^{-1} that included only 90 kg N ha^{-1} with chemical fertilizer and the remaining 40 kg from manure was usually adequate for wheat but may have been deficient for corn, particularly in years receiving normal or higher precipitation. Currently recommended N levels are 145 kg N ha^{-1} for wheat and 180 kg N ha-1 for corn in the study region.

Total phosphorus and available phosphorous

Soil TP increased significantly with lapse of time for all treatments except the CK, in which no change was noticed (Fig. 6 and Table 4). There were large differences, however, among the treatments. Great gains occurred for the treatments receiving manure or combinations of NP and organic materials, but little increase was noticed for the N treatment (Table 4). Slopes of the trend lines for soil AP (Table 4) indicated decline of about 0.20 mg kg^{-1} yr^{-1} for the CK and N only treatments, but an increase of 0.19, 0.25, 0.38, and 0.67 for the M, NP, SNP, and MNP treatments, respectively. In 1998, the 20th year of the study, the AP in the NPM treatment was 189% of that in the M treatment. This shows that inputs of P with manure combined with inorganic fertilizer exceeded plant needs and resulted in a substantial build-up AP. As estimated earlier, about 200 kg P ha^{-1} was applied annually as part of the manure.

Available potassium

In contrast to soil AP, soil AK showed significant yearly declines from the beginning level of 160 mg kg^{-1} for treatments that did not receive manure or straw (Fig. 6). Trend lines for AK (Table 4) showed yearly decline rates of 2.06, 2.44, and 2.95 mg kg^{-1} yr^{-1} for the CK, N, and NP treatments, respectively. This is contrary to the general belief that most soils of the Loess Plateau in China and of the alluvial floodplain in Asia are high in K and that K is a rare limiting factor (Su, 2001; Bajwa, 1994). However, Liu et al. (2000) and Liu and Yao (2003) also showed similar declines in northwest China. In contrast, AK levels increased with time at rates ranging from 0.98 to 1.18 mg kg^{-1} yr^{-1} for plots receiving manure or straw. This demonstrates that inputs of K with organic materials resulted in a build-up of soil AK because manure and straw contained high amounts of K. This study clearly showed that high levels of production resulting from the use of inorganic N and P fertilizers and removal of aboveground biomass greatly reduced the level of AK. The extent of K deficiency in this study, if any, is not clear although grain yields of the SNP treatment were significantly higher than the NP treatment, particularly in the latter years when the AK levels were greatly reduced. Potassium could possibly have become limiting in the NP treatment, but there is no data available to support this conjecture. Soil available K decline without straw or manure in this study indicates that AK should also be paid great attention in the intensive annual cropping system of wheat and corn in Loess Plateau. For long, farmers in this region have rarely applied K, and they are not aware of soil K deficiency when high amounts of NP fertilizer are added to improve grain yield.

Conclusions

The objectives of this study were to follow grain yield and WUE trends for wheat and corn in annual cropping systems under a 24-year dryland fertilization experiment, and to monitor long-term effects of fertilization on soil properties. Results showed that the addition of organic materials and inorganic fertilizers significantly enhanced grain yields, water use, and soil chemical properties as compared to no addition of these or addition only of inorganic nitrogen and phosphorus. Overall, the grain yields and WUEs for both wheat and corn crops showed downward trends over the study period, with the exception of MNP and CK treatments for wheat. The decline in corn was relatively higher than in wheat.

Unlike grain yield, soil nutrients showed a gradual build-up of SOC, TN, and TP in all treatments except the CK plots and the plots receiving only inorganic fertilizers with lapse of time. A gradual decline of available nutrients would certainly explain a decline in grain yields with increasing years, but this is inconsistent with the build up of SOM and the macronutrients N and P in the M, NP, SNP, and MNP. This might be linked to gradual increase in dry weather as well as its interaction with soil factors. Nonetheless, results indicate that adding only N or NP fertilizers may result in a deficiency of other nutrients and a decline in soil chemical properties, and that addition of organic materials along with inorganic fertilizers is necessary for sustainable production.

The study underpins the importance of returning straw to the soil, or adding manure in cases straw is removed. Particularly, returning straws to the soil should be recommended to farmers of this dryland area as this will help them to have better land use with minimized costs of production. The farmers of this area should be encouraged to manage the nutrients and soil fertility based on a balanced approach and organic materials should be combined with inorganic fertilizers to increase crop productivity and agricultural sustainability. More importantly, considering the results of this long-term experiment, researchers and farmers and government should come together in research, extension, evaluation, and dissemination of technologies to fully meet the objectives of regional development. Activities like regular meetings, lectures, and field days, a feedback information system between scientists and farmers should be developed to let farmers have access to the most appropriate and cost-effective technologies for the nutrient and soil fertility management in their specific situations.

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Role of improved production technology in wheat self-sufficiency in Iran

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Abstract

Wheat is the major crop in the Islamic Republic of Iran. It is grown on 6.4 million hectares, and 63% of this area is rainfed. ICARDA and DARI scientists, working together, identified in 1995 several production problems that affected wheat yields in the dry areas of Iran. The most important of these included the widespread use of local varieties having low yield potential, and a lack of appropriate soil and crop management practices. Researchers recommended the use of improved wheat varieties along with such improved production technologies as early tillage, good seed bed preparation, early drill planting, fertilizer placement, and proper weed control for large scale adoption by farmers. Joint participation of extension agents and farmers as one team was essential for achieving this through method demonstration where farmers compared on their own fields their own method with the improved technological package recommended by researchers for dry areas. There were only 4000 ha covered with improved technology in the 2001-2002 growing season. In the 2002-2003 season, the area increased to 85,000 ha, and in the 2003-2004 growing season, the coverage was over 500,000 ha. On-farm results showed a 53% increase in wheat yield compared to yields of neighboring farmers using their own technology in 2001-2002, 60% in, and 65% in 2003-2004. Wheat production in Iran reached the self-sufficiency level during the 2003-2004 season for the first time in over 40 years. The results testify the successful adoption of effective soil and crop management practices combined with improved cultivars. The participation of farmers, researchers, and extension workers in the testing, demonstration and dissemination of improved technologies led to better awareness of the technology and its adoption by a large number of farmers. This will ensure a sustainable increase in wheat productivity in the rainfed areas of Iran.

Introduction

The farming system in the dryland areas in the Islamic Republic of Iran is based on cereals (wheat and barley) and several food and feed legumes (chickpea, lentil, and some forage crops) (Table 1). The most important production constraint of rainfed farming in Iran is the shortage of water. Average annual precipitation of the country is about 250 mm, with erratic distribution; early-season and terminal droughts are of common occurrence. The extremes of temperature are the second major constraint. The temperature varies from - 35°C (absolute minimum value) in high altitudes to 54°C (absolute maximum value) in littoral zones. Pest and diseases are also important factors constraining crop productivity in the rainfed areas. Lack of dissemination of information on improved varieties and efficient practices for soil and water conservation, fertilizer use and weed control, and lack of availability of adapted machinery and seeds of improved varieties to the farmers, have jointly contributed to severely hamper crop productivity in rainfed areas. Agricultural output is therefore unstable and usually low. Land degradation and frequent occurrence of drought in the recent years have further aggravated the problem.

Dryland farmers are generally poor. Irregular rainfall on poorly-vegetated hill slopes results in severe soil erosion, downstream flooding and sedimentation. The major causes for land degradation are untimely and overgrazing of rangelands, conversion of traditional rangelands to rainfed agriculture, ploughing the lands along the slope, especially on

Table 1. Area and productivity of major crops in Iran (2003).

Crops	Area (10^6 ha)		Yield (kg/ha)	
	Irrigated	**Rainfed**	**Irrgigated**	**Rainfed**
Wheat	2.39	4.01	4878	1181
Barley	0.62	0.89	3229	1017
Chickpea	0.02	0.62	1074	434
Lentil	0.01	0.21	1094	484
Oilseed crops	0.16	0.09	1740	1366
Forage crops	0.69	0.10	13430	6975

steep slopes, and irrigation on sloping lands. They are all contributing to the degradation of the resource base and increasing relative poverty of the rural communities. A high migration of people from rural to urban areas is creating social problem.

Wheat is the most important cereal crop in Iran, with a total area of 6.4 million hectares. Irrigated wheat covers one-third of the total wheat area in the country, but accounts for more than two-thirds of the total wheat production. Despite irrigation, average yield remains low because of diseases and insect pests, persistent droughts, excessive cold in the mountainous areas, high temperatures during the late spring in the other areas, and poor agronomic practices. Complex interaction between them and the deficient moisture in the dry areas affects plant growth. The results of previous researches demonstrate that temperature and moisture are serious stress factors because of unpredictable variability from location to location and year to year (Ortiz-Ferrara, 1987).

During last two decades the national researchers in Iran, particularly those at the Dryland Agricultural Research Institute (DARI), and colleagues from ICARDA have carried out joint research projects in different agro-ecological zones to develop appropriate technology for dry areas. Work of Jam-e-Jam (1994) showed no significant differences among various techniques of tillage in fall (sub soiling, chisel plowing, and no tillage) in moisture conservation in 0-15, 15-30 and 30-60 cm soil depths during the fallow year. However, significant differences were found between various first spring tillage practices on moisture conservation. Mould board plowing provided higher moisture conservation in different depths than ducks foot cultivator. Chemical weed control provided significantly higher moisture conservation than use of ducks foot as second spring tillage to control weeds. Although tillage treatments during fallow affected soil moisture conservation, they had no effect on seed germination of wheat in the following year. Therefore, no significant differences were found in wheat yields (Jam-e-Jam, 1994). This was because of the tillage application in early spring given during the wheat season. The early tillage by any implement improved yield as compared to the late (June) tillage, which is a common practice applied by most of farmers.

Nadermahmoudi (1996) compared three sowing dates (2nd and 3rd week of October and 1st week of November) and four planting methods (Hasia, John shearer, John Deer, modified John Deer planters) for wheat. Based on results of three years, there was no significant difference in sowing between second and third week of October, but the October seeding gave significantly higher yield than the first week of November. Also highly significant effects were observed for interaction of sowing dates and planting methods. Sowing in 2nd week of October with modified John Deer drill resulted in the highest yield among all the treatment combinations.

At the DARI station in Maragheh, the highest grain yield of rainfed wheat (1100 kg/ha) was harvested on a land where pre-sowing tillage involved chisel plus disk harrow and planting was done with drill. The lowest yield (615 kg/ha) was obtained from the practice where the seeds were first broadcast on the surface and then mixed by running a disk-harrow, which again is the technique commonly applied by farmers in the region (Asghari et al., 2004; Hemmat and Eskandari, 2004). Hosainpour (1999) recommended using chisel (15-20 cm depth) in fall and ducks-foot (7-8 cm depth) in spring and summer for plowing the soil in fallow years for land preparation, Hasia (deep planter) for planting method, and a seed rate of 100-120 kg/ha. Thus, the optimal tillage system for wheat production in ‘fallow-wheat’ and ‘chickpea-wheat’ rotations in cold areas was identified (Asghari et al., 2004; Hemmat and Eskandari, 2004).

The purpose of this paper is to explain the methods used in disseminating the recommended technologies to the farmers through method demonstrations involving farmers, extension agents and researchers as one team, and the adoption of the demonstrated technologies over a large area of wheat production in the dryland farming system of Iran.

Material and methods

A farm survey conducted in 1995 in the East-Azarbaijan and Kermanshah provinces revealed several factors that hinder crop productivity in these dryland areas. Farmers were mainly growing local wheat varieties with their own production techniques. This gave low yields because of the lack of tolerance of the varieties to the biotic and abiotic stresses and inadequate moisture conservation. There was, therefore, great scope for testing and subsequently disseminating improved wheat varieties, along with improved technologies, through on-farm verification and demonstration trials.

Following the farm survey, research experiments were designed and conducted on farmers' fields to develop solutions to problems identified. Specific activities included:

- Introduction of improved wheat varieties and testing them on farmers fields;
- On-farm fertilizer trials to identify crop response in different locations and create awareness among policy makers about the need for proper soil fertility management;
- On-farm trial for comparing recommended practice for sowing with traditional farmer practice;
- On-farm evaluation of chemical weed control; and
- On-farm evaluation of the effects of sowing dates, seed rate and weeding on yields.
- Monitoring the perception of farmers regarding the new technologies was also done.

Results

An examination of the farming systems in the surveyed region revealed that 'wheat-fallow' rotation covered majority of the area under rainfed farming (90%) in the colder dryland region (Maragheh-Hashtrood), while 'wheat-chickpea' and 'barley-chickpea' cropping system dominated the rainfed farming in the milder region (Kermanshah). Cereal/livestock integration was important in both regions. Forages were mainly grown under irrigated conditions. Local or the old improved varieties with low yields were generally grown. The seed rate for wheat varied from 75 to 200 kg/ha and lower seed rates were used for chickpea and lentils. Late and infrequent tillage was performed during fallow season in the cold areas. In the moderate rainfall areas 50% of farmers applied only one tillage by moldboard. Seedbed condition was generally improper with big clods on the surface. Planting was done by 60 to 90% farmers by broadcasting seed on uncultivated soil and in 50% of the cases they then covered the seeds by running a moldboard plough. Chickpea, the second important crop after wheat in Kermanshah, was planted mostly in late spring with very low seed rates, which resulted in very low yields. Fertilizers were not available in sufficient quantities although farmers realized well their importance. Weed control was not practiced by about 75% of the farmers.

Farmers listed the lack of fertilizer use, lack of machinery and lack of adequate time for initial tillage as the most important factors, in that order, affecting their production. Also, poor transfer of improved technologies due to an absence of effective research-extension-farmer interaction was identified.

Therefore, on-farm trials were designed in both locations for following purposes:

- Wheat variety demonstrations in farmers' fields,
- Wheat and barley under different seed rates,
- Fertilizer on-farm trials to create awareness among the decision makers,
- Fertilizer trials to identify the crop response in different locations combined with the soil analysis,
- Time and frequency of tillage,
- Sowing methods to compare recommended and farmers practice,
- Chemical weed control vs. weedy check in wheat crop,
- Introduction of forage crops into crop rotation for livestock in the farming systems (for winter and spring sowing in farmers fields), and
- Monitoring of farmers perception of the new technologies and their adoption levels.

The new technology demonstrated was based on the results conducted by researchers at the research stations and the farmers' fields (Anon., 2002-2005) as summarized below:

- Four varieties of bread wheat 'Zagross', 'Azar 2', 'Niknejad', 'Kohdasht' and one durum wheat ('Saimareh') released for commercial cultivation in different ago-ecological regions of the country.
- Soil fertility and fertilizer trials on the main cereal showed that 60 kg N and 30 P was optimum for the improved wheat varieties.
- Micronutrient elements survey showed that applying 20 kg/ha Zn and Mn increased wheat yield in research station and farmers fields.
- A supplemental irrigation of 50 mm in early October highly increased yield of both local and improved wheat varieties.
- In crop rotation trials different crops based on wheat production system were compared with 'fallow-wheat' system, and the 'cereal – legume' rotation was found more productive. Study on forage and oilseed crops in the rotation are under way.
- Suitable modification was made in the drills to place fertilizer about 9 cm below seed, which was found to have significant effect on yield.
- The best seed rate and row spacing were determined and proper seed drills were introduced to farmers.
- Study on pest and diseases for the main crops carried out and different control techniques were applied. Chemical and mechanical weed control systems surveyed and joint experiments by extension service carried out across the provinces.
- In the agro-technique disciple some tillage experiments were carried out for moisture conservation and no-tillage systems, and appropriate techniques were extended to farmers fields.

Initial results were impressive. After seeing the crop productivity in the demonstration farms, farmers started widely adopting the technologies on their own farms. In the 2003/2004 season, the recommended technologies were adopted by wheat farmers on more than 500,000 ha in five provinces. This was a substantial increase from 85,000 ha in the previous season (2002-2003) and 4000 ha in 2001-2002.

On-farm results showed that the wheat grain yield increased by 53% by improved techniques as compared to farmers' own technique in 2001-2002 (1-2.5 t/ha in traditional farming and 2-4 t/ha with improved technology), 60% in 2002-2003, and 65% in 2003-2004 (Table 2). Similar results were observed for other crops, including chickpea, lentil, oilseed crops and barley in this region and other provinces. The participation of farmers, researchers, and extension workers in the testing, demonstration and dissemination of improved technologies led to better awareness of the technology and to its adoption by a large number of farmers.

Discussion and conclusion

The reform of the agricultural price policy for inputs and outputs during last 5 years, has contributed to encouraging farmers to adopt new agricultural technologies relevant to main crops. Therefore, policy makers and planners have

Table 2. Effects of improved practices on wheat yield (t/ha) in large-scale demonstrations on farmers fields in different provinces

	East Azarbaijan	**Kohgiloieh va Boir Ahmad**	**Kordestan**	**Lorestan**	**Kermanshah**
2001-2002					
Recommended	1.91	2.43	1.11	-	2.72
Farmers' practice	1.19	1.35	0.90	-	1.87
Difference (%)	60	80	23	-	46
2002-2003					
Recommended	3.22	3.18	1.69	1.61	2.00
Farmers' practice	1.80	1.73	1.33	1.24	1.50
Difference (%)	79	83	27	30	33
2003-2004					
Recommended	3.65	3.47	1.95	2.35	2.20
Farmers' practice	2.15	1.90	1.24	1.45	1.50
Difference (%)	70	83	57	62	47

achieved their goal of having farmers adopt modern technologies for wheat and other main crops. Using high-yielding varieties, chemical fertilizers, pesticides to control weeds, insect pest, and diseases, good agronomic practices for moisture conservation, seedbed preparation and time and method of sowing, and with enough rain during crop season the farmers in Iran produced wheat in quantities that exceeded the domestic demand for the first time since 1960. Not only wheat production increased from 9.46 million tones in 2001 to 14 million tones (48% increase) in 2004 but also the production of other main crops increased in this period including maize from 1.06 to 2 million tones (89% increase), colza from 30.3 to 115 thousand tones (280%increase), and sugar from 837 to 1350 thousand tones (61% increase).

The dryland areas are playing an important role in Iran's economy and hold tremendous potential for increasing agricultural production. With the adoption of new technologies the production of most crops can be doubled. Appropriate technologies will help in sustainable agricultural production and restrict environmental degradation. Drought effect should be mitigated for the future through appropriate forecasting methods and management measures. Optimal use of rainfed areas and expansion of supplementary irrigation techniques, where water is available, would help in increasing yields in many dry areas.

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Breeding for cold tolerance in wheat and barley in cold areas of Iran

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Abstract

Cold stress is a major factor limiting wheat and barley survival in cold high altitude areas of Iran. Identification of sources of genetic variability, using appropriate methods of evaluation based on a clear understanding of the mechanisms involved in the survival of winter cereals in cold stress, is imprtant in crop improvement program for these regions. This paper reports on the cold tolerance potential and vernalization and photoperiodic requirements of Iranian and introduced drylands/irrigated wheat and barley genotypes that were screened under field and controlled conditions for adaptation to cold stress. Morphological and physiological criteria useful in selecting cold tolerant wheat and barley genotypes and the role of transition from the vegetative to the reproductive phase, which is regulated by developmental genes such as photoperiod and vernalization, are discussed. Measurement of LT_{50} proved to be the most precise method of predicting cold tolerance but it requires the use of homogeneous population for a series of tests involving different temperatures and stage of growth. There was a close link between the up-regulation of cold tolerance genes and vernalization and photoperiodic requirements in cereals. Suggestions are made on the breeding strategies for improvement of cold tolerance in cereals in the regions with long mild winters like those normally experienced in the cold regions of Iran.

Introduction

Low temperature (LT) stress is one of the primary environmental factors limiting the expansion of wheat and barley production in many regions of the world. In Iran, the areas prone to LT stress are estimated to be covering about 3.7 million ha, of which 2.8 million ha are under winter cereals. The cereal yields are low often due to cold damage. To cope with LT stress, winter cereals have developed adaptive mechanisms such as vernalization and photoperiodic requirements that allow them to respond to seasonal changes and acquire protection from winter damage. Research has shown that vernalization and photoperiodic requirements allow cold tolerance genes to be expressed for a longer period of time at temperatures in the LT acclimation range under controlled conditions (Fowler et al., 1996; Mahfoozi et al., 2001). Successful plant breeding for winter crop production requires an understanding of plant development, growth cycles and the mechanisms used to survive periods of cold stress. An understanding of how plants respond to cold stress at different growth stages can also assist in the assessment of crop condition and production potential throughout the growing season.

Using the most appropriate methods for identifying superior individuals is crucial for implementing a successful breeding program for cold tolerance. The availability of genetic variability for the character under consideration along with the application of typical stress periods is also critical for the efficiency of breeding for cold tolerance. Under natural conditions, a lack of opportunity to replicate experiments over time has restricted cereal breeders in their efforts to produce and select winter-hardy genotypes, particularly in high stress regions. To overcome these problems, efforts have been made to develop tests under artificial conditions that simulate natural stress conditions. The limitations inherent in field survival trials have also encouraged researchers to search for rapid, more efficient methods for predicting low-temperature tolerance of genotypes.

