AARINENA Water Use Efficiency Network: Proceedings of the Expert Consultation Meeting

AARINENA

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Proceedings of the Expert Consultation Meeting

26-27 November 2006
ICARDA, Aleppo, Syria

Editors
I. Hamdan, T. Oweis and G. Hamdallah

GFAR

ICARDA

Association of Agricultural Research Institutions in the Near East and North Africa AARINENA

International Center for Agricultural Research in the Dry Areas

About ICARDA and the CGIAR

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is one of 15 centers supported by the CGIAR. ICARDA's mission is to improve the welfare of poor people 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 base.

ICARDA serves the entire developing world for the improvement of lentil, barley and faba bean; all dry-area developing countries for the improvement of on-farm water-use efficiency, rangeland and small-ruminant production; and the Central and West Asia and North Africa (CWANA) region for the improvement of bread and durum wheats, chickpea, pasture and forage legumes, and farming systems. ICARDA's research provides global benefits of poverty alleviation through productivity improvements integrated with sustainable natural-resource management practices. ICARDA meets this challenge through research, training, and dissemination of information in partnership with the national, regional and international agricultural research and development systems.

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The World Bank, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), and the International Fund for Agricultural Development (IFAD) are cosponsors of the CGIAR. The World Bank provides the CGIAR with a System Office in Washington, DC. A Science Council, with its Secretariat at FAO in Rome, assists the System in the development of its research program.

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Foreword

Water shortage is approaching critical levels in many parts of the Near East and North Africa (NENA) Region. Over 70 % of the Region fall within the arid and semi-arid areas of the world. Some 15 countries in the Region are below the water deficiency level of 500 m^3 per caput of the Annual Renewable Water Resources. The continued growth in demand for water is basically driven by the high population growth rates. Agriculture is the major consumer of water in all countries of the Region, with an overall average of 80%. Therefore, the Agriculture sector is under continuous pressure for *"the need to conserve water"* , in order to allow other competing demands from other economic sectors like: Urban/Housing; Industry and Tourism. The call for "*more crop per drop"*should not be considered as a slogan, but rather to be adopted as a code of practice.

Based on the above, the Association for Agricultural Research Institutions in the Near East and North Africa (AARINENA) found it timely to hold an "Expert Consultation on Water Use Efficiency". The Association aims at furnishing a forum for Experts and Country Officials to meet and exchange their countries' experiences and leassons learned. Information-sharing among specialists and institutions provides sound solutions to emerging problems. Networks of information became more accepted for the data and information exchange , by virtue of the available communications tools. In the past 3 years, the Association for Agricultural Research Institutions in the Near East and North Africa (AARINENA) managed to establish four networks: (date palm, olive, medicinal and aromatic plants, and cotton). Two more networks (on biotechnology and water use efficiency) have been recommended by AARINENA General Conference.

The present volume contains the Proceedings of the Expert consultation that convened at ICARDA, Aleppo, Syria between (26-27 November 2006). A new **Regional Network for Water Use Efficiency** was announced at this meeting. It is hoped that this Proceedings Volume would be the kick-off activity of this significant Network and much more is expected from its future work.

Ibrahim Hamdan
Executive Secretary
AARINENA

I. Executive Summary

ICARDA recently hosted an Expert Consultation Meeting under AARINENA umbrella, which convened between 26-27 November 2006 in Aleppo, Syria. The meeting, sponsored by the Global Forum for Agricultural Research (GFAR), aims to create a regional network to improve water use efficiency, to be supported by ICARDA, FAO, and AARINENA.

At the Opening Session of the meeting, *Dr. Theib Oweis, Research Director of ICARDA Water Resources Development Programme , on behalf of Dr. Mahmoud Solh, Director-General of ICARDA*, explained the rationale for this initiative. The NENA Region is considered among the world's most severe water defficient with the world's highest population growth rate. Clearly, the Region cannot survive unless water use efficiency is significantly improved, to produce more food with less water.

As Dr. Oweis explained that the challenge also comes with an opportunity: "Water is the top priority for every government in the region ; hence the opportunity and the incentive is to work together. Simultaneously, donors and policy makers are more willing to recognize the consequences of water scarcity, hence the potential availability of resources. The *Network will face the challenges, and benefit from the opportunities."*

Dr. Ibrahim Hamdan, AARINENA Executive Secretary in his opening statement, indicated the increasing importance of the technical cooperation networks, that have become a generic model for the establishment of functional mechanisms for regional collaboration and enhancement of communication and exchange of experiences among different countries and regions. He further stated that these Networks were found to reduce duplicative efforts among national institutions in several countries and to provide a cost-effective instrument for information exchange and institutional capacity building. He explained the objectives of the proposed *Network:* to improve water quality and sustainability of supplies, as well as to increase efficiency by developing integrated production packages. Such a *Network* would develop national research capacity in specialized fields, use financial and human resources more effectively for regional benefit, and help to bridge the gap between research and development.

Laying the ground for the technical sessions to follow, Dr. Oweis presented an overview of the key factors influencing water use efficiency, and described the shift in focus by Research and Development organizations from water use efficiency to the broader target of 'water productivity', i.e., return per unit of water used.

Dr. *Steduto Pasquale, Chief of the FAO Water Resources Development and Management Service*, further elaborated the technical issues, including use of the 'efficiency chain framework' to allocate resources among different steps in the chain of water use, in order to improve overall efficiency/productivity.

The meeting reviewed water use efficiency across the Region, through a series of reports from *12 countries*, including: *Egypt, Iran Islamic Republic, Jordan, Lebanon, Libya, Morocco, Oman, Sudan, Syria, Tunisia, Turkey and Yemen.* The papers covered various issues of water resources and water use efficiency and production, as well as crop water reqirements.

A session was allocated to focus on the proposed *Regional Network* regarding: location of the Secretariat, administrative issues, formation of Working Groups, recruitment/designation of Working Groups Coordinators. The discussions culminated in development of a draft proposal for a Regional Water Use Efficiency Network. The participants adopted the proposal for the establishment of this Network with the following recommended actions:

1. The venue and *the Network Secretariat will be at INRA –Morocco*
2. Elected *Dr. Ayman Abu-Hadid from Egypt* as the Chairman of the Network Board
3. Identified the following countries to host the technical working groups:

   (i) *Yemen* for the "Group on Management and Conservation of Rainwater in Rainfed".
   (ii) *Iran Islamic Republic* for the group on "Sustainable management of water in irrigated agriculture"
   (iii) *Egypt* for the "Group on Decision Making and Water Management Tools {modeling and GIS}" and
   (iv) *Syria* for the "Group on Institutional, Policy and Socioeconomic Analysis and Evaluation of Water in Irrigated Agriculture".

The participants recommended, as a priority activity for the network to be implemented in 2007, the *formulation of an ATLAS,* which would assist to compile relevant water data. These data need to be standardized. For that, participating countries need to use the same definitions, terms for common observations and indicators used in Water Use Efficiency.

II. THEMATIC PRESENTATIONS

Proposal for Establishing
Regional Water Use Efficiency Network
in the Near East and North Africa

Ibrahim Hamdan
AARINENA Executive Secretary

1. Background

Water is a critical resource for agriculture in the CWANA region. It is a major constraint in the development of agriculture in the region. It is not only the lack of water, but also the decline in its quality and inefficient use of water that is affecting improving productivity of agriculture in the region. Several national agricultural research institutes within the region and outside research water use to improve its efficiency. A network of all these Institutes and researchers will improve sharing and exchange of information, knowledge, skills and technology within the region. With this sharing, the region will benefit through more effective and efficient technological interventions in water use for agriculture.

While the Near East covers 14% of the total area of the world and home to 10% of its population, its water resources represent only 2% of the total renewable water resources of the world. Renewable water resources in m^3/head/year Projected Water Scarcity in 2025.

To overcome this situation, sound technical, policy and institutional approaches to water management need to be adopted. A water network may contribute to achieve this objective, through experiences exchange and joint implementation of collaborative research projects on integrated water management.

2. Moroccan Experience in Water Resources Management*

Moroccan experience in irrigated agricultural development is the result of increasing water shortage due to drought and high demand on water resources.

- The agricultural sector plays an important role in Moroccan economy 15 to 20 % of GDP.
- Irrigated agriculture contributes about 45 % to the added agricultural value (70 % during dry years), more than 1/3 of employment in the rural areas and 75 % of agricultural exports.

* Taken from a presentation by Dr. Hamid Narjisse, INRA DG at AARINENA, Executive Committee Meeting, Marrakech, Morocco, December 22-23, 2004.

2.1. Basins Transfer

Water transfer has been considered to develop irrigation projects in arid and semi arid zones and to supply drinking water for urban towns.

Examples of WaterTransfer

- Transfer from Oum er-Rbia basin to irrigate the perimeters of Doukkala and Haouz and supply drinking water to Marrakech, Safi, El Jadida and Casablanca.
- Transfer from Bin El Ouidane dam to irrigate Tassaout perimeter.
- Transfer from Mohammed V dam to irrigate Lower Moulouya and to supply drinking water to Oujda, Nador and Berkane.
- Planned transfer of over 700 millions m^3 between the Wahda dam and the central region, to supply drinking water and expand irrigated areas.

2.2. Legal Aspects: Water Laws

Revision of the water law in 1995 was ambitious. It introduced new rules and procedures pertaining to water management at the national and local level. Its main traits are:

- Extension of the public ownership of water and the imposition of a 5 years time limit to any claim on private water rights.
- Introduction of the “Agence de bassin”, as the main entity in charge of water issues at the basin level.
- Formal adoption of “basin water plan” by the “Conseil Supérieur de l’Eau et du Climat”.
- Introduction of new taxes based on exploitation and pollution taxes.
- Introduction of new instruments to deal with pollution and drought.
- The National Hydrological Plan validated by the “Conseil de l’Eau et du Climat”, is the main instrument to solve allocation conflicts.

2.3. Institutionnal Aspects: Consultative Institutions

« Le Conseil Supérieur de l’Eau et du Climat » (CSEC)

This body includes all administrations involved in the water sector, representatives of the parliament, of users and nominated experts who have competencies on water issues. The CSEC convenes to address issues of national dimension and formulates recommendations on planning options, mobilization and management of water resources.

2.4. Basin Agencies

They manage water resources at the basin level and monitor water quantities and quality underground and superficial. They contribute to the management of drought and adjust water allocation according to resource availability.

2.5. Regional Bureau of Agricultural Development.

It implements irrigation projects, manage the network, enforce water police and promote appropriate agricultural practices.

2.6. Water Users Associations

Water Users Associations are very important institutions dealing with network maintenance and coordination among water users.

2.7. Research in the Tadla Perimeter

There is a long history of irrigation research in the Tadla, involving many national and international institutions. A brief summary of research on irrigation includes:

- Programme on border irrigation and improved traditional small basins (ROBTA);
- SID Project: Field irrigation efficiency and salinization;
- RAB Project: Trials of lateral move overhead sprinkler system;
- PAGI-2 Project: Micro irrigation trials;

3. Proposed Regional Water Use Efficiency Network

3.1 Description

The Regional Network will be comprised initially from national research institutions in AARINENA region. The International and Regional Organizations which have interest in promoting water use efficiency activities as well as donor countries and the private sector.