Ideally, an efficient cold tolerance test should be simple, rapid, repeatable and non-destructive. It should also provide an accurate and precise measure of cold hardiness potential on single plants. The limited resolution of differences in cold tolerance between field and controlled freeze test that employs a single minimum stress level is partially responsible for some of the contradictory conclusions reported for genetic studies. However, a series of test temperatures that identifies the LT_{50} (temperature at which 50% of the plants are killed by cold stress) of each population reduces the likelihood of errors compared to other freezing tests (Fowler et al., 1999).

Many changes occur in morphological, biochemical, and physiological characters during cold acclimation periods. Attempts to associate morphological and cytological characters related to cold tolerance in wheat and barley have led to contradictory results. Levitt (1956) reviewed some studies and found no relation between plant structure and cold tolerance. Limin and Fowler (2000) reported that at 4°C, short narrow leaves and small-size guard cells were the best indicators of cold tolerance and allow the selection of very cold-hardy winter wheat genotypes for regions with high level of cold stress. Prostrate growth habit was also reported as a good indictor of cold tolerance. However, the application of these characters for selecting a genotype with medium level of cold tolerance in temperate regions with mild and long winters has not been reported. The objectives of this paper are to discuss breeding for cold tolerance and developmental regulation of cold tolerance under field and controlled conditions in low cold-stress region, characterize the existing genetic variability in the gene pool of wheat and barley, and identify appropriate method for selecting superior genotypes in breeding populations using controlled freeze test and plant characters associated with cold tolerance in both low and high stress regions.

Materials and methods

Controlled freeze test, cold tolerance potential, genetic variability and association of plant characters with cold tolerance

Irrigated wheat genotypes: A trial composed of 64 bread wheat genotypes with diverse origin (Russia, USA, Canada, CIMMYT, ICARDA, Europe and Iran) was conducted at the Seed and Plant Improvement Institute (SPII) station in Karaj, Iran, under irrigated conditions, using Alpha Lattice desigh with two replications. Cold tolerance, as measured by $LT_{50,}$ was determined for 6-7 weeks cold acclimated crowns of plants grown in the field in the fall and winter of 2004-05 season. Leaf characters (length, width and area), guard cell length, plant erectness, days to heading, and days to anthesis were recorded to determine the association of these characters with cold tolerance and the differences in response between Iranian and introduced wheat varieties. The third leaf from the bottom of the plants grown at 20°C in green house was measured for morphological characters. Leaf length was measured from the auricle to the leaf tip. Leaf width and guard cell size were measured along the midpoint of the leaf where the width was constant. Leaf area was measured by leaf area meter on both third and flag leaves of the plants grown under both controlled and field conditions. Guardcell size at 20°C was based on the average length of 20 guard cell pairs from epidermal peals of the underside of each leaf (Limin and Fowler, 2000).

Dryland wheat and barley genotypes: Two trials using Randomized Complete Block design with three replications were conducted in Maragheh station of the Dryland Agricultural Research Center (DARI), during 2002-03 season under rainfed conditions, one including 40 wheat genotypes (32 bread wheat and 8 durum wheat lines) and the other including 54 barley genotypes. LT_{50} was measured for 5-6 weeks cold-acclimated crowns of plants grown in the field.

Fifteen spring and winter barley genotypes of diverse origin with different potential of cold tolerance, grown at Maragheh and Arak agricultural research stations in 2003-04 season, were also analysed to determine the association between field survival percentage (FS%), LT_{50}, plant erectness, number of tillers, leaf characters (length, width and area), guard cell length, crown water content, days to heading, and time of double ridge formation.

Developmental regulation of cold tolerance

Phenological development and cold tolerance were determined for ‘Dobrinya’ winter barley (long vernalization requirement), 'Dicktoo' spring barley (very short-day sensitive) and 'Rihane-03' spring barley (short-day insensitive cultivar), and for wheat cultivars 'Sardari' (local facultative wheat commonly grown in cold dry areas of Iran), 'Azar2' (improved winter wheat grown in cold dry areas of Iran), 'Kohdasht' (spring wheat with no vernalization requirements grown in dry warm regions) and 'Norstar' (a long vernalization-requirement cold-hardy winter wheat from Canada), which were planted on 7 October 2002 and 12 October 2003 at Maragheh research station (37°15'N, 46°15'E; 1720 m) of DARI, Iran. Expected day lengths (sunrise to sunset) for this location were determined using the online services (http://www.cavu.com/sunsetexp.html) provided by Fly-By-Day Consulting, Inc. Soil temperatures at 5 cm depth and air temperatures (maximum and minimum) at shelter height were recorded from 1 September to 31 March using an on-location weather station. Plants for double ridge (DR) analysis and LT_{50} measurments were grown in the soil in the field and plants for final leaf number (FLN) determination were grown in pots (two plants per pot) that were placed in the same field at the same time as the trials for DR analyses and LT_{50} determination were sown. Plants of each cultivar were sampled between 4 November and 12 February in the 2002-03 season and 7 November and 14 February in the 2003-04 season to determine the stage of phenological development and the LT tolerance.

Two methods were used to determine the stage of phenological development: (1) dissection of the plant crown to reveal the shoot apex development and (2) the FLN procedure described by Mahfoozi et al. (2001). Shoot apices of plants taken from the field were dissected and photographed at each sampling date to determine the stage of development and identify when the DR stage had been reached. For determination of FLN, at each sampling date one pot from each replicate was moved into a glasshouse at 20°C and a 16 h day length starting 7 October (planting date) and then on each of the subsequent sampling dates in the 2002-03 trial. A similar procedure was followed starting 12 October (planting date) in the 2003-04 trial except that the plants were moved into a glasshouse at 20°C and a 12h day length, which was similar to the day length in the field at the start of the experiment. The leaves on the main stem of each plant were numbered until the flag leaf emerged. Transition from the vegetative to the reproductive stage was considered complete when the FLN for consecutive sampling dates became constant (Delecolle et al., 1989; Mahfoozi et al., 2001). For the FLN trial, that included three genotypes and eight sampling dates, a factorial Randomized Complete Block design with two replicates was used in both years. The trial for the determination of cold tolerance curves of barley genotypes, that included three genotypes and 11 sampling dates, was conducted in a Randomized Complete Block Factorial design with two replicates in both 2002-03 and 2003-04 seasons. The procedure outlined by Brule-Babel and Fowler (1988) was followed to determine the LT50 for plants collected from the field at each sampling date starting 27 October 2002 and 8 November 2003, in the two seasons. The determination of LT_{50} for wheat was done using four bread wheat varieties and 13 sampling dates in a trial conducted in Randomized Complete Block design with two replications in the 2002-03 season, and four genotypes and 12 sampling dates using the same design in the 2003-04 season.

Results and discussion

Controlled–freeze test and identification of sources of cold tolerance

Measurements of LT_{50} of wheat and barley genotypes grown and acclimated under natural conditions in cold and dry land areas of north-west of Iran during 2002-03 showed that among all the tested wheat genotypes the most LT tolerant cultivar was Norstar winter wheat from Canada with LT_{50} of about –25°C. Generally, Canadian cultivars had the greatest cold tolerance with average LT_{50} of about -23°C, followed by Iranian winter bread wheat cultivars which had intermediate levels of cold tolerance with average LT_{50} between –14°C and -17°C. Durum wheat varieties had the lowest levels of cold tolerance with LT_{50} ranging from -10°C to -14°C.

In the barley experiment, the maximum level of cold tolerance (LT_{50} of -15°C) was obtained from Kold and Dobrinya winter barley cultivars originating from USA and Russia, respectively. Winter barley lines from Nebraska and Dicktoo, a very short-day sensitive barley, also had a high level of cold tolerance among the tested genotypes. Barley genotypes selected from ICARDA showed lower cold tolerance with LT_{50} values of less than –12°C, while the Iranian lines derived from crosses between Iranian and foreign genotypes and newly selected from the Seed and Plant Improvement Institute (SPII) nurseries acclimated to a colder temperature had an average LT_{50} of about -12°C.

Comparative cold tolerance potential of irrigated Iranian and introduced bread wheat genotypes grown and acclimated under field conditions at SPII, Karaj (with mild winter) during 2004/2005 showed that Canadian and Russian winter bread wheat cultivars had the greatest cold tolerance with the LT_{50} ranging from -18 to - 20°C. Iranian winter bread wheat cultivars and winter wheat lines selected from ICARDA had intermediate levels of cold tolerance with LT_{50} of between -14°C and -16°C, similar to European cultivars such as 'Gaspard' and 'Gascogne'. Wheat cultivars originating from Hungary such as 'MV17,' which has been released at the Marton Vasar Institute, were slightly more cold tolerant than the Iranian and west European cultivars. True spring wheat cultivars selected from CIMMYT, ICARDA and the national breeding program had low levels of cold tolerance with an average LT_{50} of about - 8°C. The LT_{50} of facultative irrigated wheat cultivars did not exceed -12°C. The cold-tolerant parental material identified in these studies will be used in breeding programs for improvement of cold tolerance in cereals. These results demonstrate that the cold tolerance potential of a genotype depends on the adaptability of the genotype to the environment for which it was selected or in which it has evolved.

In LT_{50} method, rate of freezing must be consistent and thawing and recovery conditions must reflect, as much as possible, the conditions that the plant will experience in nature for this controlled-freeze tests to have predictive value. A series of test temperatures that establish the LT_{50} of populations reduces the difficulties associated with identifying critical selection temperatures. Measures of LT_{50} provide the highest precision and heritability of all cold tolerance prediction tests, but they require a sample of plants from a homogeneous population that can be tested using a series of test temperatures or times. This restricts the use of LT_{50} measurements to pure lines and limits its usefulness in plant breeding programs that are normally dealing with segregating populations. Increased availability of practical methods for doubled haploid production and asexual propagation, which provide means for quickly producing homogeneous populations, would expand the opportunities to use LT_{50} estimates for selection in plant breeding programs. This method is also helpful in the selection of parental material and in the characterization of advanced selected lines.

Morphological, agronomic, and phenological characters associated with cold tolerance

Sixty four wheat cultivars of diverse origins were analyzed to determine the association among guardcell length, leaf length and width, and flag leaf area, days to heading and their associations with cold tolerance in irrigated wheat genotypes. Measurments were made on plants grown in a greenhouse at 20°C. Days to heading and LT_{50} were recorded on plants grown and acclimated in the field conditions. All leaf characters, including guardcell size were highly correlated with cold tolerance and with each other. The very cold tolerant cultivars from Russia and Canada had the short narrow leaves and the smallest guardcell size. Days to heading seperated cultivars into three groups -- early, medium and late heading cultivars. Late-heading and LT tolerance of wheat genotpes was highly correlated.

In barley experiment, fifteen spring and winter barley genotypes of diverse origin with different potential of cold tolerance were analysed to determine the association among field survival percentage (FS%), LT_{50}, plant erectness, number of tillers, leaf characters (length, width and area), guard cell length, days to heading and time of double ridge formation and their association with cold tolerance. Results showed that differences among cold acclimated genotypes were highly significant ($P <0.01$) for FS%, LT50, plant erectness, width and length of leaves no.2 and 3. Estimates of crown LT_{50} gave the highest correlation with FS% and had the smallest relative experimental error and it appeared to be an appropriate screening method for cold tolerance. Analysis of principal components showed that characters such as plant erectness, small leaf length, and small guard cell size were good indicators of cold tolerance in barley. Phenological characters, such as time of double ridge, were also a good indicator of winter hardiness. Spring barley genotypes that enter reproductive phase shortly after planting were not winter hardy, while genotypes that enter reproductive phase very late after planting including winter types were cold tolerant.

Many changes that occur in morphological, biochemical, and physiological characters during low-temperature acclimation in winter cereals provide fertile ground in the search for prediction tests and differences in several characters, such as plant erectness, leaf length and width, cell size, days to anthesis, etc., which are highly correlated with cold tolerance. The use of these characters for screening for cold tolerance satisfies many of the selection criteria in breeding program for cold regions.

Breeding and developmental regulation of cold tolerance

Winter cereals grown under field and controlled conditions in cold regions of Iran reached their maximum cold tolerance about the same time as their vernalization saturation occurred. Delay in transition from the vegetative to the reproductive stages, which was regulated by vernalization response, allowed expression of cold tolerance for a longer time. However, spring cereals without any vernalization requirement reached their reproductive phase shortly after planting; thus, had a limited ability to acclimate to low temperatures. Their maximum cold tolerance was achieved soon after plant establishment and they quickly lost most of their cold tolerance. However, the short-day sensitive spring cereals that were planted in the fall acclimated to a colder temperature and in some instances achieved LT_{50} similar to winter cereals with intermediate cold-hardiness potentials. The higher level and longer duration of the expression of cold tolerance of short-day spring cereals were the result of an extended vegetative period that delayed the transition to the reproductive phase.

These results demonstrate the strong evidence of close links between the up-regulation of cold-tolerance genes and vernalization and photoperiod requirements in cereals. For example, cereals with vernalization requirements or short-day photoperiodic sensitivity acclimate upon exposure to low-temperature until the point of transition to the reproductive stage after which there is a loss in cold tolerance (Mahfoozi et al., 2000; 2001). Consequently, the point of transition to the reproductive stage is pivotal in the expression of cold tolerance genes. This interaction also makes all cold-tolerance associated characters or genes appear to be associated with developmental genes (Fowler et al. 1999; Mahfoozi et al., 2001) and explain the pleiotropic effects (growth habit and cold tolerance) attributed to developmental genes like *vrn-A1* in wheat (Brule-Babel and Fowler 1988; Sutka and Snape 1989; Roberts 1990).

A sudden drop of temperature in late winter and early spring of 2005 in north-east Iran caused severe freezing injuries on wheat cultivars that were in the advanced reproductive stage. Severe injuries were observed in the cultivars that had entered a more advanced reproductive stage. These observations and the results of this study support the idea of the linkage of cold tolerance expression with phenological development that adapts the plant to the environment where it was selected. For example, a high level of cold tolerance is no longer required after the onset of warm conditions in the spring when rapid growth and reproduction begin. Consequently, vegetative to reproductive stage transition results in a decline in cold tolerance of over-wintering plants. In fact, for species adapted to regions with long and mild winters, a high level of freezing tolerance is often less important than a rigorous photoperiod, dormancy, or vernalization requirement that prevents plants from entering the extremely cold-sensitive reproductive growth stage until the risk of cold damage has passed. Consequently, the evolution of, and selection for, genetic options that permit extensive modification of thermosensitive metabolic processes and critical structural components should not come as a surprise, especially in winter annual and perennial plants that must adapt to a wide range of seasonal challenges. This genetic system and its regulation and complex interaction with the environment make breeding for cold tolerance a continuing challenge.

The ability to acclimate or avoid cold stress varies among species and stages of crop growth. As a consequence, each plant-breeding situation is unique and it is impossible to design a single approach that will satisfy the requirements of all cold tolerance breeding programs. For example, the criteria used to select for cold tolerance are different for actively growing plants that must survive short periods of late spring frost compared to plants that must withstand exposure to long periods of below freezing winter temperatures. Plant breeders need to have a thorough understanding of the cold tolerance problems they are facing.

Addressing critical stress periods under selection, cold tolerance/avoidance mechanisms, climatic conditions, and appropriate methods for identifying superior genotypes and availability of genetic resources are the basic needs for breeders to ensure the effectiveness of breeding program. It will be highly rewarding to use landraces and wild relatives, which have evolved under typical cold stress, as parental material for germplasm enhancement and variety development activities. The cold tolerance during early stages should be combined with cold tolerance at the reproductive stages if cold stress spells are frequent after winter seasons. Genotypes adapted to cold areas should have an extended vegetative period with a quick grain filling period to avoid the effects of late drought or high temperatures often experienced in most of the winter cereal growing areas of Iran and the Central and West Asia region. Thus, the results of this study along with the germplasm tested could be of relevance to the areas having similar environments.

Summary and conclusions

Measure of LT_{50} provides the highest precision of all the cold-tolerance prediction tests but requires plants from a homogeneous population that can be tested using a series of test temperatures or times. There is a very high genetic variability for cold tolerance within the world gene pool of wheat and barley for temperate regions with low cold stress. The many changes that occur in morphological, biochemical, and physiological characters during cold acclimation provide fertile ground in the search for differences in several characters, such as leaf morphology, plant erectness, tissue water content, guard cell size and days to heading, which are highly correlated with cold tolerance. Use of these characters as screens satisfies many of the criteria needed for selection of cold tolerant genotypes in breeding program.

Based on the above observations, it is concluded that cultivar development for successful production of winter crops in both high and low cold stress regions require an understanding of plant development, growth cycles and the mechanisms involved in the survival of plants during the periods of cold stress.

Further studies are required to determine the interactions among photoperiodic sensitivity and vernalization requirements with the objective of identifying genetic combinations that extend the vegetative stage, thereby providing the opportunity for longer term protection from cold stress in regions with long mild winters like those normally experienced in temperate regions.

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How risk influences the adoption of new technologies by farmers in low rainfall areas of North Africa?

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Abstract

Risk has long been considered as an important factor that reduces technology adoption. We propose to test different hypotheses regarding the effect of risk on the process of technology adoption by farmers in semi arid and arid areas of North Africa where drought risk is prevalent. The study concerns the introduction of spineless cactus-based alley cropping risk-reducing technology, and addresses how farmers' risk attitude influences the level of adoption of this technology. To test the influence of risk on the technology adoption a mathematical programming model, that maximizes the utility function of farmers under a set of agronomic, economic and institutional constraints, was developed. The results showed that repayment period limits more the adoption of spineless cactus-based alley cropping than farmers' risk attitude. The reduction (or increase) of the coefficient of risk aversion favours stocking (or de-stocking) of live animals in agro-pastoral systems. In contrast, small farmers, with income threshold close to survival level, have little room to adjust.

Introduction

All Maghreb countries experienced the Green Revolution with its technical package that was largely sustained by subsidies. But, only little impacts were observed in the arid and semi-arid areas, which remained neglected by this revolution. The unsuccessful story of technology transfer in marginal areas such as arid and semi-arid areas had led to an overwhelming skepticism. Economists pointed out this low technological adoption rate could be explained by several factors such as human capital, lack of capital with limited access to credit, labor constraint or even lack of land capital. Risk perception and risk taking by farmers under uncertainty were also reported.

In harsh environments, farmers are mainly considered as risk averse. Two economic approaches regarding risk analysis have been developed: the first focuses on investment decisions under uncertainty; and the second explores the linkages and interactions between the risks induced by the technology and farmers' risk attitudes. We propose to test different hypotheses related to the effect of risk attitude on the process of technology adoption by farmers in semi-arid areas of North Africa where drought risk is prevalent.

Our study focuses on a promising and well-adapted technology to arid and semi-arid areas that was developed under the M&M Research Project, a collaborative project, funded by IFAD (International Fund for Agricultural Development), AFSED (Arab Fund for the Social and Economic Development) and IDRC (International Development Research Center) on the Development of Integrated Crop/Livestock Production Systems in Low Rainfall Areas of the Mashreq and Maghreb Regions, between ICARDA (International Center for Agricultural Research in the Dry Areas), IFPRI (International Food Policy Research Institute) and all the concerned national research institutes from North Africa and West Asia. We propose to test the role of farmer' risk attitude on technology adoption of spineless cactus (*Opuntia* spp.)-based alley cropping in a community of central Tunisia (Nefzaoui, 2002). A multi-period mathematical model was designed to test the effects of risk attitudes as well as the impact of different institutional options on the process of technology adoption by different types of farmers.

Brief review of the literature

While risk attitude remains a major determinant of technology adoption, many empirical works raised the difficulty of addressing risk attitudes and uncertainty considerations in the process of technology adoption. From the analysis of risk preference in a rural India case study, Binswanger (1980) underlined the very contrasting situations between risk taking and level of wealth. Kebede (1992) showed that off-farm income could reduce the risk taking in agriculture. Shapiro et al. (1992) came to the conclusion that the adopters have a risk-averse attitude compared to non adopters and that, at the end, the risk perception is more important in the decision process than the risk preference.

Focusing on the role of information and learning process, Warner (1974) showed that the efficiency of a new technology increases with experience (learning by doing). Cambrezy (1999) tried to approach the cost of access to information by considering the level of education, the distance between adopters and non adopters, and the availability of extension agents. Other workers favored the quality of information through the estimation of the subjective distribution of the yields and the process of 'learning by doing', i.e., the acquisition of information (Abadi-Ghadim, 2000; Marra et al., 2003). In their synthesis, Marra et al. (2003) noted that, in the majority of research studies, the uncertainty related to the future financial value of investment was considered as a major limiting factor of technology adoption. Moreover, results of the various research studies confirm the necessity of introducing buffer prices to reduce investment uncertainty.

In the present study, we propose to use a mathematical model to test different hypotheses regarding the effects of risk attitude and repayment period on the level of technology adoption. This was tested on the technology of spineless cactus-based-alley cropping in a community of the semi arid area of Central Tunisia.