The Network will be established as a partnership among all the different bodies and stakeholders in each of the participating member countries that are involved in any manner throughout the overall water use efficiency and research and funding support and include: NGOs, Private Sector, Research Institutions (Both Governmental and Non- Governmental) and universities as well as other national and international supporting organizations.

The role of AARINENA, GFAR, ICARDA and FAO is to initiate action and provide technical support to regional programmes.

3.2. Network Objectives

The network objectives is to contribute to water saving, improvement and sustained productivity and quality through mobilization of existing knowledge and production of adapted technology packages and natural resources and development of modern techniques for water use efficiency. These could be achieved through the following:

a) Create awareness at various policymaking and technical levels within member countries on the importance of the development of water use efficiency methods in an integrated approach.
b) Facilitate exchange of information through the development of an information system for the collection and dissemination of information on water use efficiency
c) Allow joint programs to be developed for the exchange of experiences and expertise and organization of training courses, workshops and conferences for the effective use of water management and sharing of transferable technical information and skills.
d) Enhance cooperation for the analysis and solution of common problems related to water use through joint research /development projects.
e) Contribute to the formulation of national water networks in each country to strengthen collaboration among national institutions, non-governmental organizations, private sector and universities.

3.3. The expected outputs are:

- Contribute to strengthening the capacities of specialized national institutions;
- Organize workshops, information dissemination activities to stimulate the exchange of experiences among scientists;
- Organize several activities to bridge the gap between research and development; and
- Foster cooperation among participating countries.

4. Network Composition

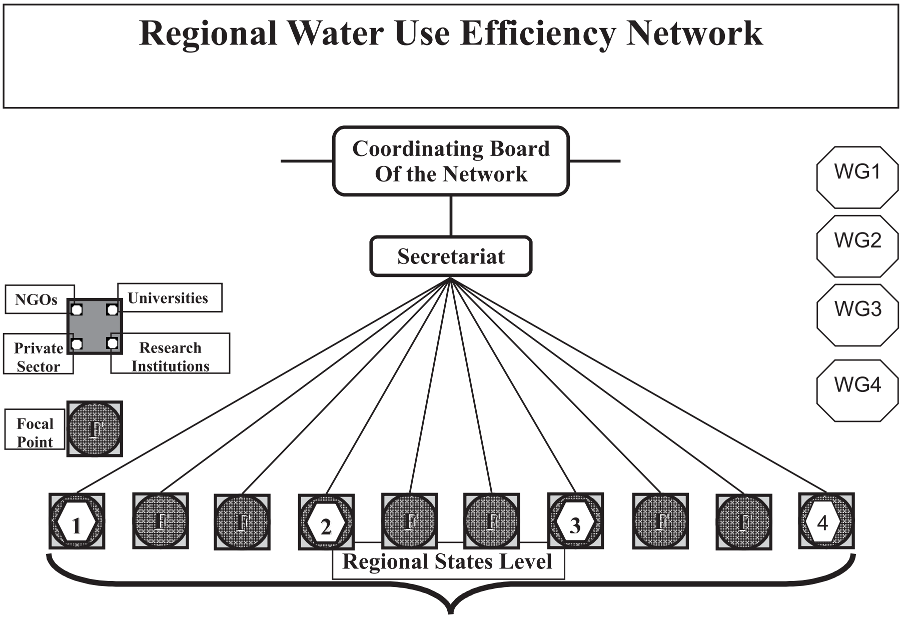
The network will consist of the following focal points and working groups (see Chart below):

4.1. Coordinating Board

The Coordinating Board includes members from each of the participating countries that may represent institutions identified as the focal points. Board representatives may be selected from the NGOs, Private Sector, Research Institutions (Governmental and non-governmental) and universities. The chairmanship will rotate every year among member nations, by election during the previous year. The Coordinating Board will meet every year and will be hosted by the institution, which the chairman represents.

The Coordinating Board may form Technical Advisory Committees and ad-hoc committees to study and follow up on certain technical matters and specific tasks, or attend to some specific issues.

The Coordinating Board may also establish a think tank of water use efficiency expertise from different technical backgrounds that can provide consultancy services to the different countries as per their needs and requirements and/or due to urgent circumstances.



4.2. The Secretariat Entity

The CWANA-WUE-NET is a network of participating institutions from the region, coordinated by a Secretariat entity.

This Secretariat can be at the Water Research Unit of the Tadla Regional Agricultural Research Center in Morocco.

The Secretariat consists of a full time Secretary assisted by staff appointed by him to carry out the functions of the Network. The host country shall provide all necessary facilities and operational logistics at the focal institution to enable the Secretariat to implement the work plan of the network.

4.3. Focal Points

Institutions, identified as focal points in member countries, may be either universities, research institutions or other competent, well established and renowned institutions depending on the set up and organizational structure in each of the countries in the region, will be the linkage among other institutions, NGOs, private industry and all stakeholders as well as the Regional Network, and shall include representatives from the NGOs, Private Sector, Research Institutions (Governmental and/or Non- Governmental) and universities.

4.4. Technical Working Groups

Priority areas on a regional basis, in which, cooperation among participating countries is needed for the development of these areas. The working groups will be selected by the participants of the expert consultation meeting for the establishment of the water use efficiency Network to be held at ICARDA in November 2006.

The suggested working groups as follows:

i. Management and conservation of rainwater in rain fed agriculture;
ii. Sustainable management and valorisation of water in irrigated agriculture;
iii. Decision making and water management tools (modelling and GIS);
iv. Institutional, policy and socioeconomic analyses;

For the optimal utilization of the limited resources available, Working Groups in the four areas identified above should prioritize, streamline and focus on the problems in each of the areas identified as priority areas. They should also seek to tie the existing activities of country members of the network rather than starting completely new programs, unless on a temporary basis, to address a specific research problem, using external funding.