Case study

In North Africa, dry-lands with less than 350 mm of rain and periodic drought are traditionally the domain of agro-pastoralists, who are deriving their incomes from both livestock and crop production. In the past, a major common trait in farmer strategies in these arid and semi-arid areas was the variety in the risk-coping practices within the same farm in order to withstand the huge inter-annual variations in climatic conditions and to face droughty years to achieve system survival. These included regulation of the livestock unit *per se*, such as selling part of their livestock, herd seasonal migration, choice of resistant sheep breed (such as *Barbarine* in Tunisia), and also, at a higher level, adjustment in the family-farm organization and operation. In one of the two Tunisian communities considered in the M&M project (Zoghmar Community), 82% of farmers benefited from emigration revenues or commercial activities that represented 37% of the total farm income in 1999[1]. Wage labor and self-employment in off-farm activities could be considered as a buffer strategy, during times of stress, rather than profit maximization. The incomes may be reinvested in the livestock system, mainly to maintain the live asset considered as the main saving asset.

At present, we observe important changes in the set of risk-coping strategies, mainly due to the reduction of the range resources. The latter along with the high vulnerability of the agro-pastoral system to dry conditions are mainly a result of past drought mitigation policies based on grain subsidies that have induced farmers to keep high stocking rates of their flock during dry years. These policies are blamed for the high degradation of rangeland due to overgrazing beyond the threshold of its resilience. In this context, medium-term risk-coping strategies are eroding because of increasing financial dependence to market and policies. Accordingly, farmers engage in opportunistic short-term flock management practices depending more on market and economic risk rather than on reducing climatic risk effects (Alary et al., 2002). For example, the majority of agro-pastoralists extend cereal crop production -- mainly wheat for self consumption and barley for animal feed-- on marginal lands, although cereal

[1]Result from a survey of 39 households in Zoghmar (Sidi Bouzid), The Mashreq/Maghreb Project, ICARDA.

yields vary considerably from year to year depending on the total amount of rainfall and its distribution. But with the drastic reduction of range resources and the increasing dependence on cereal grain, the cereal stock from a good year covers hardly the requirement during the same year. And, in drought conditions, the majority of farmers are required to purchase cereal grains and crop residues. Moreover, the off-farm diversification faces increasing limitations due to the saturation of unskilled labor domestic market and the reduction of migration flow to Europe.

The dismantling of traditional risk-coping strategies threatens the long term sustainability of the natural resource base. In fact, the weakening of traditional collective pasture-use regulation patterns appeared to be an important factor that contributed to such evolution. It encouraged "individualistic" behaviors and carelessness in the land resource sustainability (Balent and Gibon, 1992). Therefore, if the main key factors of sustainability of these systems were based on the adaptation and flexibility of farm-household strategies to the climatic conditions with acceptance of deviation from the technical optimum, nowadays, the evolution of the farming system in these areas is linked (1) to the capacity to develop risk-absorption strategies at the household level (for example, with the adoption of risk-reducing technologies), and (2) to the institutional and social changes at an upper level of organization of the agricultural systems.

In this context, alternative resources, such as cactus, *Atriplex* spp., *Acacia* spp., with their high resistance to dry conditions, constitute important innovations in these systems. Among other things, these resources ensure a set of functions: anti-erosion, soil conservation, drought resistance, low cost feed, etc. Our analysis has focused on the technology of spineless cactus in alley cropping, which was developed in Tunisia under M&M Research Project in collaboration with INRAT and the Office of Livestock and Pastureland (OEP). It consists of planting rows of cactus 20 m wide; the inter-rows may be cropped with cereals or left as fallow for grazing. The main expected outputs of this technique are: the increase of annual biomass in the inter-rows, the limitation of run-off and erosion, and the production of feed stock (cactus pads).

The case study is *Zoghmar* community in central Tunisia, an area covered by the M&M Research Project, the Femise Project[2] and the SPIA Project[3]. This community is located in dry lands characterized by less than 350 mm rainfall and periodic droughts. Agro-pastoral production systems are dominant here, and people derive their incomes from both livestock and crop production. Agronomic trials conducted in 2004 (considered as a good year) in this community under SPIA/ICARDA Project showed, in a restricted number of plots, that barley biomass increased from 4.24 t/ha to 6.65 t/ha and grain yield from 0.82 t/ha to 2.32 t/ha with a maximum of 7.6 t/ha in cactus alley-cropping system compared to the control with no cactus plants. Besides, the experimental data collected by INRAT show that cactus pads constitute a low-cost feed for animals and help withstand dry years. An exhaustive survey conducted in the community in 2002 showed that cactus consumption reduced the feed cost per head by 13.2%. Between the years 1995 and 2002, among which 5 years were dry, the live capital was reduced by 32%, instead of 40.5%, for the farmers who did not use cactus. Finally, soil analysis revealed a significant increase in soil organic matter, carbon and phosphorus content, being respectively 350%, 450%, and 100%, higher than in the non cactus cultivated land. Cereal cropping in this system could profit from these nutrients, and this could explain the increase of barley grain yields.

However, this technology implies long-term investments and this could hinder its adoption potential by farmers. A participatory approach and a strong partnership between a governmental agency (Livestock and Pastureland Office, OEP), the research team and farmers is the main option followed in implementing the adoption of such a technology. The farmers' contribution consisted of plowing the soil, planting pads and maintaining planted areas for three years. The government provided cactus pads (0.03 – 0.04 US$ per double pad), reimbursed part of farmers' expenses [soil

[2] FEMISE (Forum Euro-Mediterranéen des Instituts en Sciences Economiques) project funded by the European Commission and coordinated by ICARDA was on the resistance to technological adoption in small and medium farms.

[3] SPIA project funded by the CGIAR was on the ex post impact assessment of spineless cactus in alley cropping in Tunisia.

preparation (8.55 US $ per ha), planting (34.20 US$ per ha)], and provided compensation (38.50 US$ per hectare per year for three years). This compensation was given in kind (concentrate feeds) for a three-year freeze on grazing in the planted area. This denotes the great effort made by the government toward the development of this activity in Tunisia.

The main input of the M&M Project was its contribution in developing an innovative approach facilitating new community-organization and diffusion of new technologies and encouraging a broader collaboration within the national society. The community meetings with development agencies, public policy makers, farmers and researchers and the organization of regional workshop with farmers accelerated the diffusion of the technology.

Material and method

Data were collected from a cross sectional sample of farm households within the target area in Tunisia. The sample used was selected on stratified random sampling basis, depending on the main farming systems in the area. These surveys provided an (unbalanced) panel data of 45 farm households from Zoghmar community, for 1999, 2002 and 2003. The data was used to determine and characterize different types of farming systems in the community and the different risk management strategies used by farm types.

To analyze the risk strategies adopted by different farm types, we used a bio-economic model developed within the M&M and the FEMISE research projects. The main advantages of this model are to approach competition, interactions and feedback effects between the different sub-systems (bio-physical, decisional and environmental) and to integrate various competing or complementary goals (marketing behavior, allocation of resource to farm and off-farm activities, consumption choices, environmental). This type of model has been applied and tested under various agro-ecological conditions (dry and humid tropical lowland and hillsides) in different countries (Alary and Deybe, 2005; Nordblom et al., 1994; Deybe, 1998). This modelling approach is currently being extended in many directions: a more detailed approach of farm types, development of risk-coping strategies, procedures for aggregate analysis at the regional level, development of village/regional models to take into account the interlinked transactions and communal management of resources, and the increasingly recognized role of off-farm income in household decision-making process.

The model developed for the Tunisian community relies on a standard mathematical programming formulation (Hazell and Norton, 1986). Here, it is the maximization of the net income function (including animal stock) under socio-economic constraints (resource endowment, cash flow, risk attitude, credit access, etc.) and technical opportunities and constraints. To consider the trade-off between the present and future, we developed a dynamic model. Risk behavior is one of the main factors to explain technology adoption. This risk behavior will depend on farms' characteristics (diversification, capital endowment, characteristic of the head of the family, etc...), the market conditions and the technology perception. The risk taking is formulated under the Target Motad approach proposed by Tauer (1983) at the individual level and the objective function is written as:

Max $E(Z) = \sum_{ye=t_0}^{T} \frac{C_{ye} X_{ye}}{(1+\tau)^{ye}}$ + $\mathbf{K}/1+\tau T$ Avec : $A X_{ye} \leq B_{ye}$; $B_{ye} = bX_{ye-1}$; $X_{ye} \geq 0$

Under risk constraints :

$$T - \sum_{j=1}^{n} C_{ye,j,r} \cdot X_{ye,j} - \lambda_{ye,r} \leq 0\ ;\ r = 1,\ldots,s\ ;$$

$$\sum_{r=1}^{s} P_r \lambda_{ye,r} = \Omega\ ;\quad \Omega = M \to 0\ ;$$

$$X_j \geq 0, \lambda_{ye,r} \geq 0\ ;$$

where E(Z) is the objective function for maximizing, C_{ye} the vector of expected income from productive activities in the year (ye), X_{ye} the vector of activities' level, T the minimum target income, Ω risk aversion coefficient according to Target MOTAD method, λ_{ye} the sum of negative deviations related to the income threshold (fixed for each farm type), T the planning horizon, τ the discount rate, A the input/output matrix and B_{ye} the matrix of available resources that depend on decision in the previous season (ye-1). The prices are exogenous and we suppose that the farmers take their decisions according to the prices of the previous year and the probability to have a good, medium or bad year. The community model represents a simplified picture of an aggregation of typical whole farm systems. These typical whole farm systems are identified through cluster analysis on the database provided by household surveys (Fig. 1). Each farm is characterized with its different resource endowments (land, labor and capital) and its management (crop and livestock systems, and family objectives). The farmers interact among themselves through exchange of items like non-storable fodder, labor forces, land, and credits. At the community level, the farmers are linked to the market for input purchases and output sales and the institutional environment for credit access or land and labor access.

The main structure of the model is presented in Alary (2005). The validation was performed in collaboration with M&M team and the results are presented in Alary et al. (2004).

Results and discussion

Cactus adoption between investment decision and risk attitude

Risk has long been considered as an important factor that reduces technology adoption (Just and Zilberman, 1983; Marra et al., 2001). Here we propose to focus on the investment decisions under uncertain environment.

At the community level, just two years after the introduction of the technology, the rate of adoption and the degree of adoption in 2002 reached 30.6% and 29.7%, respectively. When these indicators were calculated according to land or live capital, important differences among farmers were observed. The average area allocated to the technology varied from 1.54 ha for the small farms (less than 5 ha) to 9.9 ha for the large farms (more than 15 ha). The rate and degree of adoption were, respectively, 61.3% and 43.22% for the large ones and 13% and 14.5% for the small ones. Similarly, the rate and degree of adoption were, respectively, 46.1% and 36.8% for the large herders (more than 50 heads of small ruminants) and 25.8% and 22.6% for the small ones (less than 15 heads).

To explain these gaps, one hypothesis could be that small herders are reluctant to make investment decisions due to the lack of resource. And, the small farmers would be more risk averse.

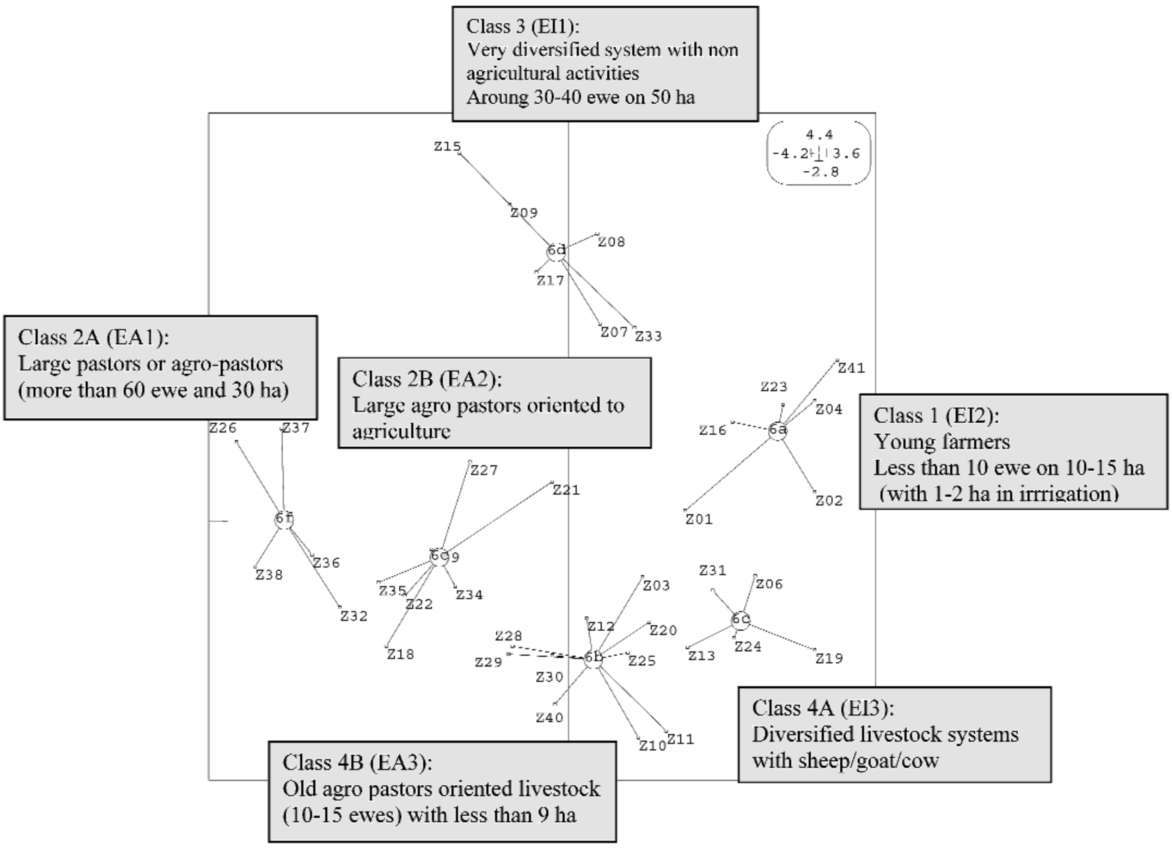

Fig. 1. Farm systems characterization.

Three scenarios were tested:
(C1): Increase of the planning horizon from 5 to 10 years;
(C2): Decrease of risk-aversion coefficient by 20% for all farm types; and
(C3) Increase of risk-aversion coefficient by 20% for all farm types.

The results are reported in Table 1 and 2.

Firstly, it is noted that, with the expansion of the planning horizon from 5 to 10 years, all the farmers increase the adoption of technology. The area covered by the new technology doubled in the case of agro-pastoralists (EA1) and the mixed farming systems with irrigation (EI2). For the small dry farms (EA3) and the diversified farms (EA2), the area increased by 16.5% and 5%, respectively. For other scenarios, there were no changes in the rate of adoption, expect, for the farm type (EI2) for which the area increased by 21%.

At the same time, live capital increased. But, while the majority of investment in the technology were realized by farmers without irrigation (EA1, EA2, EA3) the animal capital increase concerned mainly the farms with irrigation (EI1, EI2, and EI3). The new cactus plantations induced a new allocation of land: (1) agro-pastoralists allocate two-third of their cereal area to barley, against 43% before, and (2) the small herders (EA2 and EA3) who allocated 90% of their cereal area to barley are sharing the area between barley and wheat. If a reduction of the annual cash flow in the first five years of the planning horizon is observed, a decrease of the feed cost (by 11.30 and 5.6% for EA2 and EA3, respectively) is experienced by the small farmers. Besides, a reduction of the community inequity is observed; the Gini coefficient decreases from 0.33 to 0.28, in average, on the planning horizon.

Knowing that in reality farmers have not increased their area with the technology these results show that one of the main obstacles to adoption is the management period on which farmers base their decision. In fact, most of them have problems of cash flow in the short term and their management does not exceed a year span. In this context, only the funding of the technology or the establishment of a credit system could favor the adoption of the technology.

The reduction of the coefficient of risk aversion favors the stocking of live animals in the case of large and medium livestock oriented farms (EA1 and EA2). These farms experience a decrease of cash flow mainly due to the increase of feed

Table 1. Variation of ewe stock for the different scenarios (in % of deviation from the situation of reference) (Zoghmar Community, central Tunisia).

	C1	**C2**	**C3**
	Planning horizon	**Reduction of risk aversion**	**Increase of risk aversion**
EA1	-12.95	17.18	-20.39
EA2	-16.17	2.79	-4.86
EA3	3.82	0.00	0.00
EI1	52.81	0.00	0.00
EI2	11.97	0.00	0.00
EI3	0.00	0.00	0.00

Table 2. Variation of cash flow for the different scenarios (in % of deviation from the situation of reference) (Zoghmar Community, central Tunisia).

	C1	**C2**	**C3**
	Planning horizon	**Reduction of risk aversion**	**Increase of risk aversion**
EA1	-9.25	-5.573	0.22
EA2	-6.92	-5.53	-1.32
EA3	-4.45	0.00	0.00
EI1	-27.17	-1.82	1.10
EI2	-13.33	0.00	0.00
EI3	-49.44	0.00	0.00
Community	**-8.87**	**-1.39**	**0.02**

expenditure. On the other hand, the increase of the coefficient of risk aversion induces a great de-stocking in live animals by the same farms. This shows that the agro-pastoralists and mixed systems without irrigation are the most sensitive to risk and they regulate their livestock according to risk. On the other hand, small farms (EA3), close to the income survival threshold, have very little room to adjust to risk occurrence.

Besides, cactus plantation, as perennial crop, complies with the long-term view of the farm. But, emerging tendencies show farmers are more dependent on purchased feed in the short term, which presents a serious constraint to the adoption of long-term based technologies.

Effect of market opportunities derived from the adoption of the new technology

In a new set of simulations, the opportunity to sell the of cactus pads production either at the community level (C5) or at the national level (C6) was introduced. We suppose that the national demand could absorb 20% of the community production. In the scenarios C7 and C8, we compare the impact of market in a context of liberalization. In C7, we suppose the liberalization of barley and meat markets with random fluctuation of prices with more or less 15%. In C8, we introduce the alternative to sell 20% of the production on the market. Table 4 and 5 show the impacts of the organization of pads' market on the ewe stock (live-stocking) and the cash flow (welfare of farmers).

The four scenarios seem interesting for all farm types in dry areas (without irrigation), except the scenario of liberalization (C7). All the farm types without irrigation (EA1, EA2 and EA3) increase their flock size and experience a positive cash flow progress. But, farm types with irrigation become potential buyers of cactus pads in the case of the organization of a community market. This community market induces a new repartition of the wealth between the farm types with and without irrigation to the benefit of the farms without irrigation. This explains a reduction of the Gini coefficient from 0.33 to 0.25.

But this result is mainly attributed to the formal-

Table 4. Variation of ewe stock for the different scenarios of markets (in % of deviation from the reference with no market) (Zoghmar community, Tunisia).

	C5	C6	C7	C8
	Community market	**Regional market that absorbs 20% of the supply**	**Liberalization on meat and barley sectors**	**Liberalization + Regional market that absorbs 20% of the supply**
EA1	23.07	22.76	-20.08	23.39
EA2	44.33	43.20	6.22	54.94
EA3	68.48	68.96	17.24	116.45
EI1	-4.87	0.00	0.00	0.00
EI2	-1.57	2.17	-2.05	3.27
EI3	0.00	0.00	-2.87	-9.75

Table 5. Variation of cash flow for the different scenarios of markets (in % of deviation from the reference with no market) (Zoghmar Community, Tunisia).

	C5	C6	C7	C8
	Community market	**Regional market that absorbs 20% of the supply**	**Liberalization on meat and barley sectors**	**Liberalization + Regional market that absorbs 20% of the supply**
EA1	9.24	22.35	45.11	34.39
EA2	11.23	11.83	0.80	13.16
EA3	21.66	21.58	2.61	20.47
EI1	-14.47	9.15	-2.46	0.57
EI2	-28.49	-0.38	-3.28	-4.37
EI3	3.58	11.36	1.62	10.36
Community	15.30	18.32	5.14	18.36

ization of the community exchanges in the model. With the aggregate model, the exchanges in the community are such that they benefit more farm types that generate the largest amount of utility. In this case, due to the low weight of irrigated farms in the population (less than 13%), the exchanges favour the farm types which don't benefit from the irrigation.

Under scenario C7, liberalization leads to a great de-stocking in the case of agro-pastoralists (EA1) for whom the main constraint is barley price fluctuations given that these farmers are net buyers. But, the possibility to sell pads could alleviate this negative impact under liberalization context C8. Besides, small and medium farms with irrigation (EI2 and EI3) increase area allocated to cactus.

Therefore, the organization of a market for cactus produce will have positive impacts on all farm types. It would stimulate live re-stocking and slow down the effects of prices fluctuations in a context of liberalization.