It is important to have precise and realistic work plans, which assign responsibilities to members and to the secretariat for each aspect of an activity. Some of the specific tasks that may have to be addressed by the working groups in each of these areas are summarized below. These should be looked at as only guidelines that have to be prioritized and may later be modified and updated as deemed necessary. They include the following.

The host institution of the working group would provide local facilities and expenses, but funds for regional programs and research activities, training and collection and dissemination of information would be sought from national and/or multilateral sources. Cost sharing among participating countries should be encouraged. FAO, GFAR, ICARDA, and AARINENA will continue to provide technical assistance for the activities of the working group.

5. Criteria for the Location of the Secretariat

The following criteria are suggested for the selection of a national institution, which would host the Secretariat of the Regional Network.

a) The location of the institution should be centralized in the Region as much as possible to ensure easy communication, transportation and contact.
b) The host country should be accessible to all other member countries through the granting of visas and internal travel.
c) The institution should have adequate physical facilities and technical competence.
d) The host country should be able to provide the required facilities for the smooth operation of the secretariat.

6. Functions

6.1. The Coordinating Board will have the following functions:

a) Planning, coordination and follow-up of research, training and other work programs.
b) Review and approval of the annual budget as well as the work programs of the sub-networks.
c) Fund raising from private donors, funding agencies and international organizations for the strengthening of the network activities.
d) Facilitation of communication among the different focal points and working groups and the Regional water use efficiency Network.

   Cooperation and coordination of activities with other national, regional and international organizations involved in water use efficiency.

e) Decision on policy matters including introduction of new member countries and establishment of new working groups or changes in the existing ones.
f) Promotion of technology to the users in member countries.

6.2. Secretariat Functions

The Secretary, will be responsible to the chairman of the Coordinating Board of the Network on the following functions:

a) Provide AARINENA web–page with a comprehensive database on all aspects relevant to water use efficiency and an overall marketing and promotional programme.
b) Provide AARINENA newsletter for enhancement of dissemination of information and preparation of a biannual report highlighting the different activities and achievements of the different groups.
c) Collection, compilation and dissemination of all documents, reference material and correspondence as well as technical information.
d) Preparation and follow-up of work programs (research, training, workshops, conferences, etc) and budgets approved by the Coordinating Board.
e) Administrative responsibilities of the Network, including the preparation of the annual budget in coordination with the working groups in the different countries.
f) Preparation of evaluation criteria for the assessment of the performance and efficiency of the network. An outside team of experts will perform evaluation.

6.3. The Focal Point National Institutions will have the following functions:

a) Establishment of communication channels among all national organizations, research institutions, private & non-governmental organizations, universities as well as other stakeholders through out the water use efficiency chain, and facilitation the exchange of information, concerns and aspirations of all groups.

b) Collection and dissemination of information at the national as well as regional level through the Network's Secretariat.
c) Coordination of programs with other national institutions in the country as well as other non-governmental organizations, private industry, universities and all other stakeholders in the water use efficiency chain on research, training (particularly women), extension and marketing requirements.
d) Linkage with the Network on all activities (sub-regional and regional research projects, training courses, workshops, conference etc…).
e) Advice government agencies on matters related to policy, programs and coordinated activities for the development of water use efficiency.

6.4. Working Groups Functions

Each working Group will have the following functions:

a) Collection and dissemination of information through the Network Secretariat. This information will be in the form of literature information, research and development results, patents consultancy services, institutional news, technologies, annual reports, etc.
b) Planning and implementation upon the approval of the Network's Coordinating Board, training programs including seminars and workshops.
c) Planning and coordination of research and development programs in cooperation with other member institutions.
d) Provision of technical assistance to various national institutions. Consultants from institutions in the Region would be used and from outside the Region whenever competence is not available within the Region.

This would require keeping an updated record of national institutions, expertise and technologies available in the region on water use efficiency.

7. Financial Requirements

7.1. The long-term objective of the network is to gradually become self-supporting and assume more of its own expenses. However, at the initial stages, external inputs and technical backstopping by GFAR, ICARDA, FAO and AARINENA are essential. Contributions by various governments will be determined by the coordinating Board in consultation with AARINENA.

7.2. Other potential sources for covering up of some of the expenses include the following:

a) Consultation fees when services of the expertise of the think tank are utilized by any of the countries. A certain percent (about 15-25%) of the consultancy cost is retained by the network as an overhead, like it is being currently done in many universities and research institutions (consultation fees can be secured from international organizations and donors).

Overhead cost for coordinating regional projects that are funded e.g., research, training, extension, conferences, etc. (about 10% of the total).

a) Charges (reasonable and affordable) for providing information to prospective users, including the private sector.
b) Revenues from sale of developed promotional material, posters, standards, publications, etc.

7.3. Donations and funds from national, regional and international organizations as well as the private sector.

Contributions from the private sector, including water use efficiency industry, wholesalers, and auxiliary industries supporting the water use efficiency industry. The contribution of the network to the private sector would be in kind, providing services, technical support, consultation, and others.