Conclusion

The investment period is more limiting the adoption of cactus-based alley cropping technology than risk attitude. But, cactus plantation, as perennial crop, fits well with the long-term view of the farm profitability. However, based on current tendencies, farmers seem to depend more on feed purchase in the short term. This constitutes a constraint to the adoption of long-term risk mitigating technology. The reduction (or increase) of risk aversion coefficient favours stocking (or de-stocking) of live animals in the case of agro-pastoralists. On the other hand, small farmers, with income threshold close to survival level, have very little room to adjust. Therefore, the main constraint to the adoption of natural resource sustainable management options, such as cactus alley cropping, is the short term time span on which farmers base their management practices. To engage in long-term risk management strategies, farmers do need financial support while waiting for repayment period. Moreover, as is the case for all technologies, limited experience and lack of knowledge about expected outputs limit the level of adoption. Finally, the organisation of a market for pad produce could encourage the adoption of this new technology.

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Prospects and progress of research on oilseed crops in drylands of Iran

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Extended abstract

About 90 % of the edible vegetable oil needs of Iran are met through imports, which amount to around 900,000 tons and cost almost one million US dollars. The main reason for the shortage of local production of edible oil is that there is very little area under oilseed crops, and the crops like rapeseed and mustard are not grown at all commercially. From the last one decade Government of Iran is making proactive efforts to create and develop area under important oilseed crops with emphasis on cultivation of 'double low' rapeseed, usually called 'Canola'. The plans are to enhance the area of oilseed crops in the dry-land region, mostly using winter-grown oilseeds. These oilseeds are suitable for the rain-fed region that is cold, semi-cold and warm in climate.

Oilseed crops research program at the Dry Land Agriculture Research Institute (DARI) of Iran is focused on three crops that can be grown under rain-fed conditions of Iran, i.e. rapeseed and safflower in winter, and sunflower in spring and summer season. Results obtained so far show that fall planting of rapeseed in cold areas where below zero temperatures occur for about 125 days is not possible because the rapeseed crop in this period is in the cotyledonary leaf stage, and can not survival the cold. In this climatic condition, however, *Brassica juncea*, also called mustard, can be grown as a spring crop.

In semi-cold areas under rain-fed condition fall planting is possible, if the first effective rain falls by the end of October, otherwise it needs one or two initial irrigations at the time of planting. Frost events in this region occur for about 90 days. Three winter type varieties 'Parade', 'Aviso' and 'Modena' had produced the highest average seed yield of 1605, 1439 and 1354 kgha^{-1}, respectively over three years in the semi-cold region.

In the warm southern rain-fed areas of the country spring type rapeseed can easily be grown in the winter season. Results obtained during a three-year study revealed that in these areas hybrid varieties 'Hyola 401' and 'Hyola 308' had 13 to 23 per cent higher seed yield than the open-pollinated varieties, especially in those years when the drought stress was mild, but under harsh drought conditions (seasons with lower rain than long term average) open pollinated varieties produced 11 to 21 per cent higher seed yield compared to these hybrids.

In another research program to reduce the shattering of seeds in rapeseed, inter-specific crosses between *B. napus* and *B. juncea* have been made, and F1, BC1 and BC2 generations have been obtained. Also to increase cold tolerance and earliness in promising varieties, crosses between winter and spring types of *B. napus* have been made.

Our research in the last few years shows that fall planting of safflower in semi-cold and warm rain-fed areas can be done easily. Average seed yield of several varieties is about 1100 to 2300 kg ha^{-1} in rain-fed semi-cold areas. Safflower fall planting has produced 60 to 140 per cent more seed yield compared to spring planting in these areas.

In the cold climatic conditions, spring planting of safflower is recommended. It produces an average seed yield of about 500 kg ha^{-1}. On-

farm as well as on-station trials showed that local varieties of safflower 'Isfahan Local', and 'Zarghan 279', had always produced less seed yield than the promising varieties in spring and fall planting. Promising varieties selected showed 30 to 120 per cent more seed yield than checks. Variety 'PI-537598' is a high yielding safflower line that has been selected after evaluating a large germplasm collection.

Effect of Zinc and Boron nutrition on the productivity of fingermillet and groundnut based cropping system for Alfisols under dryland conditions of Karnataka, India

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Abstract

Increased removal of micronutrients as a consequence of adoption of high yielding varieties and intensive cropping systems together with a shift towards the use of high analysis NPK fertilizers has pushed the level of the micronutrients in the soil below the critical levels required for normal productivity of crops. Zinc and boron deficiencies (69.14% and 26.27% respectively) are most wide spread in Alfisols of deccan platue of India, particularly in Karnataka. In this context an experiment was conducted in the Dryland Agriculture Project at the University of Agricultural Sciences, Bangalore, to study the effect of zinc and boron on growth, yield and seed quality of fingermillet and groundnut during the rainy (*kharif)* seasons of 2001 to 2004. Fingermillet and groundnut responded significantly to the application of boron and zinc. Soil application of $ZnSO_4$ @ 12.5 kg ha^{-1}+ borax @ 10 kg ha^{-1} to fingermillet significantly improved plant height, total dry matter accumulation, grain yield attributes and yield, and benefit-cost ratio. Seed germination and vigor index also improved. In case of groundnut, the foliar application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} along with recommended dose of NPK improved plant height, dry matter accumulation, pod yield, haulm yield, and benefit-cost ratio. The shelling percentage, 100-kernel weight, seed germination and vigor index also improved. This treatment was followed by soil application of $ZnSO_4$ @ 25 kg ha^{-1} +borax @ 0.5 kg ha^{-1} in efficacy in impacting the growth and yield attributes of groundnut. Thus, use of boron and zinc is necessary in order to maintain higher productivity of fingermillet and groundnut in the Alfisols of Karnataka under dryland conditions.

Introduction

The stabilization of crop yields under dryland condition is highly dependent on the use of balanced mineral nutrient inputs. The introduction of high yielding varieties, intensive cropping system, continuous use of high doses of high analysis inorganic NPK fertilizers that do not contain essential trace elements, limited use of green manures, compost and organic manures, and adoption of monocropping have caused decline in the level of micronutrients in the soil below the level critical for normal growth and productivity of crops. Yield declines are therefore becoming common in spite of heavy inputs of macro-metabolic nutrients as fertilizers in the Alfisols of dry areas of Karnataka, India. The management of the soil micronutrient status is urgently required to achieve balanced crop nutrition for full realization of the yield potential and sustain crop yields in such areas.

Of various essential micronutrients, the deficiency of zinc and boron is reported to be most wide spread (69.1% and 26.3%, respectively) in the Alfisols of Karnataka. Zinc is recognized as a key element in protein biosynthesis and it plays important role in biological nitrogen fixation by legumes. Boron is known to arrest the flower drop and increase biomass production in crop plants. It plays a vital role in cell division, nodule formation and carbohydrate and fat biosynthesis (Bergmann, 1992; Lourdraj et al., 1998; Subramanyam et al., 2001). In this context, research is being conducted on micronutrient management in dryland crops under the Dryland Agriculture Project, at the University of Agricultural Sciences, GKVK Bangalore. Fingermillet (*Eleusine coracana*) and groundnut (*Arachis hypogia*) are important dryland crops grown in the drylands of Karnataka during the warm rainy (*kharif)* season. This experiment was conducted for four years (2001 to 2004) to study the effect of zinc and boron application on growth, yield attributes, yield and seed quality of finger millet and groundnut grown on Alfisols of Karnataka.

Methods and material

A field experiment was carried out in the Dryland Agriculture Project, at the University of Agricultural Sciences, Bangalore, Karnataka during the *kharif* seasons of 2001-2004 in the finger-millet – groundnut cropping system. The soil here is Alfisol. The texture of the soil in the experimental field was sandy loam. It had a pH of 6.25, was low in available N (250 kg ha^{-1}), medium in available phosphorus (9.0 kg ha^{-1}), high in potassium (160 kg ha^{-1}), available Zinc (0.33 ppm) and boron (0.16 ppm). The groundnut cultivar used was 'JL-24' and the fingermillet cultivar was 'GPU-28'. The experiment was laid out in randomized complete block design with 3 replications and 16 combinations of micronutrient treatments along with a control. In one set of treatments, micronutrients were applied to soil at the time of sowing with different combinations of two levels of Zn (12.50, 25.00 kg/ha $ZnSO_4$) and four levels of B (0, 5, 10 and 20 kg/ha Borax) along with the recommended dose of NPK fertilizers (for groundnut 25:40:25 kg NPKha^{-1}; for finger-millet, 50:50:25 kg NPKha^{-1}). The other set of micronutrient treatments involved foliar application of all combinations of four levels of B (0, 0.50, 1.00 and 2.00 kg ha^{-1} Borax) and two levels of Zn (1.25 and 2.50 kg ha^{-1} $ZnSO_4$) at 20 DAS and at flowering on the plots that received same basal application of NPK as the other set. The NPK alone treatment served as control. The crops were grown following all the cultivation practices as per the production package recommended by the University of Agricultural Sciences, Bangalore (UAS, 2003).

The rainfall and rainy days during the growing seasons are given in Table 1.

At maturity, yield attributes and yield were recorded for each crop. Seed quality parameters viz. seed germination and vigor index, were analyzed by following appropriate procedures.

Results and discussion

Fingermillet

The effect of selected treatment combinations, including the control (T1) and most outstanding treatments, on growth, yield attributes, and yield are shown in Table 2. Soil application of $ZnSO_4$ @ 12.5 kg ha^{-1}+ borax @ 10 kg ha^{-1} (T4) registered higher finger millet grain and straw yield as well as higher benefit-cost (B: C ratio) over the other treatments. Among foliar spray treatments, $ZnSO_4$ @1.25 kg ha^{-1}+ borax @ 0.5 kg ha^{-1} (T11) gave higher grain and straw yield than other foliar spray application treatments. The increase in grain yield was 24 % with the soil application (T4) as compared to the control (T 1).

Application of $ZnSO_4$ @ 12.5 kg ha^{-1} along with boron at different combinations holds promise in terms of yield and yield attributes. The increase in yield of finger millet was brought about by increased growth attributes, leaf expansion and dry matter accumulation because of improved nutritional status of the plants. Also a higher germination percentage and vigor index was recorded in the seeds under the soil application of $ZnSO_4$ @ 12.5 kg ha^{-1}+ borax @ 10 kg ha^{-1} perhaps because of the improvement in the source-sink relationship and improved availability of the nutrients to the developing seeds as a result of better growth. Such a seed would have greater agronomic significance for planting in the next seasons

Groundnut

Significant increase in growth and yield attributes were recorded due to Zinc and Boron application at different levels in groundnut (Table 3). Foliar application of $ZnSO_4$@ 2.5 kg ha^{-1} + borax @ 0.5

Table 1. Total annual rainfall and the rainfall during the cropping period in 2001 to 2004.

Parameters	2001	2002	2003	2004
Total rainfall (mm)	1000.5	628.3	649.0	997.0
Rainfall during cropping period (mm)	729.0	293.0	495.0	584.0
Rainy days during cropping period	43	19	37	32

Table 2. Effect of application of zinc and boron on growth, yield parameters and seed quality of finger millet (pooled over four years)

Treatments	Growth parameters		Yield parameters			Germination (%)	Seed vigor index	Grain yield (kg/ha)	Straw yield (kg/ha)	B:C ratio
	Plant height (cm)	Total dry matter (g/plant)	Earhead length (cm)	No. of fingers per ear head	1000 Seed Weight (g)					
T1- Control (only NPK)	90.8	30.3	6.71	5.14	2.13	86	98	3067	4133	0.90
T3- ZnSO4 @ 12.50 kg/ha + Borax @ 5 kg/ha (Soil)	112.8	39.0	7.54	7.33	2.94	90	252	3775	4938	1.21
T4- ZnSO4 @ 12.50 kg/ha + Borax @ 10 kg/ha (Soil)	115.4	41.0	7.75	7.52	2.97	99	574	3812	4984	1.22
T5- ZnSO4 @ 12.50 kg/ha + Borax @ 20 kg/ha (Soil)	108.5	38.0	7.31	7.19	2.89	90	100	3736	4902	1.13
T11- ZnSO4 @ 1.25 kg/ha + Borax @ 0.50 kg/ha (Foliar)	102.6	36.0	6.78	6.75	2.77	96	495	3624	4785	1.21
T12- ZnSO4 @ 1.25 kg/ha + Borax @ 1.00 kg/ha (Foliar)	104.8	36.0	6.83	6.91	2.81	93	381	3650	4834	1.20
F-test	*	*	*	*	*	*	*	*	*	-
SEM	9.68	1.65	0.25	0.09	0.06	1.5	13.8	153.2	45.2	-
LSD (0.05)	27.89	4.76	0.74	0.29	0.16	4.4	38.6	458.7	130.2	-

Table 3. Influence of boron and zinc application on mean values growth, yield attributes, yield and seed quality of groundnut over four years

Treatments	Growth parameters		Pod yield (kg/ha)	Haulm yield (kg/ha)	100-kernel weigh (g)	Shelling (%)	Oil content (%)	Germination (%)	Seed vigor index	B:C ratio
	Plant height (cm)	Total dry matter (g/plant)								
T1	22.0	59.1	607.4	920.7	21.9	38.7	43.49	85	91	0.88
T4	26.9	67.3	775.6	1223.8	28.8	44.0	44.05	96	132	1.15
T5	27.0	69.0	802.6	1244.6	29.3	44.6	43.92	95	137	1.14
T7	24.5	63.4	778.4	1245.8	28.3	44.0	44.78	98	145	0.82
T11	26.1	65.2	819.0	1322.2	29.6	44.7	44.78	98	141	1.09
T15	27.1	69.9	874.5	1407.9	31.2	45.7	44.69	100	152	1.35
T16	26.8	66.8	796.2	1280.6	29.3	44.5	43.49	96	139	1.19
F-test	*	*	*	*	*	*	NS	*	*	-
SEM ±	1.00	2.47	24.32	45.39	0.95	0.67	0.43	2.04	3.263	-
LSD (0.05)	2.89	7.12	68.95	128.09	2.67	2.05	-	5.87	9.396	-

T1- Only NPK; T4 ZnSO4 @ 12.50 kg/ha + Borax@ 10kg/ha (Soil); T5 ZnSO4 @ 12.50 kg/ha + Borax@ 20 kg/ha (Soil); T7 ZnSO4 @ 25.00 kg/ha + Borax@ 5 kg/ha (Soil); T11 ZnSO4 @ 1.25 kg/ha + Borax@ 0.50 kg/ha (Foliar); T15 ZnSO4 @ 2.50 kg/ha + Borax@ 0.50 kg./ha (Foliar); T16 ZnSO4 @ 2.50 kg/ha + Borax@ 1.00 kg./ha (Foliar) kg ha^{-1} (T 15) recorded significantly higher pod and haulm yield, kernel weight, shelling percent and the B: C ratio as compared to other treatments (Table 3). However, it was closely followed by the treatment T5 (soil application of Zn SO4@ 12.5kg ha^{-1} + borax @ 20 kg ha^{-1}). The pod yield increased by 28 % with the foliar application of $ZnSO_4$ @ 2.5 kg ha^{-1} and borax@ 0.5 kg ha^{-1} as compared to control.

The use of zinc and boron significantly increased the yield and seed yield attributes of groundnut because of superior crop growth.

There was also a slight improvement in oil content in the kernels because of the micronutrient application. This may be because of the beneficial effects of zinc in activation of NADPH dependent dehydrogenase enzyme involved in the fat synthesis (Gupta and Vyas, 1994). The higher seed germination and vigor index of groundnut because of T15 might be attributed to better transfer of photosynthates and other nutrients to the developing seed. The presence of high amount of carbohydrate, protein and total soluble salt in seeds are known to be beneficial for improving the germination and vigor index of seed (Bergmann, 1992).

Conclusions

Combined foliar application of zinc and boron along with recommended doses of NPK was found to be beneficial in obtaining the enhanced growth and higher pod yield in groundnut. In case of finger millet conjunctive soil application of zinc and boron along with recommended doses of NPK performed better as compared to their individual application.

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ICARDA's emerging experience in institutionalizing knowledge management and dissemination

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Abstract

The international public goods (IPGs) generated by research must have an impact on rural communities and poverty. The creation of a knowledge management and dissemination (KM&D) program is considered by ICARDA as the best response to the growing concern about the cost effectiveness and impact of public investment in pro-poor research. The primary task of KM&D is to integrate the Center's work on knowledge management and dissemination into the overall research and capacity building program, and to enhance equitable access to pro-poor knowledge that contributes to ICARDA's goal of food security, poverty reduction and preservation of natural resources. The KM&D Program aims to address the following causes of poor access and adoption of agricultural knowledge: (a) limited and uncoordinated international and national support for dissemination of available knowledge; (b) limited capacity of the national programs to take advantage of advances in information and communication technologies (ICT) to acquire, share and disseminate knowledge; (c) inadequate analysis of the existing knowledge pathways that emerged from research for development projects; and (d) lack of research programs exploring innovative methodologies and approaches for knowledge management (documenting, learning, sharing and dissemination). The overall strategy is to develop and implement a systematic and consultative approach for knowledge management and dissemination to the widest possible segments of the rural poor, and to establish an integrated ICT-KM program supported by the principles of ownership, coordination, capacity building, sustainability, impact and appropriateness.

Introduction

The international public goods (IPGs) generated by ICARDA's research must have an impact on rural communities and poverty. ICARDA's approach to knowledge management and dissemination (KMD) aims at assuring immediate and optimal use of IPGs by the rural poor in the dry areas. The **KMD approach** is considered by ICARDA as the best response to the growing concern about the cost effectiveness and the impact of public investment in pro-poor research. Therefore, the overall goal of KMD approach is to promote and expedite equitable and wide use of public-funded agricultural research results. The approach aims to help ICARDA scientists and their partners find the most successful ways of sharing and disseminating research results. This could be decentralized within individual research projects or centralized through intermediaries or specialized communicators. The approach is aligned with all the Consultative Group on International Agricultural Research (CGIAR) System Priorities, with the strongest contribution being to the development of capacities, institutions and policy environments favorable to capturing and utilizing IPGs produced through research. The overriding goal is to enable ICARDA to contribute systematically to the millennium development goals (MDGs) of poverty reduction, environmental sustainability and to promote gender equality.

ICARDA's KMD approach focuses on a strongly integrated ICTs and KM processes that operate through strategic linkages between "research" (developing IPGs from research results), "services" (information and communications technologies - ICTs - and capacity building) and "development" (dissemination, upscaling and outscaling of research results). The approach acknowledges the importance of co-learning, sharing, networking and building partnerships. The approach strongly advocates behavioral changes within the research continuum that commits to the common values of participation, respect, empowerment, consistency, transparency and accountability; all essential attributes to the generation of community-based, demand-driven and feasible pro-poor agricultural knowledge.

The approach pays high attention to awareness and capacity building programs that enable the national institutions (public and private) and the communities to conduct participatory and demand-based research that leads to the generation and use of pro-poor agricultural innovations. In this respect, it is essential to understand which particular approaches used by scientists and technology transfer agents in the field could be relevant to stakeholders at the national, regional and international level. Such stakeholders include national agricultural research institutes (NARS), universities, advanced research institutes (ARIs), consumer and marketing groups, and policymakers.

To help establish best methodological practices, the focus is to analyze the "knowledge pathways" emerging from ICARDA's completed and current research. To do this, ICARDA has been exploring the best ways to identify the priority research results and to package them into Technical, Institutional and Policy Options (TIPOs) for dissemination, upscaling and outscaling. ICARDA's KMD approach allows for the investigation of the following possible questions:

- How to integrate dissemination into research and development projects?
- In what ways could ICTs speed up dissemination?
- What delivery mechanisms (oral, print, multimedia, etc.) for new knowledge are most effective in the social/cultural (especially gender) context?
- What is the effect of farmer-to-farmer extension on uptake and adoption of research results?
- How can ICARDA's knowledge-generation capacity complement the KMD capacity of other partners, NARS, universities?
- How to measure credibly the impact of delivered knowledge from the ICARDA-generated technology (e.g. impact of innovations)?
- What are the best KM approaches that make knowledge optimally accessible to a user community?
- Is knowledge delivered to client populations/partners making a difference in the lives of the poor in the region?
- What are the best examples of pro-poor innovations (in a country, region, and ecoregion or at global level)?
- Can pro-poor innovations be replicated or upscaled, if so, how (e.g. the impact?

Major achievements and current activities

Development of a model and a conceptual framework for KMD

A conceptual KM model (Fig. 1.) was developed in 2005. This was followed by the construction of a framework that involves analysis of the knowledge generated by research scientists, "knowledge pathways", identifying the key results, and publishing the lessons learned for wider adoption at regional and global levels. The approach was publicized and shared with internal and external peers through two key channels of communication: (1) the development and publication of the KMD Brochure (1st edition September 2005; 2nd edition end of 2006), and (2) internal and external consultations to generate understanding of, and feedback on, ICARDA's KMD approach. One major objective of the consultation is to form Internal and External Communities of Practice (CoPs) to mentor and develop the KMD approach in ICARDA.