From Water Use Efficiency to Water Productivity: Issues of Research and Development

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Abstract

The availability of freshwater is one of the great issues facing humankind today. Water shortage and needs are increasing, and the competition for water among urban, industrial, and agricultural sectors is growing more intensive. With the rapid industrialization, urbanization and population increase, economic realities seem certain to reallocate water increasingly away from agriculture to other sectors. Moreover, now the opportunities for large captures of new water are few. This implies that we must produce more food with less water. Agriculture is by far the largest user of water and often blamed to be the least efficient consumer. Therefore, agriculture must cope with the increasing demand for food, feed, and fiber, but with less water. It is, therefore, essential that substantial changes be made in the way water is valued and managed to help overcome water shortages. Under these circumstances it is crucial that the role of water in securing food supply is understood and the potential for improving overall agricultural productivity with respect to water fully realized. It has been widely accepted that the most promising option to achieve food security and sustain acceptable standard of living in the water scarce areas is to improve the efficiency of water use or productivity. There are three primary ways to enhance agricultural water productivity: One is to increase effective use through improved water management; and the second is to increase crop yields through agricultural research.The third way is to reform policies and increase investment, particularly in rainfed areas. Improving agricultural water productivity implies getting more output or return per unit of water used. However, sustainability issues must be carefully taken into consideration. Water will be the key agent in the drive to raise and sustain agricultural production. Therefore, agricultural policies and investments will need to become much more strategic. They will have to unlock the potential of agricultural water management practices to raise productivity, spread equitable access to water and conserve the natural productivity of the water resource base. This paper addresses the major issues, concepts, and methodologies related to agricultural water- productivity/use efficiency and its improvement.

Introduction

The availability of freshwater is one of the great issues facing humankind today. Water shortage and needs are increasing, and the competition for water among urban, industrial, and agricultural sectors is growing more intensive. Mining groundwater is now a common practice in the dry regions, risking both water reserves and quality. In many countries, securing basic human water needs for domestic use is becoming an issue, not to mention the needs for agriculture, industry and environment. The average annual per capita renewable supplies of water world-wide is about 7000 m3. The threshold for water poverty level is 1000 m3, which looks ample for countries like Jordan, where the annual per capita share has dropped to less than 200 m3 (Margat and Vallae, 1999). With the rapid industrialization, urbanization and population increase, economic realities seem certain to reallocate water increasingly away from agriculture to other sectors. Moreover, now the opportunities for large captures of new water are few. Most river systems suitable for large-scale irrigation have already been developed. Unacceptable depletion of the flow to downstream users will become increasingly difficult to avoid.

The water scarcity situation in the dry areas is getting worse every day. Over the coming years, this situation will worsen with increasing demand, given the fact that the possibility of new supplies is limited. If the world's population keeps growing at the current rate (about 90 millions each year), we will be facing the challenge of feeding 8 billion people very soon – in 2025. More than 80% of these people live in developing countries. This implies that with nearly the same water and other natural resources base, we must produce food for an additional 2 billion people besides supplying expanding domestic and industrial water needs. The increasing pressure on this resource will, unless seriously tackled, escalate hydropolitical conflicts and seriously damage the already fragile environment in the region.

Agriculture is by far the largest user of water, accounting for about 70 percent of all withdrawals from rivers, lakes, and aquifers, and up to 95 percent in many developing countries. The water needed for crops amounts to 1,000 – 3,000 cubic meters per tonne of cereal harvested. It takes 1 – 3 tonnes of water to poduce1kg of grain. Furthermore, it is estimated that only 45% of the water used in agriculture are effectively used by crops (UN/WWAP 2003). The rest is partially lost by either evaporation or by loosing quality while joining salt sinks. Some part of it recharges aquifers, or flow downstream to be reused. Therefore, agriculture is not seen as the most efficient water user. The ever-growing competition among water-using sectors is certainly forcing agriculture to give up part of its share to higher priority uses, especially the domestic and industrial sectors. Meanwhile, agriculture must cope with the increasing demand for food, feed, and fiber, but with less water. It is, therefore, essential that substantial changes be made in the way water is valued and managed to help overcome water shortages. Under these circumstances, it is crucial that the role of water in securing food supply is understood and the potential for improving overall agricultural productivity with respect to water fully realized.

It has been widely accepted that the most promising option to achieve food security and sustain acceptable standard of living in the water scarce areas is to improve the efficiency of water use or productivity. There are three primary ways to enhance agricultural water productivity: One is to increase effective use through improved water management; and the second is to increase crop yields through agricultural research. The third way is to reform policies and increase investment, particularly in rainfed areas. Improving agricultural water productivity implies getting more output or return per unit of water used. However, sustainability issues must be carefully taken into consideration. Water will be the key agent in the drive to raise and sustain agricultural production. Therefore, agricultural policies and investments will need to become much more strategic. They will have to unlock the potential of agricultural water management practices to raise productivity, spread equitable access to water and conserve the natural productivity of the water resource base.

This paper addresses major issues, concepts, and methodologies related to agricultural water- productivity/use efficiency and its improvement. Special emphasis will be given to the evolution of these concepts and the new directions associated with them.

From Efficiency to Productivity: the Concepts

The term **"***efficiency"* in general reflects the ratio of output to input. When it comes to water, this term, efficiency, is widely used in irrigation systems engineering design, evaluation, and management. There are many efficiency terms in irrigation; each has a specific meaning and use. Among these terms are Water Conveyance Efficiency (WCE), which reflects losses of water from the conveyance system; Water Application Efficiency (WAE), which reflects losses of water below crop root zone and tail water runoff; Water Distribution Efficiency (WDE), which reflects how uniform water is applied to the field; Water Storage Efficiency (WSE), which reflects the sufficiency of water stored in the crop root zone, and overall irrigation project efficiency (Hansen et al.,1980 ; Jensen et al., 1981; Walker and Skogerboe, 1987; James, 1988; and Keller and Bliesner, 1990).

These irrigation related efficiencies are engineering terms necessary for sound design, monitoring, and performance evaluation of all irrigation systems. Because water is usually *lost* by seepage and leakage during conveyance, the diverted amount of water should be more than the water needed to be delivered, which brings the WCE into the play. Because water is *lost* by spray evaporation, wind drift, and deep percolation; the applied amount of water (water discharged) by the irrigation system should be more than the water needed by the plant, which brings the WAE into the picture. Similar arguments apply for the WDE, WSE and overall project Irrigation efficiency which equals the product of WCE with WAE. The output (numerator) and input (denominator) components of these irrigation-based efficiencies are expressed in same units. These efficiencies are expressed in percentage (%) with a maximum value of 100%. Values less than 100% imply *losses* during the process.