Combining supply and demand driven approaches to KMD:

The **KMD** conceptual framework (Fig. 2) is based on the understanding that the results generated from international agricultural research (past, current and future research) are IPGs and, therefore, must be widely and equitably used in rural poverty reduction efforts. Therefore, the implementation plan for ICARDA's KMD approach is based on:

- ***Supply-driven*** **approaches** justify the benefits of public investment in agricultural research and development to the concerned donor community in the short/medium-term.
- ***Demand-driven*** **approaches** explore ways in which knowledge (human experience) can be utilized in the development and dissemination of new technologies. Existing methodological

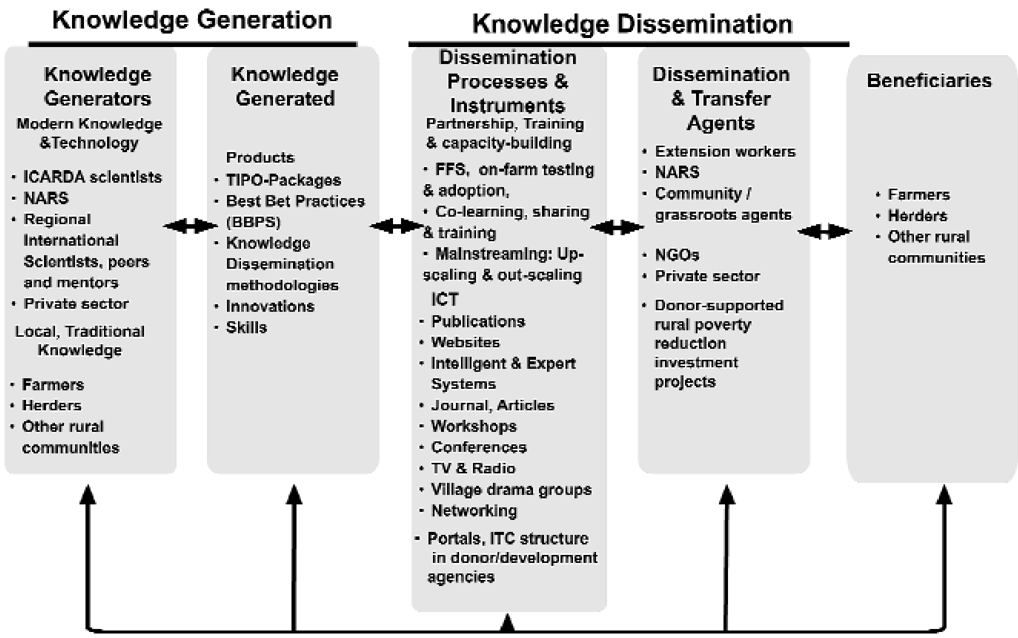

Fig. 1. ICARDA's Knowledge Management Model.

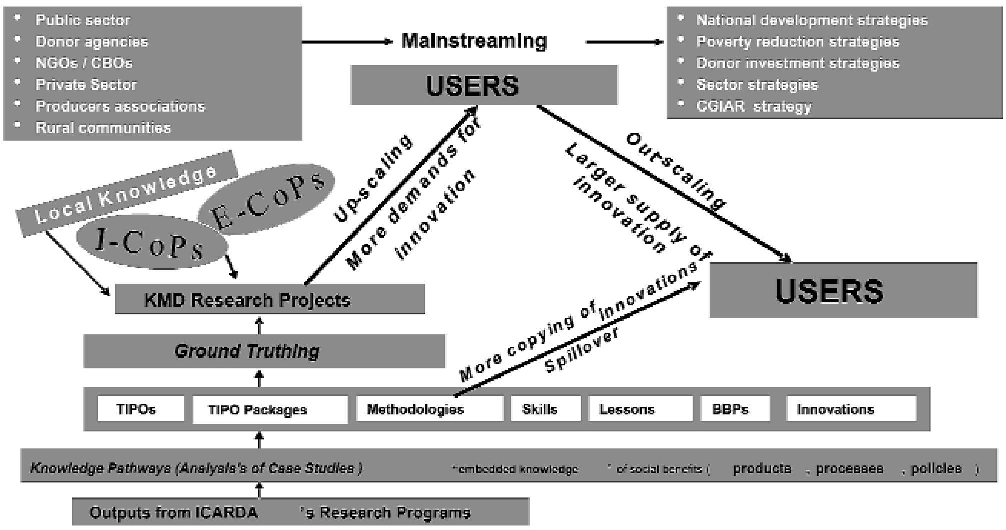

Fig. 2. ICARDA's KMD famework and processes consider how the stakeholders (rural communities, public and private sectors, scientists, civil society organizations, *etc.)* can be brought together in coalitions to facilitate mainstreaming, up-scaling and out-scaling.

approaches to dissemination include the use of community development communication, development journalism, and village drama.

Development of an implementation plan

Step 1: Analysis of Knowledge Pathways generated from current or past research projects:

The analysis of the research results (beyond publication of outputs) enables the identification of the Key Agricultural Knowledge Elements - KAKEs (TIPOs, TIPO-packages, Best Bet Practices, Methodologies, Skills, Lessons and Innovations) emerging from current and past research projects. To do this KMD has developed a Case Study Template (CSTs) to ensure consistent analysis and documentation (Box 1).

Box 1: The Key Agricultural Knowledge Elements (KAKEs)

Outputs*:* A form of knowledge is the results (data and information) which ICARDA generates from research. Outputs could be technological, institutional or policy options (TIPOs)
Lesson Learned: Is another form of knowledge that ICARDA has not assessed systematically. The lessons learned include knowledge of positive/negative factors, circumstances and conditions that affect projects and their outputs.
Methodologies*:* A third form of knowledge is the approaches and methodologies developed in generating and disseminating outputs. These processes may: (a) be based on the existing Technology Transfer systems; (b) influence and lead to policy and strategic shifts (e.g. community- driven development (CDD), gender mainstreaming); or (c) influence demand for research results.
Best Bet Practices (BBPs)*:* Innovative procedures, approaches and tools that offer win-win scenarios for pro-poor growth through agriculture.
Technical advisory notes (TANs): are "concise communication guides" of specific TIPOs accepted and adopted by users and stakeholders at small scale- pilot levels.
Innovations: are improved/ cost-effective new learning, ideas and approaches that address problems/opportunities faced by the rural poor. The "approaches" could be TIPO – packages, BBPs, networks, partnerships, etc.

Step 2: Ground Truthing:
The ground truthing surveys (GTS) are interdisciplinary tasks that involve the bio-physical scientists and the socioeconomists in ICARDA HQ, outreach programs and the collaborating NARS. The purpose is to 'screen' priority KAKEs which have optimal relevance and acceptance of the broader stakeholder community **-** an essential step in turning them into valid IPGs ready for wider use.

Step 3: Use of research results:
Once identified and melded into local knowledge and practices, the promising KAKEs could be mainstreamed for up-scaling and out-scaling according to supply and demand rules.

Integration of KM and ICT

The success of ICARDA's KMD approach requires a strongly integrated KM and appropriate ICTs that operate through strategic linkages between research, services and development domains as shown below**:**

Research:
- to develop demand based International Public Goods (from past, current or new research)
- to identify the most appropriate policy and institutional frameworks needed to promote generation and use of IPGs

Services:
- *ICTs:* Advanced, appropriate and flexible systems capable of assimilating, representing knowledge and other human experiences, supported by**:**
- *Capacity Building:* programs that aim to enables the NARS, universities, TT and extension organizations to conduct participatory and multidiscipline community based research and to extend the results to large number of users.

Development:
- Effective use of development and investment projects as Technology Transfer Agents instrumental in mainstreaming, dissemination, upscaling, outscaling processes.

Crop rotations in dryland agriculture of Central Asia - research achievements and challenges

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Abstract

Dryland agriculture in Central Asia is based on rotations of small grains with summer fallow (SF) in general. In northern Kazakhstan (NK), generally adopted rotation is continuous spring wheat with SF while in southern Kazakhstan (SK) and in Kyrgyzstan winter wheat is rotated with SF, which is normally practiced once in three to five years. Among other crops some area in both regions is occupied by barley. Long-term research in the north and four year research in the south indicated that in both sub-regions there is no justification for SF to be a base for the crop rotation. The SF practice is usually advocated as means of moisture conservation and weed control. Studies in all three sub-regions indicated that advantage of SF in accumulation of soil moisture on average are not remarkable to spend the whole year with no crop. As to weeds, there are opportunities to control them using efficient chemicals. SF however provides some advantage of more available nitrates before wheat planting because of accelerated organic matter decomposition during the year of summer fallow, which positively influences grain yield and its quality. However, N-fertilizer would wipe out this advantage in the continuous cropping systems instead of leaving the land with no output for one year. The field trials in all three sites have shown that SF provides higher grain yields (10-20 %) as compared to continuous cropping but it is not enough to justify one crop in two years with such a marginal increase in yield. The best results were obtained when SF was replaced by oats or dry pea in NK, by chickpea and alfalfa in SK, and by dry pea and safflower in Kyrgyzstan. But most important is the fact that SF combined with numerous mechanical tillage operations is major cause of soil erosion and land degradation. At the same time, it is not economical compared with continuous cropping systems.

Introduction

Large scale grain production in northern Kazakhstan began in mid-1950s, and it involved conversion of grasslands ecosystems into croplands. From the very beginning, the recommendation was to grow spring small grains, primarily spring wheat, continuously with summer fallow once every 5 years. This recommendation was based mostly on the Canadian practice of following a ‘summer fallow – wheat’ rotation in dryland agriculture. Spring wheat in northern Kazakhstan is sown in the second half of May and harvested between mid-August and mid-September. Thus, the summer fallow period lasts 20-21 months. For a long period since development of new lands in mid-1950s, summer fallow was considered necessary for the success of dryland farming. The only debatable point was the frequency of incorporating fallow in the rotation cycle.

The first report in the former Soviet Union casting doubts about the necessity of summer fallow on black soils in northern Kazakhstan was from Suleimenov (1988). It was published for starting a discussion among agronomists working in dryland agriculture on this important topic. They unanimously concluded that something was wrong either with the research methodology used or with the interpretation of the data in that report, which led to erroneous conclusions. Thus, there was a need for additional data in support of the earlier conclusion on the importance of annual cropping for obtaining economic and environmental benefits and eliminating the summer fallow (Suleimenov and Akshalov, 1996; 2005). Dryland agriculture in winter wheat based cropping systems in south Kazakhstan and Kyrgyzstan also includes summer fallow as obligatory component of crop rotation, which usually consists of rotation of fallow and small grains. This paper reports the results of these additional studies carried out in north and south Kazakhstan and Kyrgyzstan.

Material and methods

Spring wheat trial

At the Shortandy station in north Kazakhstan a field was selected in 1983 for establishment of the experiment. It had heavy clay loam black soil and had been growing small grains continuously since 1979. A 5-year rotation, 'summer fallow-wheat-wheat-barley-wheat,' was used as 'control'. In the second rotation, 'summer fallow' was replaced with oats sown in 1984 making it a crop rotation of annually grown small grains, 'oats-wheat-wheat-barley-wheat'. The third rotation was 'continuous wheat'.

The second factor in the study was the three crop management practices, 'simple', 'common', and 'best'. The 'simple crop management' (SCM) treatment was a poor management system involving no use of any fertilizers and pesticides. The 'common crop management' (CCM) treatment included widely used practice of applying phosphorus fertilizers (80 kg ha^{-1} of P_2O_5) once in five years during the fallow period, and application of 2,4-D herbicide to control broadleaf weeds. In addition, snow ridging was done once in winter using special snow ridge plows to trap snow drifts. The 'best crop management' (BCM) treatment included application of both phosphorus and nitrogenous fertilizers. Ammonium nitrate was applied annually before sowing at the rate of 30-40 kg N ha^{-1}. The BCM practice also included application of herbicides whenever necessary. Snow ridging, as 40-50 cm snow windrows, was done twice during winter to assure adequate snow accumulation.

The average annual precipitation in Shortandy is 320 mm, distributed throughout the year with maximum rainfall during summer and peak rainfall in July. Winter precipitation, as snow, is an important source of moisture and constitutes about one third of the total annual amount. Out of the 20 years, 4 years were extremely dry, 5 years were dry, 9 years were moderately dry, and 2 years were favorable in terms of the total amount of precipitation received. Crop yield data used for discussion were from 1988 onwards because this was the year when the full cycle of the five-year crop rotation was complete.

Winter wheat experiments

Two research sites for winter wheat based rotations were Krasniy Vodopad station in south Kazakhstan and Zhany Pakhta farm in Kyrgyzstan. The trial in south Kazakhstan included comparison of three rotations consisting of two years of continuous winter wheat after either summer fallow, or alfalfa or chickpea. In Kyrgyzstan, the trial included sowing winter wheat after three types of summer fallow (common, improved by application of green manure with pea, and improved by application of 30 t ha^{-1} manure) against replacement of summer fallow by either pea or chickpea or safflower. Application of fertilizers included 60 kg P ha^{-1} and 45 kg N ha^{-1}.

In Krasniy Vodopad station and Zhany Pakhta farm the average annual precipitation is 350 mm and 300 mm, respectively, with major rainfall in winter to spring period.

Results

Spring wheat study

Moisture conservation is supposedly one of the most important advantages of summer fallow. According to the long-term data in Shortandy, water storage in 0-100 cm soil layer prior to sowing spring wheat in mid May depended on summer fallow or stubble and on the intensity of snow management. During the summer fallow, moisture storage depended on snow management intensity as follows: 60 to 100 mm for simple, 120 to 140 mm for common, and 140 to 160 mm for intensive management. In the same years, water storage on stubble fields ranged from 40 to 70 mm for simple, 90-120 mm for common and 130 to 150 mm for intensive snow management. These data show no great advantage of summer fallow in moisture storage for the same intensity of snow management. Fallowing increased only 10 to 30 mm of available water in one meter of soil layer.

Weed control is one of the widely recognized advantages of summer fallow, because numerous tillage operations during summer fallow period ensure weed-free crops for several years. The data obtained showed that there was no need to practice fallow for weed control because weeds can be effectively controlled by herbicides in both rotations with or without summer fallow including continuous wheat since 1979.

Analysis of the soil sampled prior to sowing of crops showed that nutrient concentration depended on crop management, and there was a notable advantage of summer fallow. In spring 2004, prior to sowing spring wheat, NO_3 -N concentration in 0-20 cm soil layer in summer fallow was 3.29 mg 100g^{-1} with SCM, 4.76 mg 100 g^{-1} with CCM and 8.1 mg 100 g^{-1} with BCM. The NO_3 -N concentration was lower on stubble land and ranged from 1.93 to 3.62 mg 100 g^{-1} of soil. These data show that nitrogen availability is substantially improved by summer fallowing. Before sowing in stubble land, nitrogen fertilizers were applied in BCM practices at the rate of 30-50 kg N ha^{-1}, which improved nitrogen availability up to the medium supply level.

The most important integrated assessment of pre-cropping management is its influence on crop yield. It is often emphasized that summer fallow drastically increases grain yields in the dry areas. This was the reason for analyzing the grain yield data in groups of years with different moisture regimes. The driest year was 1991 and in this year the grain yield for continuous spring wheat under SCM treatment decreased to 0.16 t ha^{-1}. On average, in extremely dry years, spring wheat yield for SCM practice was only 0.32 t ha^{-1}. The spring wheat grain yield on stubble land in rotation with fallow was a little better but still very low. Also, in dry years, summer fallow was quite efficient in the case of SCM treatment. The grain yield of the first wheat crop after fallow was 54% higher as compared to that of the continuous wheat since 1979. The grain yield on stubble land in rotation with summer fallow was also 19-24% higher as compared to that of the continuous wheat. When the crop management was improved by introducing CCM practices, the advantage of summer fallow over continuous wheat reduced from 54% to only 25%. Under the BCM, the crop yield increased dramatically (more than doubled in all fields) and was very high during the dry years. On average in dry years, increase in grain yield of wheat sown after summer fallow-against stubble land was 24%.

In the moderately dry years, which represent the most prevalent climatic conditions, the advantage of summer fallow over continuous wheat was rather small. On average for seven moderately dry years, and under SCM, advantage of summer fallow against stubble land was as high as 15% with no difference in wheat yields on stubble land over the long duration. On average, wheat yield on summer fallow was higher than that on stubble land by about 10%.

The last five years of the experiment had favorable rainfall, which was also above average. In the most favorable years (2001-2002), average grain yield under summer fallow practice increased from 1.29 t ha^{-1} to 2.55 t ha^{-1} due to better crop management. In continuous wheat, increase in yield ranged from 1.32 to 2.62 t ha^{-1}. On average, grain yield in three treatments of wheat sown on summer fallow was higher than that from stubble land by 4-7%.

Considering the average yield for 16 years (1988-2003), wheat sown in summer fallow treatment produced 15% more grain yield compared with that from continuous wheat grown during 24 years on one field. The long-term data indicated that the advantage of summer fallow was 15% with continuous wheat, 21% under SCM and 13% under both CCM and BCM. These data support the conclusion that significant yield advantage in wheat grown after summer fallow over continuous wheat occurred with low input technologies, and especially in dry years. Also, there was no decrease in wheat grain yield during continuous wheat cultivation when the same cultural practices were used.

The impact of growing feed grains (e.g., barley and oats) in the rotation cycle was also studied. Both feed grains produced more grain yield than the spring wheat, and their yields depended on the crop management practices. On an average, grain yields of barley and oats were higher than that of spring wheat by 33-41%. Oats were higher yielding, and a better preceding crop for spring wheat than barley. The grain yield of wheat sown after oats was 8% higher than that of continuous wheat, and the wheat yield was not affected when sown after barley.

Although grain yield is an important indicator for assessing the efficiency of crop rotations, total production from the entire area practicing summer fallow, which produces nothing, is also an important criterion. The ‘control’ involved a five-year crop rotation, which included three crops of spring wheat and one of barley. In ‘annual grain cropping’ rotation the fallow was replaced by oats. Thus, total production involved five fields in both rotations, which was divided by five in the case of both rotations. The comparative data of 13 years show an advantage of annual cropping in grain production for all crop management practices (Table 1).

Data on grain production from the total area show that, first and foremost, crop management is more important than crop rotation. Grain yield from total cropland area increased for CCM and BCM as compared to SCM to 1.63 and 2.17 times, respectively. In addition, crop management influenced the efficiency of crop rotation. Under the simple crop management, average grain yield from total area decreased in continuous wheat by 10% because of dramatic yield reduction in continuous wheat during the dry years. However, even under SCM, the annual grain cropping including oats instead of summer fallow increased grain yield from the total cropland area by 15%.

Under the CCM practice, even continuous wheat produced 8% more grains than the rotation based on summer fallow, whereas annual small grains cropping increased grain production by 18%. Under the BCM, growing continuous wheat or annual small grains increased grain production by 19% and 28%, respectively over the fallow-based rotation.

Economic assessment is the most important criterion for farmers to make decisions, although prices for inputs and outputs change over time. Approximate economic analyses were done for the five-year data (1996-2000) at prices of US $100 t^{-1} for wheat and US$ 80 t^{-1} for feed grains. For SCM, CCM and BCM, respectively, the net profit ha^{-1} was US $9, 25 and 49 in the fallow-based rotation, US $27, 43 and 75 for the annual rotation of small grains, and US $ 13, 37 and 77 for continuous wheat. Hence, continuous wheat or annual small grains were economically more profitable under any crop management. These conclusions contradict the belief commonly held prior to conducting this study about the importance of summer fallow in the production of spring wheat.

An important consideration for sustainable agriculture is the maintenance of soil fertility, of which the main factor is the soil organic matter (SOM) content. In 2005, after 17 years of complete establishment of three cropping systems, ‘F-W-W-B-W’ (control), ‘O-W-W-B-W’ and ‘continuous wheat’, the SOM content in 0-30 cm soil layer under BCM slightly decreased in ‘control’ (the fallow-based cropping system) from 3.40% to 3.35%. In contrast, the SOM content increased to 3.80% in the ‘continuous grains’ and 4.03% in the ‘continuous wheat’ systems. Measurements of SOM contents were made in small plots which were not prone to soil erosion. But losses of SOM through erosion on summer fallow fields were much higher than those reported herein on small plots.

Winter wheat study in south Kazakhstan

In south Kazakhstan, in winter wheat based rainfed cropping systems, data obtained at the Krasniy Vodopad station also demonstrated possibility of reducing summer fallow area in dryland agriculture (Table 2).

Table 1. Grain yield (t ha^{-1}) from total cropland area as affected by crop rotation or continuous wheat under different crop management practices in north Kazakhstan (average for 1991-2003)

Cropping system	Crop management practice			Average	
	Simple	Common	Best	t ha^{-1}	%
F-W-W-B-W	0.90	1.38	1.77	1.35	100
O-W-W-B-W	1.04	1.63	2.26	1.64	121
Continuous W	0.81	1.49	2.10	1.47	109
Average	0.92	1.50	2.04	1.49	-
LSD (0.05)	0.16	0.20	0.26	-	-

Table 2. Grain yield (t ha^{-1}) as affected by crop sequence in south Kazakhstan (average for 2001-2005)

Rotation	Year			Average
	1st	2nd	3rd	
Fallow-wheat-wheat	-	2.29	1.69	1.33
Alfalfa-wheat-wheat	-	2.14	1.81	1.32
Chickpea-wheat-wheat	1.06	1.86	1.47	1.46

Wheat sown on fallow gave the highest grain yields. Usually, this is one of the major justifications for including summer fallow in rainfed agriculture into any crop rotation. In favorable years wheat on fallow gave 3.0-3.2 t ha^{-1} while in the dry years it provided 1.42-1.45 t ha^{-1}. The average yield was 2.29 t ha^{-1}. On an average, during the second year, the wheat grain yield went down quite remarkably by 26% with no big differences in dry and wet years because in every year there are some periods of drought. Also, weed infestation and nitrate availability play their role.