Although most of the water losses referred to in the irrigation-based efficiencies are recoverable (such as seepage during conveyance, deep percolation, and tail water runoff), engineers strive to minimize these *losses*. These irrigation- based efficiency terms are not directly or explicitly related to crop production and/or economy per se. They are mainly used for design purposes and most of them, particularly WAE and WCE, must be assumed or known (selected) beforehand for the purpose of designing the irrigation system. For example, if due to physical constraints and limitations of the irrigation system – such as non-uniform water application or spray loss by evaporation or unavoidable deep percolation below root zone -, and then an additional amount of water above crop water needs must be added, thus bringing the WAE into the scene regardless of the possibility of recapturing these deep percolation losses. We all agree that, on larger scale such as basin level, this deep percolation is not a real loss (but only on paper), but this has nothing to do with the validity and purpose of use of the WAE.

Irrigation Engineering Efficiencies

Proper farm irrigation systems design and performance evaluation rests on three fundamental and interrelated efficiency terms: WAE, WDE, and WSE (also known as Adequacy of Irrigation). These three terms are strongly interrelated (Figure 1). According to this Figure, WAE is the ratio of the S to I where S = I – D – R. Therefore,

$$\begin{aligned} WAE &= [(I - D - R)/I] \times 100\% \\ &= 100\% - (D/I) \times 100\% - (R/I) \times 100\% \qquad (1) \\ &= 100\% - \%\ D\ losses - \%\ runoff\ losses \end{aligned}$$

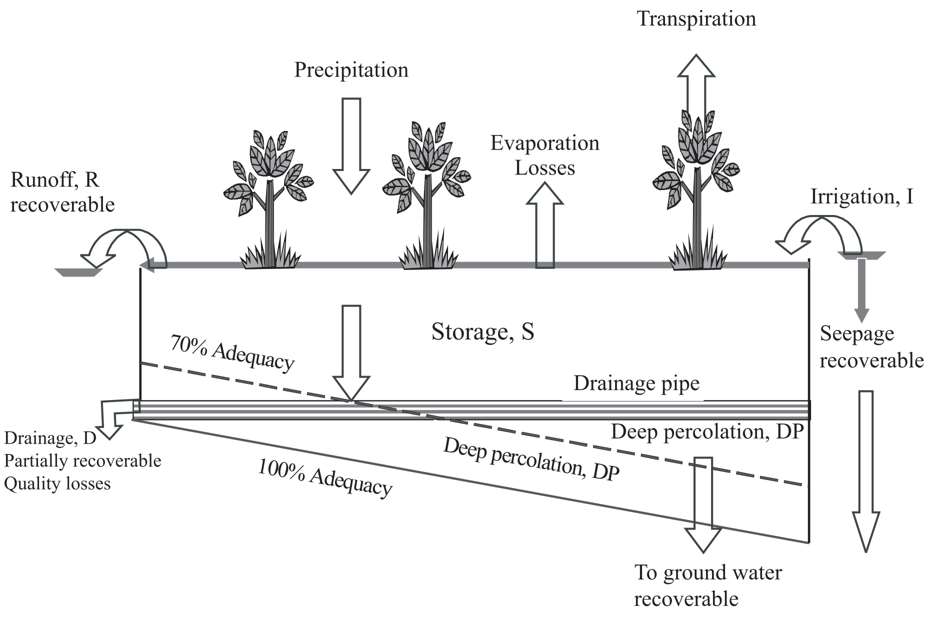

Figure 1. Field water balance showing two cases of field irrigation adequacy: 100% (no irrigation deficiency) and 70% (deficient irrigation over 30% of field area).

Here, we use the term losses, because water has flown outside the boundaries of the area or region of interest (the field). The most important point which should be highlighted here is that: although part or all of these losses could be captured/recovered and reused on the same farm, this will not affect the value of I or any other term in Equation (1). Figure 1 is typical water balance for a surface irrigated field (furrows, border strips, etc.). Deep percolation and runoff exist even with best designed surface irrigation systems. Nevertheless, these losses are in many cases are recoverable, though at a cost, and can be beneficially used for other purposes

There is misconception and misunderstanding concerning efficiency from irrigation engineering and agricultural standpoints. In our opinion, there are two main reasons for this misunderstanding: Irrigation engineering efficiency terms are coined during an era of relative abundance of water supplies during which the problem of water needs are solved by increasing the supply. Nowadays, however, there are no more of such water luxuries—it is now the era of water demand management. The second reason, in our opinion, is that quite often we find agronomists attempt to take the responsibilities of irrigation engineers and vice versa. It is true that water is everybody's business, but specialties must be respected. It is true that water is certainly at the center of human's life and development, but all specialists, workers, and people interested in water must know how to work as an integrated team. It is really sad to find out economists and sociologists working in the hardware of water science and engineering, thus, resulting in more confusion and harm to the water sector.