The crop rotation including alfalfa looks rather more attractive. Wheat sown after alfalfa gave yield just 7% lower than on fallow but wheat in the second year after alfalfa gave grain yield 5% higher. Thus over the two consecutive years after both fallow and alfalfa wheat productivity was the same. But alfalfa itself produced on average 2.9 t ha^{-1} of excellent hay and improved soil fertility.

Chickpea failed only once in five years, in the very dry 2001. All other four years, yields were quite high for rainfed agriculture. In Kazakhstan, chickpea is not a commercial crop but in the neighboring Uzbekistan chickpea prices are about US$ 300 per ton, and yields of about 0.5 t ha^{-1} in rainfed conditions are enough to break even. On average, wheat yield after chickpea was higher than the second year wheat after fallow because of better nitrogen availability in the soil. This shows that chickpea could be a very good crop to include in the crop rotations. It is important also to emphasize that in recent years an improved chickpea line from ICARDA was included in the study, which further improved crop yields.

OM content decreased during the two years of wheat growing after alfalfa from 1.26 to 1.20% while in rotation with fallow it decreased from 1.16 to 1.11%, which indicates that including alfalfa into a crop rotation could contribute to sustainability of the farming system.

Winter wheat study in Kyrgyzstan

In the drylands of Kyrgyzstan, summer fallow had no gain in moisture accumulation against stubble land. However, application of manure improved moisture storage in soil while growing a green manure crop in the fallow period proved to be better than black fallow, although it was not as good as with the improvement of fallow by application of manure.

Comparative study of soil organic matter in 0-25 cm layer was conducted in different summer fallow treatments. During ten years (1990-2000), content of organic matter in rotation with black fallow got reduced by 0.05%, while in rotation with green manure (pea) it increased by 0.22%. Crop rotations with food legumes were introduced later and there was not enough time to expect any significant changes in organic matter.

All crops tested provided quite high grain yields even in the driest year (i.e. 2006) when they were sown on otherwise fallow land. With no fertilizers applied, the best yields on average were obtained with chickpea (1.57 t ha^{-1}) because of the advantage in normal and dry years. Safflower provided rather high yield under favorable weather conditions and on average ranked second after chickpea (1.43 t ha^{-1}). Pea proved to be lower yielding (1.20 t ha^{-1}) as compared to chickpea in all three years.

Application of fertilizers improved productivity of all crops but in different way. The highest response to fertilizer was observed in pea (33%) followed by safflower (24%) and chickpea (8%). Because of the fertilizer application the grain yield of pea improved more notably and was nearly the same (1.60 t ha^{-1}) as chickpea (1.69 t ha^{-1}) although in dry year chickpea still had advantage. Safflower provided very good return under fertilizer application in favorable conditions and exceeded the other crops on the basis of an average of three years (1.78 t ha^{-1}). In the most favorable weather condition the best crop was safflower while in moderate and dry weather conditions the best crop was chickpea.

The grain yield of winter wheat sown in the three years after different crops as compared with traditional summer fallow showed no advantage of leaving one year fallow with no crops (Table 3). Winter wheat response to fertilizers on summer fallow was lower than after pea and safflower and it did not affect ranking of preceding crops in their effect on winter wheat productivity. The most important point is that there is no advantage of summer fallow over food legumes in affecting the yield of winter wheat. Attempts to improve summer fallow technology by application of manure and green manure slightly improved the efficiency of summer fallow as compared to the traditionally tilled black fallow, which served as 'control'. Safflower sown on otherwise fallow land definitely proved to be a bad preceding crop for wheat reducing its yield in each year, both with and without fertilizers.

Table 3. Winter wheat grain yield (t ha^{-1}) as affected by fertilizer and preceding fallow or crop in Kyrgyzstan (average for 2004-2006)

Fallow or crop preceding winter wheat	Fertilizer treatment -	Fertilizer treatment +
Summer fallow	1.90	2.05
Fallow with green manure	1.83	2.14
Fallow with manure	2.00	2.24
Pea	1.90	2.14
Chickpea	1.86	2.15
Safflower	1.45	1.54

Although the 'black fallow' is standard and commonly-adopted practice in dryland agriculture in Kyrgyzstan it produces no crop while other crops tried as its replacement provided quite high yields. Economically food legumes are well ahead of safflower as their yields are high and prices are also very good. And these crops were grown on otherwise fallow land. Winter wheat provided net profit almost three times lower than chickpea and dry pea.

Discussion and conclusions

When the first publication appeared on the subject in 1988 (Suleimenov, 1988) contradicting the prevailing view on the importance of summer fallow in the production of wheat on black soils in Kazakhstan, the report was dismissed by the agronomists of the region with the argument that the reported data on summer fallow were too scanty to draw decisive conclusions. It was emphasized that crop response would be different in long-term studies including very dry years.

The studies conducted since then showed that benefits of summer fallow in north Kazakhstan were definitely more during dry years as compared to moderately dry and wet years. There was an increase in yield because of the 'summer fallow' over 'stubble land' during the dry years. On average, increase in yield of wheat by summer fallow in comparison with continuous wheat was 28-30% in very dry years, 18-24% in dry years, 8-10% in moderately dry years, and 4-7% in wet years. The benefit of summer fallow to wheat productivity also depended on the crop management. It increased in dry years under simple crop management without application of snow trapping and crop and weed management technologies. The average increase in yield of spring wheat sown on summer fallow compared to that sown on stubble land was only about 15%, and the grain yield was not affected by the duration of continuous wheat up to 25 years. This hypothesis was put forward in 1988, and has been substantiated by the data from the long-term experiment.

Shnider (2004), a progressive farmer from western Siberia in an area adjacent to north Kazakhstan, reported that he was using continuous grain cultivation until 2001, primarily spring wheat, without using summer fallow. During 1994-2001, the average grain yield on his farm was 2.11 t ha^{-1} compared to 1.59 t ha^{-1} in the neighboring farms, which on average maintained 14.3% of land under summer fallow. He farms without any summer fallow, although local scientists strongly recommended allocating 25% of cropland to summer fallow (Moshchenko and Bormotov, 2000). There are many advocates of 3-year rotation, with 33% of cropland under summer fallow in north Kazakhstan (Dvurechenskiy, 2003).

Summer fallow supposedly improves moisture supply to the crop, but the increased moisture storage under fallow occurred only in two years for one crop. In the present experiment, double snow ridging made water storage on stubble land similar to that under summer fallow. In Pavlodar Province, a technology of wheat harvesting left a lot of straw as tall stubble on the land that trapped enough snow to provide the same water storage as on summer fallow (Mustafaev and Sharipov, 2006).

While complete elimination of summer fallow is not recommended immediately, cropping systems based on frequent summer fallow are unsustainable because summer fallow is rather destructive in any farming system due to severe soil erosion by water and wind and accelerated decomposition of SOM. Some soil scientists have reported high risks of soil erosion on summer fallow, and yet advocate this practice. According to Shiyatiy (1996), soil losses by water erosion were 31 times more under summer fallow than those from a stubble land. In another study on the same research site, Funakava et al. (2004) concluded that, given the possible adverse effects of the summer fallow on enhanced decomposition of SOM, snow management must be the main strategy for capturing water rather than the summer fallow practice.

Studies on winter wheat based cropping systems in both sites in south Kazakhstan and Kyrgyzstan have also shown that dryland agriculture can be more successfully run without summer fallow. In south Kazakhstan, better alternatives to summer fallow were found in crops such as alfalfa for forage or chickpea for grain while in Kyrgyzstan promising results were obtained by replacing summer fallow by pea and chickpea as well as by safflower.

Future agricultural research must address the issue of replacement of summer fallow by identifying a better choice of either food legumes or oilseeds.

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Gmelina arborea and lemongrass based agroforestry system for sustainable development of degraded lands in Central India: an appraisal

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Abstract

Wastelands constitute a severe natural resource management problem in India. The population pressure on land resources is quite acute especially in the state of Madhya Pradesh (Central India). Madhya Pradesh is spread on some 30.75 million ha of land out of which 49 % is under cultivation and 19.3 % is degraded land. Nearly one-third of the area is unutilized cultivable wasteland that can be brought under vegetative cover with reasonable efforts. The present paper advocates the use of *Gmelina arborea* (known locally as Khamer*)* and lemongrass *(Cymbopogon flexuosus)* based agroforestry systems for sustainable development of degraded lands. *G. arborea* is a fast growing indigenous woody perennial tree species yielding timber, fuel wood and medicinally important root and bark. As a compatible component, lemongrass is a perennial aromatic species that is commercially cultivated for aromatic oil. Two months old seedlings of lemon grass were planted in rows (60 x 60 cm) in between tree row of *G. arborea* under two planting geometries i.e. 5m x 2.5m and 2.5m x 2.5m. The tree-crop interaction was evaluated by computing growth and physiological productivity parameters of both the components. Under shaded condition of 5m x 2.5m planting geometry of *G. arborea*, the growth and yield of lemon grass was superior to that under close spacing of trees (2.5m x 2.5m). This system not only provides the added biomes but also accelerates efficient nutrient cycling thereby halting the land degradation. It can be seen as a phasic development of productive agro-ecosystem and an alternate land use system, wherein farmers can manage their degraded soils by growing trees and aromatic grass for the services and/or products. The tree-crop interaction parameters quantified in the study clearly indicate the advantages of the system in improving soil conditions and boosting farm income under dryland situations.

Introduction

A sizable proportion of the land area in India produces suboptimal amount of biomass because of such environmental and other constraints as water logging, soil erosion, salinity, alkalinity, and desertification. Due to increasing pressure of population, there is an excessive demand of more land especially for agricultural use. Exploitation of the marginal fragile lands for agriculture is leading to further degradation. Thus the area under wastelands is increasing and causing ecological problems. In India, wastelands constitute a sizeable part (~57%) of the total geographical area. It has been estimated that more than half of the geographical area is suffering from some form of degradation. As per the estimates by the National Bureau of Soil Science and Land use Planning (NBSSLUP), a dominant fraction of the wastelands is under water erosion while wind erosion, chemical deterioration, and physical deterioration account for smaller proportion.

After the new state of Chhattisgarh was carved out from Madhya Pradesh (MP), a couple of years back, the geographical area of MP state got reduced to 30.75 million ha, out of which 49% is under cultivation. The majority of cultivated area is under rainfed (69%) with enormous unexploited agricultural production potential. Nearly 7 million ha is total wasteland, out of which 1.5 million ha is unutilized cultivable wastelands. This land is however amicable for use in agricultur if appropriate methods are developed. These methods have to be ecologically sound so that there is an economic utilization consistent with conservation of the resource base. Medicinal plant based agroforestry systems offer such an option, whereby woody and non woody components can be grown in close proximity as intercrops. Lemongrass *(Cymbopogon flexuosus)* is a perennial species that is commercially cultivated for its aromatic oil. Little is known about growing lemongrass in association with medicinally important trees, although some studies on irrigation (Singh, 1997; Singh et al., 1997; Singh et al., 1999), intercropping (Chauhan et al., 1999a, 1997 b; Singh and Shivraj, 1998) and nutrient management (Rao et al., 1998) have been conducted on this species.

In this study the potential of Khamer (*Gmelina arborea*) and lemongrass (*Cymbopogon flexuosus*) based tree-crop interaction has been investigated for use and improvement of cultivable wastelands. The objective was to study biophysical tree-crop interactions of Khamer and lemongrass under different tree-planting geometry and to evaluate the productivity of the two components on cultivable wastelands.

Materials and methods

Characteristics of *Khamer (Gmelina arborea):*

It is an indigenous medium sized timber tree species of tropical dry deciduous forest next to teak (*Tectona grandis*) in its importance. It can be grown well on environmentally stressed sites in the dry areas. Fruits are edible and leaves have fodder value. It is medicinally important and is used for treatment of stomach disorders. Wood is used for furniture, bentwood, boat building, paneling, brushes, slate frame, and wood pulp for making different kinds of papers.

Characteristics of lemongrass *(Cymbopogon fIexuosus):*

Lemon grass is perennial aromatic grass that yields an essential oil used in perfumery and pharmaceutical industries. It is commercially cultivated in many parts of India, mainly as rainfed crop on poor marginal lands. It is a hardy, drought resistant species that can grow under a wide range of climatic conditions. The leaves give lemon like odor and contain 75-80% citrol, which is used for manufacturing vitamin A. The oil is used for manufacturing of soap, cosmetics and essence. The crop is best propagated through seed raised in nurseries.

Experimental site and design

This investigation was conducted in the Medicinal Garden of the Crop and Herbal Physiology Department, College of Agriculture, JNKVV, Jabalpur (MP). The Khamer + lemongrass based agroforestry systems in two different tree planting geometries was established in the year 1998-99 and the present study was carried out during the period 2003-05. The experimental area lies at 23° 51’ 49’’ N latitude, 79° 59’ 42’’ E longitude, and an altitude of 400 m above mean sea level. A randomized complete block design with four replications was used. The two geometries (5m x 2.5m, and 2.5m x 2.5m) in which Khamer had been planted in 1998 served as the treatments. They were intercropped with lemongrass. For comparison of lemongrass performance as affected by the intercropping a pure crop of lemongrass in the open field was also included as the control treatment. Mainly two types of lemongrass are recognized, namely, the red stemmed cultivar which is a selection of ‘OD-19’ (Dodakkali, Kerala) and the white stemmed cultivar (*C. fIexuosus* var. *albescence*). In the present investigation the red-stemmed lemongrass was used as it has high citrol content. Ten kg of the seed produces enough seedlings for a hectare. About two months old seedlings were planted in rows 60 x 60 cm apart at the start of rains (in mid July). The crop was harvested in mid February. Yield data are of the three harvests in a year.

The observations recorded to evaluate the performance of the systems included the growth parameters of both the components, yield of lemongrass, root characteristics, litter dynamics and soil properties.

Result and discussion

The Khamer tree was significantly higher (6.03 m) in 5m x 2.5m planting than in the 2.5m x 2.5m planting. Similar pattern was observed for other growth parameters i.e. tree mean diameter, basal area, tree canopy diameter, average number of branches per tree and average number of leaves per tree (Table 1).

All the growth parameters of lemongrass show its potential for good performance under shade as compared to open (Table 2). The horizontal root length density of lemongrass was found more in wider tree planting geometry than in the closer geometry (Table 3).

The leaf area of lemongrass grown under different planting geometries of Khamer tree showed difference. The partial shade condition and more moisture under tree plantation favored the lemongrass growth, as reflected in improvement in all the growth parameters, as compared to the lemongrass grown in the open. The available soil moisture, varied significantly between two tree planting geometries and open field and also across the month and seasons with a maximum under 5m x 2.5m tree planting and a minimum under open condition. Similar trend was also observed in case of soil temperature with respect to the intercropping, but the temperature was highest in the open field. Soil moisture was more during rainy season but gradually decreased during the early winter. The litter fall of Khamer tree was higher under wider spacing (Fig. 1). The tree litter is an important source of nutrients for lemon grass grown underneath the Khamer canopy favoring the lemongrass growth. These findings are in conformity with those of Singh and Gupta (1977). Litter decomposition trend, studied by putting litter in a bag and weighing it at different intervals, was similar under the two spacings and hence average values are presented in Fig 2. The rate of decomposition in the winter months was relatively

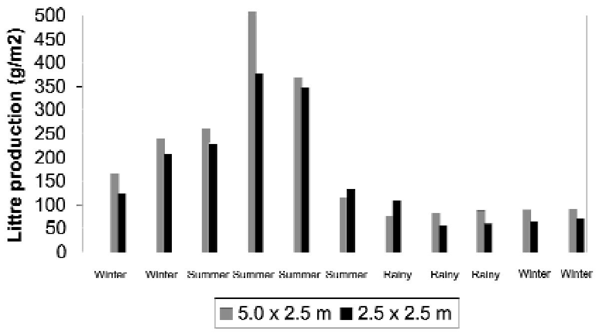

Fig. 1. Effect of planting geometry and season on litter production of *Gmelina arborea* for the year 2003.

Table 1. Effect of different tree spacing treatments on growth parameters of Khamer (*Gmelina arborea)* when intercropped with lemongrass

Growth parameter	Tree spacing		SEm±	CD(0.05)
	5m x 2.5 m	2.5m x 2.5 m		
Height (m)	602.8	421.6	2.95	10.04
Basal area (cm^2)	71.7	30.6	1.13	3.14
Diameter (cm)	9.5	6.2	1.10	3.06
Canopy diameter (m)	3.9	2.5	0.30	0.83
Number of branches per tree	35.8	15.8	1.19	3.30
Number of leaves per	766	348	7.7	21.3

Table 2. Growth behavior of lemongrass intercropped with Khamer trees planted at two different spacings as compared to lemongrass grown in the open

Growth parameter	Intercrop with tree spacing		Open	SEm±	CD(0.05)
	5m x 2.5m	2.5m x 2.5m			
Height (m)	1.51	1.26	0.93	0.106	0.295
Canopy diameter (cm)	22.8	16.2	11.5	1.09	3.03
Tillers per plant	54.0	44.0	39.0	1.09	3.03
Leaf area (cm^2)	445.0	439.4	371.2	1.09	3.03

Table 3. Root growth of lemongrass intercropped with Khamer trees planted at two different spacings as compared to lemongrass grown in the open

Growth parameter	Intercrop with tree spacing		Open	SEm±	$CD_{(0.05)}$
	5m x 2.5m	2.5m x 2.5m			
Horizontal length (cm)	29.1	25.7	20.5	1.10	3.06
Diameter (cm)	0.41	0.27	0.22	0.074	0.206
Number per plant	41.0	31.6	28.6	1.13	3.13

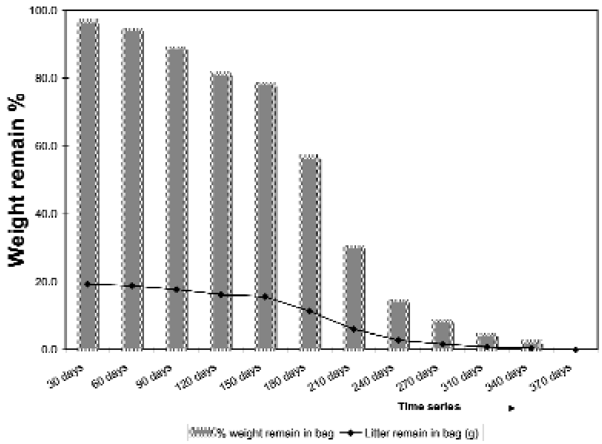

Fig. 2. Rate of litter decomposition under two different densities of *Gmelina arborea* trees intercropped with lemon grass.

lower in the beginning because of low temperatures and scanty rainfall. Singh and Gupta (1977) also recorded similar observations.

The litter decomposition of Khamer resulted in increased soil organic carbon content and the availability of mineral nutrients in the soil. The Khamer tree + lemongrass combination had higher contents of NPK in the soil than the lemongrass grown alone (without tree). The estimated maximum values of NPK additions were 200.5, 19.4 and 258.6 kg ha^{-1} respectively in wider spacing (5 x 2.5 m^2). The findings are in agreement with those of Chauhan et al. (1997a). The soil nutrient status, after six months of intercropping, revealed significant amelioration effect in the two intercropped treatments as compared to the treatment of lemongrass alone.

The light intensity incident on lemongrass was more in the open (without tree canopy) than under Khamer + lemongrass based system (Table 4). In the closer tree spacing (2.5m x 2.5m) the tree canopy got nearly closed, and therefore the light intensity at the surface of lemongrass decreased as compared to wider planting geometry. Higher incident light under 5m x 2.5m tree spacing as compared to 2.5m x 2.5m spacing favored the underneath lemongrass crop.

Land equivalent ratio (LER) is an easy way to evaluate the productivity of the different components of the system (Rao and Coe, 1992). In the present study the LER was higher in 5m x 2.5m tree planting geometry intercropping (Table 5). This indicates that this was the most productive system.

Table 4: Comparison to light intensity in Khamer + lemongrass based agroforestry system. Three observations for each spacing

Tree spacing	Light intensity(Lux) Outside canopy	Below canopy	Percent light falling on lemongrass
	1048	694	66.23
5m x 2.5m	1024	713	69.69
	1001	721	72.00
	1058	533	50.40
2.5m x 2.5m	1109	642	57.90
	1033	509	49.30

Table 5. Land equivalent ratio (LER) of Khamer + lemongrass based agroforestry system

Tree spacing	L_{iy}/L_{sy} lemongrass	K_{ip} / K_{sb} Khamer	LER whole system
	1	2	3
5m x 2.5m	1.25	1.38	2.63
2.5m x 2.5m	0.83	1.09	1.92

L_{iy} = Yield of lemongrass in intercrop; L_{sy} = Yield of lemongrass in sole crop; K_{ip} = Biomass yield of Khamer in intercrop; K_{sb} = Biomass yield of Khamer in sole crop.