Water Use Efficiency

Water Use Efficiency (WUE) reflects on how well the water is used in producing crops. WUE is by no means an engineering term, because WUE depends on so many factors and involves so many biophysical processes that are beyond the scope of engineering field. However, the term Water Use Efficiency (WUE) has been defined in the literature in various ways by hydrologists, physiologists and agronomists depending upon the emphasis that one wishes to place on certain aspects of the problem. This term is an outgrowth of a series of older terms which are more or less related to the water use by crops, such as: duty of water, consumptive use, transpiration ratio, and transpiration coefficient; Hanks (1983), Viets (1966), Howell et al. (1990) and Fageria (1992). Viets (1962) used the term WUE to characterize the ratio of crop yield (biological or economical) to crop water use (transpiration or evapotranspiration). WUE, in general, refers to the amount of plant material (biomass) produced per unit of water used, and therefore, can be expressed as follows:

$$WUE = \frac{Y}{W} \tag{2}$$

The numerator Y may represent total plant material produced, above ground dry matter, or economic yield (grain or straw or both). The denominator W may represent: water transpired by the plant, evaporation from soil and plant plus transpiration (evapotranspiration), or water applied to the field (rainfall plus irrigation if any). The component Y is usually expressed as a mass (g, kg, and tonne), while the component W is expressed as a unit volume of water, m^3 or ha-mm. WUE is not a physical engineering efficiency, which is usually dimensionless and has a maximum value of 100%. The *efficiency* name for this biological ratio has caused some concern and confusion with irrigation and water resources efficiency terms. Gregory (1991) stated that some workers prefer to speak about a *"dry matter: water use*" ratio or coefficient (e.g. Monteith 1986). As Sinclair et al. (1984) pointed out, that WUE "*has been used interchangeably to refer to observations ranging from gas exchange by individual leaves for a few minutes to grain yield response to irrigation treatment through an entire season*".

Although *efficiency* is a measure of output per unit input, we rarely consider all the outputs or all the inputs involved in crop production. Therefore, one should be careful and cautious in dealing with this term. Plant growth and yield are more strongly related to transpiration than to evapotranspiration; Hanks (1983), Joshi and Singh (1994). However, WUE is sometimes evaluated per unit of water transpired (WUET), or per unit of irrigation water applied (WUEI). Often, WUE is based on evapotranspiration (WUEET). The difference is important since suppression of soil evaporation and prevention of weed transpiration can improve the WUEET, however, it need not improve the WUET, which is a measure of crop performance.

The term WUE is used in two very different senses hydrologically and physiologically, Stanhill (1986). Hydrological concept of WUE satisfies the formal requirements for a definition of efficiency in that it represents a fraction, which cannot exceed one, or be less than zero. The concept has proved useful in both experimental and field studies of crop water use in dryland and irrigated agriculture. Such hydrological studies of crop water use efficiency are normally the province of irrigation and water conservation engineers rather than agronomists. In the physiological sense, the term WUE is inappropriate to the intended concept behind it, because a maximum established (by theory or observation) does not exist for reference.

To throw more light on WUE terms, Figure (2) depicts, under normal field conditions, the relationship between crop yield, Y, and each of transpiration, T, evapotranspiration, ET, and Irrigation water, I. To simplify the analysis, the change in soil water storage in the root zone between the beginning and the end of the growing season is assumed small, thus neglected. Also, in capturing and reusing irrigation water losses, there are two important issues that should be considered: (1) cost and feasibility of recovering these water *losses* (all or part of it) and (2) the quality of the recovered water *losses*. Referring to Figure 3, the transpiration WUE (WUET), the evapotranspiration WUE (WUEET) and the Irrigation WUE (WUEI) are defined as:

$$WUE_T = Y/T \quad (3)$$

$$WUE_{ET} = Y/(T+E) \quad (4)$$

$$WUE_I = Y/(T+E+(1-r1\ r2)(R+D))$$

$$= Y/[I - r_1 r_2 (R+D)] \quad (5)$$

in which:
R= surface runoff *losses;*
D= deep percolation (drainage) *losses;*
r_1= fraction of (R+D), that is recoverable with water quality the same as that of the irrigation water, I.
r_2 = is a factor of equivalence due to deterioration in water quality; depends on water quality of I and r_1(R+D). If the quality of the recovered water is the same as that of I, r_2 = 1, whereas if it is less than the quality of I, r_2 becomes less than 1 and approach zero if the quality of the recovered water is unfit for irrigation.

It is evident that: $WUE_I < WUE_{ET} < WUE_T$. However, if E=0, then $WUE_{ET} = WUE_T$. Also, if the runoff (R) and drainage (D) *losses* are equal to zero, then $WUE_I = WUE_{ET}$, and so on.

Further analysis performed on Equations (1) through (5) results in the following relationship among these efficiency terms, particularly between WUE and field water application irrigation efficiency, WAE, where R_f = D + R:

$$WUE_{ET} = WUE_T(1 - \frac{E}{ET}) \tag{6}$$

$$WUE_I = WUE_{ET}\left(\frac{I - R_f}{I - r_1 r_2 R_f}\right) \tag{7}$$

$$WUE_I = WUE_{ET} * WAE \tag{8}$$

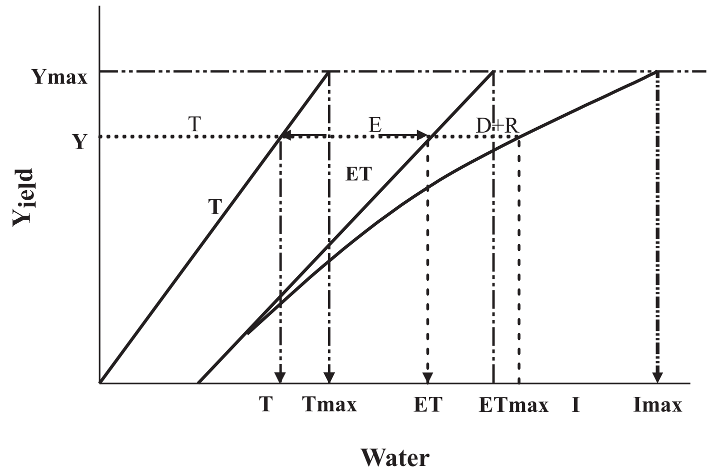

Figure 2. A diagram showing water use efficiency terms and components. (Source: Oweis and Hachum, 2003)

To conclude this section, it seems that the concept of WUE has many facets. Probably, the relevant ones are physiological, agronomic, hydrological and socioeconomic. The current definition of WUE is not totally accepted by workers in all of these fields. To overcome this shortcoming, the term ***water productivity*** was introduced instead (Molden, 1997). However, the term *water use efficiency* is still widely used interchangeably with the term *water productivity*.