Conclusion

The Khamer (*Gmelina arborea*) based agroforestry system, in which trees were planted at 5m x 2.5m spacing and lemongrass (*Cymbopogon flexuosus*) was grown in between the trees as an intercrop, not only provided more economic returns but also accelerated efficient nutrient cycling thereby halting the land degradation. Hence, promotion of this land use through people's participatory approach would permit achieving both environmental as well as food security goals.

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Farming in the desert - advantage and limitation, the Israeli experience

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Abstract

Only ten percent of Israel's population lives in its desert areas, which cover about sixty percent of its total land area. Traditional agriculture in the desert, as practiced by the nomadic Bedouin population, is based on relatively small numbers of hardy animals such as camels, sheep and goats kept on extensive pastureland, and on the produce from occasional planting of low yielding drought resistant grain crops on small patches. Although developed over thousands of years to adapt to the harsh desert conditions, this traditional system remains sensitive to the extremes of climate and frequently occurring droughts. Modern agriculture is developed in the desert by using water from external resources, including the "National Water Carrier", transporting water from the Sea of Galilee, or recycled sewage water from the densely populated central urban part of the country. The local saline water resources are used for irrigating tolerant crops such as tomatoes, melons, grapes, olives, dates and others by drip irrigation systems. Also new crops like Jojoba, Pitaya and *Opuntia* cactus, and various flowering crops have been successfully introduced. The harsh desert climate is successfully controlled by the greenhouse industry, producing mainly for export, off-season vegetables, flowers and herbs. Integrated pest management (IPM) methods are successfully applied, including zero cultivation periods, biological control, solarization and the release of sterile male flies for controlling the Mediterranean Fly. The sand dune zone in the coastal area is made productive by using recycled sewage water for irrigating citrus, avocado and mango plantations. For producing vegetables and flowers the greenhouses use integrated fertilization and irrigation drip systems. The hilly areas, with an annual precipitation of 200 mm, had been drastically eroded in the past; these are presently undergoing intensive reforestation. Advanced soil conservation and water harvesting methods are being applied in this process. Livestock, such as dairy cattle, but also ostriches and Tilapia fish, are successfully being raised under desert conditions. The positive results achieved by developing modern agriculture in a desert region can be mainly attributed to the human factor and a successfully managed Research and Development System for different agricultural regions. The system is producing applied know-how and agro-techniques, as well as infrastructure and living conditions well adapted to the prevailing adverse environmental conditions.

Introduction

Agricultural production and desert conditions are usually considered to be antagonistic or at the best incompatible. Since the desert is an area with adverse climatic and soil conditions with a marginal natural resource base, it is unattractive for modern agriculture, even though it also has specific characteristics which could be useful for agricultural development and production. It is necessary to identify the advantages and disadvantages of each of these characteristics and existing natural resources before deciding on large-scale development.

For developing modern agriculture in desert areas, it is necessary to generate know-how and specific technologies needed for the utilization of the desert resources. This can only be done by heavily investing in local research under desert conditions. The success or failure of desert development depends on the human factor. There is need for dedicated manpower ready to settle in the desert and capable of using scientific and technologically advanced cultivation and environmental control methods needed for achieving successful performance under adverse desert conditions. For developing and applying these technologies, abundant economic resources are required.

The desert is characterized by wastelands, low population density, a large number of sunny days with high temperature and radiation levels and scarcity of water. Usually, the few existing limited sweet water resources are only found in oasis. However, in most deserts there are deep saline water aquifers that may be utilized when applying specific technological methods. Such climatic phenomena, as frequent strong winds, sand storms and extremes of temperatures, dominate the desert climate.

Modern agricultural production methods, particularly protected agriculture in greenhouses, have been specifically developed for utilizing the favorable features of the desert areas, such as high temperatures and intense solar radiation, for achieving high production of biomass. Local saline water resources are advantageously used for crop irrigation. Applying state-of-the- art technologies in greenhouses makes it possible to control almost all factors influencing plant growth, such as temperature, humidity, radiation, protection from wind, growth media and plant nutrients. One of the characteristics of the desert loess soils is their very low infiltration rate, resulting in rapid sealing of the surface layer once the soil becomes wet and causing almost immediate water run-off in the form of streams and flooding even after a short rainfall. These run-off waters can be harvested and directed into reservoirs for later use.

Israel is a small country in the Middle East with a total land area of about 26,000 km^2. Sixty percent of its territory is desert, with rainfall not exceeding 200 mm/annum and limited to the five winter months from November to the end of March. Only 10% of the total population of Israel lives in this area. The Israeli desert is not a homogenous complex. It includes the Arava Valley extending from the south of the Dead Sea to the northern part of the Red Sea, and which is part of the Afro-Asian Rift Valley, part of which is below sea level. Dates, mango, vegetables, flowers and milk are produced in this valley.

Another part of the desert is a high plateau area 600-800 m above the mean sea level. This area produces flowering bulbs such as irises, narcissus and gladioli, as well as olives, grapes, melons and vegetables grown in open fields and in greenhouses. Also Tilapia fish is raised in greenhouses in thermal saline water.

Still another part of the desert is comprised of the flat and hilly areas covered by loess soils on which rainfed and irrigated wheat, vegetables, flowers, forage, apple, apricot and citrus (mainly lemons) are produced.

The part of the desert near the Mediterranean Sea predominantly consists of sand dunes. These dunes can be easily flattened and cultivated. By using drip irrigation, integrated with fertilizer application, Israel’s most outstanding agriculture is practiced on these once desolate looking sand dunes. The crops grown include citrus, avocado, mango, vegetables, and flowers.

‘Desert agriculture’ and ‘agriculture in the desert’

Almost 3000 years ago, an ancient agricultural system, known as the ‘Nabatean Agriculture’, was successfully practiced in the desert of Israel. This system was based on water harvesting from nearby bare slopes. The run-off water, directed to, and accumulated in, cultivated plots located at lower levels, was used for increasing soil moisture. Various vegetables and fruit crops like olives, almonds, figs and others were successfully grown under this system. This system mainly fits small-scale subsistence farming and is not practically applicable for more advanced agriculture. However, the system has high potential for adoption in the Sahel region of Africa or in other desert areas in Africa, Asia and Latin America. Under this system, *Eucalyptus* trees can be grown for fire wood, *Leucaena* trees for fodder for goat and sheep, and olive trees for oil production for human consumption.

Another type of traditional agriculture, practiced in the hilly loess soil area is the rain-fed cereal cultivation during the rainy winter season. Precipitation in this desert area is around 200 mm per annum. This amount of rainfall can produce 2 t/h of cereal grain. During summer, sheep and goat herds graze on the cereal trash. This is the type of agriculture characteristically practiced by the nomad population of the desert, the Bedouins. Under the new reality and habits of Israel, modern agriculture is developing and has established itself in the desert. This advanced agriculture, which the present article is dealing with, can be named ‘Agriculture in the Desert’.

Water

Modern agriculture in the desert, first and foremost, depends on the availability of water for irrigation. One has to distinguish between external and local water resources. External water resources are transported by the ‘National Water Carrier’ over a distance of more than 300 km from the Sea of Galilee in the north of the country. Another external resource is the recycled sewage water from the central urban area of Tel Aviv and its satellites cities, with a total population of 1.2 million, located 80 to 100 km to the north of the target area. After secondary biological treatment, the sewage water undergoes further treatment. It is filtered through sand dunes down to a depth of 80 m where it is stored for a prolonged period of time. After reaching a very high quality, almost comparable to potable water standard, the water is pumped into the distribution system. These two water sources from the north are either directly used by the agricultural sector in the south or stored in the target area in big reservoirs, some of which may contain up to one million m^3 of water.

One of the local water resources is the saline water in the 1000 m deep aquifers. Water is pumped from 700 m deep artesian wells. Salinity of the water ranges from 1000 to 2500 mg salt per liter and the temperature is about 40°C. The successful use of saline water requires knowledge and specific technology.

An Israeli innovation of the early seventies, the drip irrigation method, makes it possible to use saline water for irrigation. Using this method, the comparatively long and frequent irrigation applications at a very low water discharge rate provide for the permanent leaching of salts from the root zone of the plants. Compared with other irrigation systems, the salt content accumulating around the root system remains relatively low. Before starting a new crop in fields where sal ine water has been used for irrigation, it is necessary to make an alternative, sweet water system available for flushing and leaching the accumulated salts deep below the root zone.

Research carried out in the recent years has provided a long list of crops which are tolerant and resistant to saline water. Among others, they include asparagus, broccoli, beet-root, celery, cabbage, tomato, melon, lettuce, Bermuda grass, Rhodes grass, wheat, sorghum, sugar-beet and cotton. These crops give economical yields under a saline water irrigation regime. In some crops, as in tomatoes, the use of saline water for irrigation results in increased concentration of sugar in the fruits. Using saline water in the vineyards, the grapes attain a high level of dry matter resulting in the production of high quality wine. Saline water irrigated olives have improved oil quality.

By using a special sealed pipe system installed near the plants, the thermal water pumped from the well is used for raising the air temperature in the greenhouse during cold nights. After cooling, the same water is reused for irrigation. The thermal water can also be used for the cultivation of tilapia fish raised in fish ponds protected by greenhouses.

Introduction of new botanical species

Most of the commercial crops produced by Israel were developed from species introduced from other parts of the world. As in other agricultural fields, research is continuously searching for new species to be adapted to the local desert conditions. In the last years, new crops such Jojoba, *Opuntia* and Pitaya, were commercially introduced on a large scale. The introduction process includes various phases like observations, demonstration plots, and semi-commercial and commercial plots.

Harnessing the climate

The desert area of the Arava Valley, part of which is below sea level, is known for its warm temperatures and mild climate during the winter season. Precipitation in the Valley is low and erratic, usually not exceeding 100 mm per annum and relative air humidity is also low. Winter season, when it is cold and rainy in the northern part of the country, is the best time for producing off-season vegetables, flowers and herbs here. These products fetch the highest price in the market and are mainly destined for export. The limiting factors to be dealt with are wind and hail storms, and sometimes extreme temperatures. Growing crops under protection in greenhouse is the best solution for these problems. The agriculture growing season in this area lasts from September to May.

Soils

The growing media in the greenhouses usually consists of sand which is especially brought from often far away dunes, or specially prepared material consisting of mixtures of sand, compost, peat, vermiculite, etc., used as detached media. Rock wool, an artificial product, is also in common use. Irrigation, integrated with fertilizer application, is fully computer controlled. The amounts of water and fertilizers to be applied as well as irrigation frequency are determined by field tests for establishing water and nutrition demands. Special sensors, such as tensiometers and extractors are installed on the plots and used for monitoring soil moisture status and controlling irrigation. In the sandy desert area near the Mediterranean coast, a very advanced agricultural system of citrus, avocado, mango, flowers and vegetables is practiced. The sandy dunes can be easily leveled and cultivated. Based on the drip irrigation method, high quality recycled sewage water is used for irrigation. The climate in this area is usually mild and the vicinity of the sea limits frost hazards.

Control of other factors

Under greenhouse conditions air temperature, humidity, radiation can be automatically controlled and wind storms avoided. Furthermore, the greenhouse is protected by insect-proof nets for preventing infestation by insect, many of which serve as vectors transmitting virus diseases in addition to causing physical damage to the plants. The plastic sheets used for covering the greenhouse possess ultra violet (UV) or infra red (IR) characteristics, thereby achieving additional advantages. The greenhouse atmosphere, enriched by CO_2, facilitates improved photosynthesis resulting in higher yields.

Plant Protection

Pests and diseases, including nematodes and mites, may inflict heavy damage to the crops and indeed are the most serious limiting factor in green house conditions. Virus diseases, transmitted by vectors such as aphids, mites and white-fly, are capable of completely destroying a crop. The existence of the Mediterranean Fly limits the export of fresh produce to the USA. and Japan.

As already mentioned, the protection in greenhouses by insect-proof netting and IR plastics is very useful for controlling insects and thereby the spread of virus diseases. A plant protection special project running in the Arava valley aims at controlling pest and disease damages. The project is based on the principle that the valley is isolated from other agricultural areas and that the agricultural plots in the valley itself are also isolated from each other. The principles of the project are:

1. Cultivating in autumn, winter and spring and maintaining zero-cropping during mid summer.
2. Removing all crop residues and trash immediately after harvesting.
3. Monitoring and applying control treatments based on threshold values.
4. Introducing beneficial insects for biological insect control.
5. Using environmental friendly, biologically non harmful pesticides.
6. Introducing sterile males for controlling the Mediterranean fruit fly.
7. Using methyl bromide for soil disinfecting; this method however is now being increasing replaced by solarization.
8. Solarization by covering the moist soil bed with plastic sheets during the mid summer for a period of one month. The plastic cover traps sun radiation and increases soil temperatures to more than 50 centigrade over a prolonged period of time, thereby achieving the desired soil disinfecting effect.

The project has already runs for 5 years and has succeeded in drastically reducing the pest and disease damages and achieved the eradication of the Mediterranean fruit fly in the whole zone, which has resulted in lifting the restrictions on exporting agricultural produce from the area to the USA.

Reforestation

The northern desert area includes the southern part of the Judean Hills. In this area precipitation is around 250 mm per year. During the last centuries, the hills were completely eroded. By using appropriate soil conservation methods like terracing, fencing with stones and bushes, rain water is harvested and soil moisture status is increased.

Species such as *Eucalyptus occidentalis, E. strick-landii, E. sarangetii, Prosopis alba, P. juliflora, P. nigra, Accacia salicina, A. raddiana, Tamarix aphylla, Ceratonia siliqua, Pistacia palestina, Pinus halepensis, Parkinsonia aculeata*, etc. are planted in the area and are slowly turning into forests which are completely changing the landscape.

Raising animals under heat-stress conditions

Tilapia fish:
The existing deep aquifer in the desert is saline and thermal (40°C). Tilapia fish easily adapt themselves to this type of water. The optimum temperature for harvesting commercially profitable fish (size ~400g) is 30°C. Under these conditions, the life cycle is short, making it possible to obtain two cycles per year, compared with only one cycle for fish raised at the normal water temperatures. Raising fish in the greenhouses, with a forced oxygen environment, has the capacity of yielding 15 ton per 1000 m^2. This is a very capital intensive but profitable agricultural branch.

Ostriches:
Ostriches are well adapted to desert conditions and can survive on eroded land of very limited alternative use. They efficiently utilize the scarce natural vegetation produced on the pastureland, supplemented with food from other sources. The commercial ostrich products are meat, eggs for ornamental purpose, skins for the leather industry, and live animals sold for raising. All in all, this is a very profitable agricultural enterprise.

Dairy cattle:
Under heat stress, cattle waste energy for keeping the body cool instead of producing milk and as a result the milk yield is low. Technological innovations were introduced for overcoming heat stress problems. They include high and well aerated structures; high-potential ventilators; sprinklers for spreading water droplets; frequent wetting of the cattle; and continuous supply of cool drinking water. All these means help reducing the temperature in the cattle shed and diminish heat stress. Under such circumstances, milk production in the hot desert zones can be increased.

Human factor

Among all factors and resources influencing agricultural development in the desert, the human factor is the most important. The farmer who nowadays settles in the desert is usually very dedicated, but also strongly economically oriented type and attempts to exploit the advantages of the desert environment, while overcoming the disadvantages, by developing innovations and applying relevant knowledge and technologies needed for the purpose.

Under the prevailing Israeli circumstances, the Regional Agricultural Research and Development system has proved to be very effective. The system is based on regional cooperation, between farmers, researchers and extension workers. Within the framework of such cooperation, the objectives, working plans, and allocation of economic resources are approved and implemented. The aim is to produce the most relevant, immediately needed and practical knowledge and technologies to be used by the farmers for sophisticated and modern agricultural production.

The development of agriculture in the desert requires relatively high capital investments and additional capital is needed for the purchasing highly sophisticated production inputs. The cost of a 1000 m^2 large greenhouse alone is about 100,000 US dollars.

Such high investments are justified due to the intensive, sophisticated and profitable farming developed as a result of the cooperative management and research efforts of all partners. Farming settlements in the desert require a well developed regional infrastructure, based on physical and social regional planning and development. This infrastructure includes, among others, access roads, communication systems, access to production inputs, credit and banking services, and supporting systems for grading, packing and cold storage. Supporting technological systems and agricultural extension and research services are also essential as well as strong leadership.

The settlers in the desert need living conditions that allow them to overcome the harsh climatic conditions. This can be achieved by technological innovations in desert architecture, air conditioning and other related fields. An impressive number of such innovations have been recently achieved. All in all, if intelligently managed by dedicated manpower, the desert has a very high potential for human settlement and for food production.

High density cropping system for cash crop production in marginal land with less water

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Abstract

The production of high value crops requires a certain quantity and quality of water that is practically impossible to obtain in a dry region such as the Arabian Peninsula. The underground water level has been rapidly declining and is becoming increasingly brackish because of high withdrawals. Good quality fresh water can only be obtained by using expensive desalination techniques. Soil-less techniques offer a way of improving water-use efficiency and obtaining better water and fertilizer management in crop production. The main aim is to increase quality and quantity of produce per unit of water, area, and manpower. Soil-less growing techniques were developed by the Arabian Peninsula Regional Program (APRP) of ICARDA and adopted in Arabian Peninsula countries. High density cropping or vertical soil-less growing system is an excellent system to grow many herbs, specialty leafy green vegetables and strawberries. The system uses a tower of interlocking stackable pots. The Styrofoam pots have drainage holes and are filled with soil-less media. Nutrient solution is collected in the catchments channels under the bottom pot. This solution is re-circulated. The system was adapted for the production of the strawberries in marginal and non-productive lands with limited water in Bahrain, Kuwait, Oman, and Saudi Arabia. Since the year 2000, several joint adaptive research and agro-economic studies were conducted by ICARDA in collaboration with national scientists in AP countries, and results are promising. The yield increased significantly and the productivity per unit of water increased more than 70% compared to normal soil-based systems. This would enable growers to increase their production area with same amount of water. The transfer of this technique to growers has been initiated in Oman and Kuwait through on-farm research activities. Nine growers in Kuwait and one in Oman have adopted the system. The success of the pilot growers has encouraged the neighboring farmers to adopt the technique.

Introduction

Arabian Peninsula is one of the most severely affected regions in the world in terms of water scarcity, and soil and groundwater salinity. The region is extremly arid and has limited renewable water resources. There is hardly any renewal of groundwater, which is being mined from aquifers for irrigation purpose. Overuse of groundwater for irrigation to meet agricultural production targets has resulted in declining water levels and intrusion of saline water in many coastal areas.

The production of high value crops requires a certain quantity and quality of water that is practically impossible to obtain in such a dry region as the Arabian Peninsula. The soils of the Arabian Peninsula reflect the aridity of the climate. Most are poorly developed, shallow, and high in lime, gypsum, or salt contents. In addition, transported materials such as sand dunes and sheets cover large areas.

Lack of sufficient soil and water are the major limiting factors for agricultural development in the Arabian Peninsula. Bad crop management practices, even under Protected Agriculture are causing low yields because of increasing soil-borne diseases that necessitate the use of extra agrochemicals. In many cases, seedlings are lost in large numbers and young plants became dry and die earlier, due to salinity problem and soil borne diseases in the greenhouses (GH).

Soil-less production techniques to solve the problem

To tackle the problem, ICARDA's Arabian Peninsula Regional Program (APRP) has developed and introduced different soil-less culture (hydroponics) production systems to the region. Simple growing systems have been developed using locally available construction materials and experimented in the Bahrain, Kuwait, Oman, Qatar, UAE, and Yemen, for the production of tomato, cucumber, pepper, strawberry, and lettuce. The main objectives are to increase quality and quantity of produce per unit of water, area and manpower. Soil-less growing technique appears to be the best alternatives for the GH use where the soil has deteriorated due to salt accumulation or high infestation with soil-borne pathogens (Figures 1, 2 and 4). It can increase water-use efficiency and improve water and fertilizer management in crop production. A grower adopting good management can achieve the same yield levels in a closed soil-less cultivation system as in the open but with 50-100% less water.

Vertical Production System

Different production systems for different crops were introduced to small growers in the APRP region by ICARDA-APRP. For production of cash crops such as strawberries and beans, the vertical soil-less production system was adapted to maximize growing space by growing the crops vertically. Such technique for strawberry has been investigated for last four years in Bahrain, Kuwait, Oman and Saudi Arabia and has proved promising from the view point of productivity, cost and water saving. The fundamental structure of the system is the columns, which consist of 8-12 growing containers on top of each other as shown in Fig 2 a. The crops are planted in the 4 corners of these containers. The irrigation water and nutrition solution are re-circulated in closed system. The growing containers were made locally and the system could be installed in any greenhouse or even in the open field.

Main advantages of the system

The production of strawberries in the vertical hydroponics system was quite successful. The hydroponics system showed followings advantage over the traditional soil-bed production system:

1. 30-50% savings in the cost of the production materials;
2. More yield per unit of water;
3. Double yield per square meter of land area;
4. Longer production season;
5. Increased income due to early season production when prices are high; and
6. Far less incidence of pests and deceases. As a result, lesser chemicals used and higher quality produce obtained.

Fig. 1. System of soil-less cultivation of vegetables.

Fig. 2. Vertical hydroponics system: a. Styrofoam pots arranged one over the other; b. Beans grown in hydroponics; c. vertically grown lettuce; d. vertically grown strawberries.

Agro-economic comparison between vertical soil-less and soil-based systems

A comparison between vertical soil-less and traditional soil-bed systems was made in Kuwait. The study was based on data collected from a private farm in Al Wafra, Kuwait. All cost and production data from the two growing systems were reported by the grower. The area used in the study was 20,000 m² and 6,000 m² for the soil bed and hydroponics systems, respectively. Results showed the total cost of production in vertical soil-less system was 40% less than soil-bed system while the production (Fig. 3) increased 4 times per unit of area. The productivity per unit water increased by 70%.

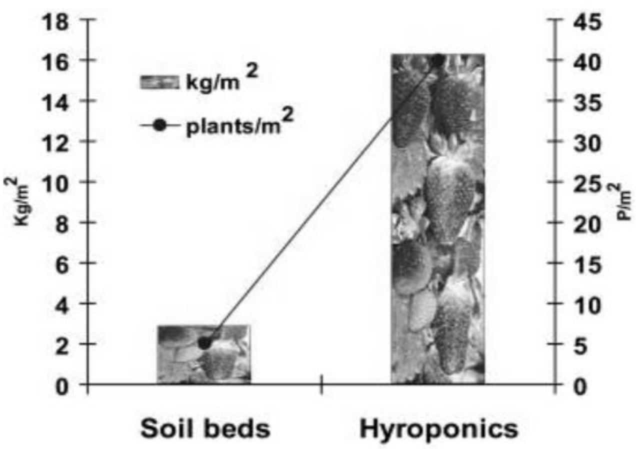

Fig. 3. Number of strawberry plants per unit area and yield under soil-bed and soil-less system in Al Wafra, Kuwait.

Fig. 4. Vertical hydroponics system in operation in the AP countries.

Future Prospects

The joint research activities between ICARDA-APRP and national agricultural research system (NARS) in Bahrain, Kuwait Oman and Saudi Arabia are progressing. ICARDA will focus on encouraging other growers in the AP countries to adopt the system. ICARDA and NARS will continue to support and provide technical backstopping for the new growers who wish to adopt the system.

Acknowledgment

The efforts and dedication of the research team and technicians at PAAAFR, Kuwait and Rumaies, Oman are appreciated. The activity was supported by AFESD, IFAD and OPEC Fund through a project grant to ICARDA’s APRP.

Panel Discussion

Panel Discussion: Implementation of the United Nations Convention for Combating Desertification

Panel co-chairs

Prof Dr. Adel El-Beltagy and Prof Dr. Hans van Ginkel

Panel members

Dr. Zafer Adeel, Acad. Djamin Akemaliev, Mr. Tanveer Arif, Dr. Margaret Catley-Carlson, Prof Dr. Iwao Kobori, Prof Dr. Shinobu Inanaga, Dr. Noureddin H. Mona, Dr. Dave Mouat and Prof Dr. Tao Wang

Summary of the discussion

Prof. Adel El-Beltagy welcomed the panelists and introduced them to the participants. Introducing the topic, he referred to different global conventions and said they were all initiated by intergovernmental bodies secure a better future for the whole humankind. The United Nations Convention to Combat Desertification (UNCDD) was adopted because of the global environmental and human livelihood concerns. The implementation of the Convention was however dependent on the will and commitment of the people and the governments of member states. There was a need to scan what has so far been accomplished, what are the gaps and how best can these gaps be bridged. He then invited Co-chair Prof. van Ginkel to move the proceedings forward.

Co-chair Prof. van Ginkel suggested that a comparison may also be made between this Convention and the Convention on Global Climate Change to draw lessons which might help in enhancing the efficacy in the implementation of the UNCCD. While there was a need to have patience, a measure of impatience would be in order to make progress in a balanced manner. With these words, he invited panelist Acad. Akemaliev to express his views on the subject.

Acad. Akemaliev said Bishkek, Kyrgyzstan has a platform for implementing UNCCD. It recently held a meeting to review the progress. Kyrgyzstan is working on research for preventing land degradation in the mountain areas, which are highly vulnerable and are home to ..... people, about 80% of whom are below poverty line. Kyrgyzstan is organizing a Conference to review the problems of mountain areas and assess the progress made in developing effective solutions. The deliberations would be of benefit to the entire region of Caucasus. Prof. van Ginkel thanked Acad. Akemaliev and said he expected substantial scientific input from these deliberations. He then invited Mr. Tanveer Arif from Pakistan to share his views.

Mr. Arif thanked ICARDA for giving him the opportunity to participate in this Conference. He had participated in several meetings of the UNCCD since it was negotiated and has developed a reasonable understanding of its operations and effectiveness. The launch of UNCCD generated a lot of expectations and therefore when adequate resources did not become available for its implementation there was a big disappointment. Some of the developing countries added to the disappointment by not having a continuous representation on the Convention. This reflected the lack of seriousness and commitment on the part of these countries. In Asia, the National Action Plans were not developed, which disappointed the civil society. There is a need for the involvement of local people in diagnosis of the problems and development of solutions. Lack of this involvement compromises their capacity as combatants. They also do not have access to several new technologies, such as alternative sources of energy, and credit for innovative activities. Lack of initiative at national levels has constrained the implementation of the thematic networks in the National Action Plans. Prof. van Ginkel thanked Mr. Arif and said there was a need to have a consultative unit to facilitate feedback on the implementation of the Action Plan. He then invited

Prof. Kobori to reflect on how the implementation could be improved.

Prof. Kobori emphasized the need for greater involvement of national scientists in implementing and reporting the results. He said that in 1997 the UNCDD published several country reports which were prepared by foreign experts, not the national researchers. The United Nations University therefore took several measures in 1998 and organized meetings where national scientists participated. Desertification was like a cancer, and it was important to recognize that it could not be prevented and the desert could not be converted to green land without exorbitant costs. There is a need for slow transfer from preliminary research to more advanced one. Research in the field to find reliable solutions to the problems encountered in deserts is essential, and a realistic approach with peoples' participation is essential. Prof. van Ginkel said National Plan was basic to the implementation and focus was needed for different environmental situations. The issue is more 'living with deserts' rather than changing them. Hence there is a need for well focused national plans. He then gave the floor to panelist Prof. Tao Wang.

Prof. Wang said China had successfully implemented its National Plan. Working for last 25 years in an institute devoted to desert research, he has often reflected on the role of science in this area. Although a lot of scientific research has been conducted and advanced knowledge generated, it has not contributed to improving the lot of the people living in these harsh environments. Research on social aspects is crucial to formulate policy options for the local governments. The local community should be assisted by field research stations through transfer of suitable technology. Prof. van Ginkel agreed that having research closer to the people and listening to their ideas in formulating the research was essential for adoption of the results. He then gave the floor to Dr. Zafar Adeel.

Dr. Adeel described the context in which the performance of the UNCCD has been rather disappointing. The first is at the policy level; the governments have not been convinced of the need for the Convention. At the scientific level we have not been very effective. There is a need to pay a lot more attention to the policy dimension. And the research has to be in the context of benefiting the society. Research should address the question as to why the national policies are not working and how they could be enhanced. There is a need for greater information dissemination. The knowledge management program of ICARDA was a good example and there was a need for expanding it to make a network of information dissemination.

Panelist Dr. Mouat agreed with Dr Adeel about the need for the research to benefit the society. It is important to identify gaps and how to fill them, how to enhance the participation of people, particularly women, how to assess the effectiveness of action, and how to harness synergy with other conventions. The action plans of 45 African countries were recently reviewed. The result was very disappointing because there had been no adequate guidance given by the UNCCD. Research connected with communities is crucial for achieving success in the field.

Panelist Prof. Inanaga laid stress on two major points. First, the Secretary of the UNCCD should pay more attention to making more effective use of resources and making them available to the poor. Second, scientists should recognize that the technology is already available and this should be adapted through applied research to link to the community. Lessons from traditional knowledge should be learned because people have survived for generations in these environments using indigenous knowledge. Ways to pull out the people from the grip of poverty have to be found to prevent the root cause of desertification. Greater public awareness about the importance of combating desertification is essential. Hence greater promotional efforts are needed.

Panelist Dr. Mona said that combating desertification was vital for improving the livelihood of the people living in the dry areas. Excellent research is being done in this area as was reflected in the presentations during the Conference. However, the greatest challenge is to translate the results of complex research into simple recommendations that could be passed on to policy makers. Consolidation of holdings and right to ownership are essential for sustainable use of natural resources. The users should be convinced of the efficacy of the interventions suggested and they should be part of the decision making process. Desertification is not a national but an international issue and thus requires global attention. Information dissemination is therefore crucial. The second issue is the need for capacity building at the technical as well as policy level. The gap between 'what is' and 'what should be' needs to be identified and effectively bridged. The policy makers have to be taken aboard. Developing an understanding of the indigenous knowledge and effectively using it could be a key to success in many specific situations. Information on success stories like that of 'Khanasser Valley Project' in northern Syria operated by ICARDA needs to be widely disseminated. The Food and Agricultural Organization of the United Nations, as an executing agency, needs mechanisms for information dissemination.

Dr. Margret Catley-Carlson reminded the house that there was a problem of 'too much of everything' being thrust to the government departments, as revealed by her personal visits to the governments in various African countries. The Millennium Development Goals were not being integrated into other plans. It was not correct to say that there was no clear recognition of the research agenda. The governments are faced with an overwhelming number of conventions them and they are being constantly asked to do more without recognizing that their capacity has been stretched to limits. One should look at small scale private sector to play more active role by giving them the needed incentives.

Prof. El-Beltagy thanked the panelists for presenting their views which should help in developing a passionate discussion on the subject. The suffering of the people continues in spite of the mechanisms existing to alleviate them. Time is crucial and hence there is not much scope for complacency. Let us deliberate a little more on what is missing. With these comments Prof. El-Beltagy opened the discussion to the participants.

Dr. Richard Thomas emphasized the importance of drylands and said we should be proud of the people of drylands for their resilience. We should highlight the comparative advantages of drylands and show the cost of doing nothing to develop them. The major deficiency in the UNCCD framework was the lack of adequate research. The CGIAR research agenda of 'Drought and Poverty' is filling this gap. There is a need for greater networking among the researchers. He appreciated the succinct statement of Mr. Arif that there was a lack of implementation and the things at national level were not working. There is a need for mainstreaming desertification into the government policy. A look into technological and policy options available is very important.

Dr. Pratap Narayan said he was task manager for TNP-2 and is therefore aware of major shortcomings in the implementation. The National Action Plans were developed in a great hurry. Several ministries were involved, however, only one ministry was assigned the responsibility for implementing the plan. There was no adequate consultation between various agencies involved.

Dr. Murray McGregor said there were several cross-cutting issues that needed attention. The importance of indigenous/traditional knowledge should be duly recognized and this knowledge should be used in designing interventions. Sharing experience across ecologies is vital because the drivers of desertification are common. The private sector has a great role to play, and should not be ignored.

Dr. Elnour Abdalla Elsiddig emphasized the need for effective education and enhancement of awareness of the local population and getting them involved in the decision making. There was also need for review of the policy of some governments in promoting extensive agriculture in vulnerable areas.

Prof. van Ginkel strongly supported the views of Dr. Catley-Carlson and said that, for example, small islands in the Pacific Ocean suffer from the lack of technical people even to read the recommendations of the conventions, leave aside their implementation. They have to be helped to set their priorities based on which national plans could be developed. Often, this aspect is unfortunately ignored.

Prof. Adly Bishay said experience has shown that expecting the implementation of the plan by the governments was unrealistic. The plan has to be implemented by the people in the communities with the help of non-governmental organizations and other members of civil society including the private sector.

Dr. S.M. Jafar Nazemosadat was of the view that the government cannot be ignored in the implementation. Instead, the government, the people of the region, and the scientific community should work together in a collaborative mode. Local community participation in the diagnosis of the problem and designing interventions is very important. He suggested that this can possibly be the main focus of any future Conference of the International Dryland Development Commission.

Dr. Mekhlis Suleimenov said that in the Central Asia and the Caucasus region there was a Consortium for Sustainable Development operating for last several years but the environmental degradation of the region was continuing. Part of the reason was that agriculturists were not participating in the Consortium. A multifaceted approach is needed to halt degradation and achieve sustainable development.

Mr. Raanan Katzir emphasized the need for on-site research involving farmers and extension agents to develop effective and feasible interventions to prevent land degradation and achieve sustainable increases in the productivity of the available natural resources.

Dr. Gemma Shepherd indicated that in her view the major gap was the missing link between science and policy. Scientists have to present their results in such a way that they attract the attention of policy makers. We need to come up with approaches that enhance global participation of various stakeholders in the implementation.

Dr. Mohamed El-Mourid said there are several success stories and well researched cases of participation of local people in communities with civil society organizations. There is a need to give visibility to these to encourage such efforts elsewhere.

Dr. Lena Lindenberg emphasized the importance of land tenure, although the related issues were complex. There is a need to look into the resource utilization rights to enhance the tenure for utilization. On the other hand, the issue of mobile pastoralism also needs attention. Many believe that nomads should be settled while many others think otherwise. Referring to the UNDP paper on mobile pastoralism, she said it has been established that it is a good practice for using drylands and should therefore be encouraged in the strategy for sustainability.

Mr. Dominic The-Chuan Yin, reflecting on his NGO experience, said that the government, entrepreneurs, scientists and farmers have all to work together to achieve tangible results. There is a need to make more efforts in convincing the governments on what could be done to make a difference in the livelihoods of the poor and the sustainability of the natural resources on which they depend.

The Co-chair El-Beltagy thanked the participants for their views and invited the panelists to make one last observation before the discussion could be concluded. Prof. Wang said that all the work should be done on ground. Dr. Adeel emphasized the need to focus on ideas and target the end-users in this exercise. Dr. Mouat said there were two basic issues. One was how the UNCCD could do better. The second was irrespective of what UNCCD was doing, there was huge international effort which could make a difference. Prof. Inanaga agreed and said that he and his colleagues have kept on convincing the Japanese tax payers on the need for combating desertification and in producing trained personnel for the purpose. Dr. Mona said combating desertification was a moral commitment for the well being of the future generations. Dr. Cately-Carlson said there was amazing amount of knowledge available but the way it is used needs to change. The instrument of Conventions has been overused, and some attention has now to be given to find out ways to effect change. Prof. Kobori said the philosophy must change from ‘Man against Desert’ to ‘Man with Desert’. Mr. Arif said the ‘people power’ should exert itself more. Acad. Akemaliev said that the IYDD should start the conversion of desert to oasis. Prof. El-Beltagy thanked all the panelists for their contributions and invited Co-chair Prof. van Ginkel to present his synthesis and concluding remarks.

Prof. van Ginkel, summarizing the discussion, said that there is a consensus on the issue that the humankind has to live with nature rather than work against the nature. One has also to understand the value of the expression ‘less is more’. The complexity cannot be reduced to simplicity, and the challenge is quite complex. What is the strategic lever by which the process of progress could be hastened has not been answered. However, it is clear that the people themselves have to bring the change. We should help them in finding new ways to do the things better. What would work are the things that can be done by people themselves. The National Plans should enable the people to move forward. Work will have to be done at the grassroots level. Hence networks are important for harnessing synergy in developing site-specific solutions. Most of the drylands in the developing world are in Asia and Africa. New 'South-South' partnership of universities and other institutions is crucial for developing sustainable use of these lands. 'Education for sustainable development' would be helped by this process. ICARDA and UNU therefore have agreed to launch the 'CWANA Plus' Network initiative to work together in this venture by establishing a small secretariat at ICARDA and enlisting the partnership of all the interested institutions in these regions. It is the aim that at least one institution in each country could be identified to link with this network ensuring national participation in design and implementation of projects of interest to the country. This would optimize the resource use and effectiveness and avoid duplication.

Co-chair El-Beltagy thanked Prof. van Ginkel, panelists and all the particpants for a very useful discussion. He reminded that time was running and the damage to environment was increasing and interventions at the level of people/communities were essential. Desertification and land degradation is a local, regional as well as global problem and the momentum has to be maintained to protect the environment and alleviate poverty in the dry areas.

Appendices

Appendix 1

Report of the meeting of the Board of the International Dryland Development Commission (IDDC) during the 8th ICDD, Beijing, China 27 February 2006

1. The Board of the International Dryland Development Commission (IDDC) met at 1200 hrs on 27 February 2006 in Friendship Hotel, Beijing, Peoples Republic of China under the chairmanship of Prof. Dr. Adel El-Beltagy, President of IDDC.

2. The meeting was attended by the following members:
   a. Prof. Dr. Adli Bishaye, Member
   b. Academician Prof. Dr. Djamin Akimaliev, Member
   c. Prof. Dr. Iwao Kobori, Member
   d. Prof. Dr. Wang Tao, Member
   e. Dr. Pratap Narayan, Member
   f. Prof. Dr. Mohan C. Saxena, Executive Secretary

3. The Chairperson welcomed the members of the IDDC Board. He expressed special pleasure at the attendance of Prof. Dr. Adli Bishaye, who was one of the founding members of the IDDC. The Chair introduced the agenda of the meeting. The members adopted the agenda.

4. The Executive Secretary distributed the draft minutes of the last meeting of the IDDC held in September 2003 during the 7th International Conference on Dryland Development at Tehran, Iran. The Members approved the draft minutes as presented.

5. The Chairperson drew attention of the members that the Board had a few vacancies because, as per the tradition of the Commission, the non attendance by a member of two consecutive meetings of the Board would lead to loss of membership. Ambassador Arba Diallo, Executive Secretary of the UNCCD, Bonn, and Prof. Dr. Manual Annayo, Director, Centro de Edafologia, Mexico City, Mexico did not attend the meetings held in past couple of years. Hence, there was a need for identifying new members. The Chair sought nominations from the Members for candidates who were globally known for their contributions and commitments in the field of sustainable development of drylands and thus promoting substantially the objectives of the IDDC. The new names proposed were:
   a. Prof. Dr. Hans van Ginkel, Rector of the United Nations University,
   b. Prof. Dr. Shinobou Inanaga, President of JIRCAS and former Director of the Aridland Research Institute of the Tottori University, Japan.

6. The Board unanimously approved these nominations. The Chairperson then formally invited Prof. Dr. van Ginkel and Prof Dr. Inanaga to join the meeting and participate in the remaining business of the meeting. The members warmly welcomed Professors van Ginkel and Inanaga to the meeting. The new members thanked the Board for their appointment and assured their full commitment to the objectives of the Commission.

7. Following business was transacted and decisions reached:
   a. In keeping with the objectives of the IDDC to enhance networking and promoting application of cutting-edge science in developing solutions to the problems confronting sustainable development of the drylands and other dry areas, the Commission would hold an International Symposium, entitled "Advanced Technology: The Future of the Drylands," in 2008. The Symposium would deal with application of advanced technologies, including genomics, nanotechnology, technology for renewable energy generation, etc., in research for sustainable development of dry areas. Because of the specialized nature of the selected subject matter of the Symposium, the participation would be limited to a small group of appropriate specialists/scientists. The Board requested Prof. Inanaga to take the lead in developing the details of the Symposium in consultation

with appropriate resource persons. Prof. Inanaga accepted the responsibility of developing draft program and potential participants and sharing the same with the members electronically for their further input.

b. The Board also decided to hold the next (the 9th) International Conference on Dryland Development in 2009 under the theme "Sustainable Human Development and Built Environment". Such a theme will provide a holistic coverage of various fields related to the sustainable development in the dry areas. The *Bibliotheca Alexdrina*, based in Alexandria, Egypt, has extended an invitation to the Chair of the IDDC to hold the next meeting in its premises. The Chair asked the members to explore if there were other invitations. The final decision on the venue would be taking in the due course after consultation with the members electronically.

c. The Board felt that, although the Commission has so far transected its business based on traditions, there was a need to develop a formal Charter for the IDDC. It was therefore agreed that the Executive Secretary of the Commission would develop the first draft of the Charter in consultation with the Chairperson to be finalized through the electronic consultation with the members.

d. In view of the fact that Latin America and Sub-Sahara Africa had large areas under drylands, the Board considered it important to include representation from these regions in the membership of the Board. The Board also felt the need for attracting larger participation from the francophone countries in the deliberations of the Commission. Prof. Bishaye agreed to contact relevant organizations and come up with suggestions for achieving this.

e. The members proposed a hearty vote of thanks for the Chinese Academy of Sciences and Prof. Wang Tao for excellent arrangements in organizing the 8th International Conference.

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