Water Productivity

The definitions

It is now well understood that the issue of water productivity is multidisciplinary and scale- or level-dependent. In the more general sense, water productivity WP is defined as:

$$WP = \frac{\text{Return}}{\text{Unit of water consumed}} \qquad (9)$$

The return in Equation (9) may be:

- biomass, grain, milk, meat, etc, (kg)
- Income ($)
- Environmental benefits (Carbon sequestration)
- Social benefits (employment, land abandon, living standards, …)
- Energy (cal)
- Nutrition (protein, carbohydrates, fat,…)

The water consumed in Equation (9) is meant to be the water depleted from the production system rendering the return. Water depletion is the use or removal of water (from a domain, particularly a basin) that renders it unavailable for further use. Water may be depleted by evaporation, flows to sinks (such as sea or saline groundwater), or incorporation into products (such as bottling water). Therefore, it is important to distinguish between water depleted and water diverted, because not all water diverted (or supplied) to irrigation is depleted. Recoverable losses (such as surface runoff, and deep percolation) from any WP level or domain's boundaries can be reused within the same domain or higher levels. The word ***consumed*** is more appealing to use than ***depleted***. In irrigation, for example, diverted or supplied water represents depth of irrigation water applied to the field, I, while the depleted water is equal to the denominator of the ratio in Equations (5) or (9). More specifically, depleted water includes:

- Evaporation
- Transpiration
- Water quality deterioration
- Water incorporated in the product or plant tissues.

When discussing the banner “More Crop per Drop”—a slogan used recently by the Secretary General of the United Nations as a response to the threatening crises of water scarcity, Molden et al. (2003) put forward an interesting question concerning the terms in Equation (9) when using biomass or grain for the return: (which crop and which drop?). Waters vary in quality, location (surface or groundwater), and time of availability.

Potential improvements of WP

Figure 4 shows, worldwide, ratio of biomass and yield of common small grain crops to transpiration, T, along with yield/ET ratio for two selected regions. The slope of the second line from top is greater than the slope of the top line that indicates potential improvement in harvest index. The two lower lines in the Figure indicate that improvements in water productivity are possible through improved management that increases the ratio of yield to evapotranspiration (slope of line). But in many of the most productive areas of the world, such as the lower Yellow River Basin, large improvements have already been made and the remaining scope is small. The implication is that for these areas achieving higher yields will require more evapotranspiration. The areas with the highest potential gains are those with very low yields, such as Sub-Saharan Africa and South Asia. These are also areas of extreme poverty, with the largest concentration of poor people and high dependence of the poor on agriculture.

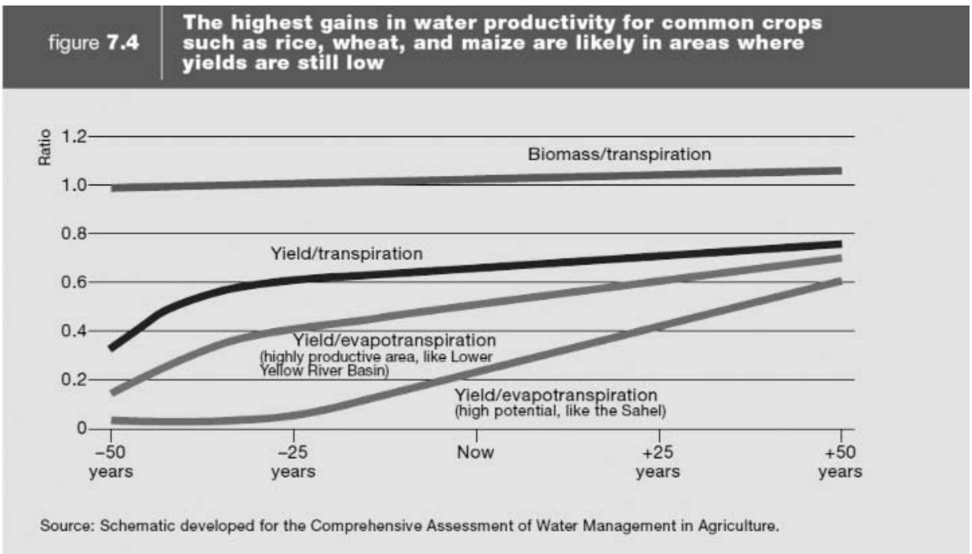

Figure 3. Ratios of biomass/transpiration , yield/transpiration, and yield/evapotranspiration for common grain crops (wheat, maize, rice); worldwide and for selected regions. (Source: Comprehensive Assessment of Water Management in Agriculture, chapter 7, 2007)

Breeding, targeting early growth vigor to reduce evaporation, and increasing resistance to drought, disease, or salinity could all improve water productivity per unit of evapotranspiration. But there are several indirect means to improve water productivity in which biotechnology can play a role:

- Targeting rapid early growth to shade the soil and reduce evaporation.
- Breeding for resistance to disease, pests, and salinity.
- Boosting the harvest index for crops such as millet and sorghum that have not received as much attention as the green revolution's grains.
- More value per unit of evapotranspiration can be achieved by improving the nutritional quality of crops and by reducing agrochemical inputs by planting disease- and pest-resistant crops.

Drivers for WP improvement at various scales

WP is addressed at different scales (plant, farm, project, and basin levels) and a conceptual framework for better understanding of WP and water accounting across scales is introduced. It has been pointed out that highest WP at one scale need not necessarily result in highest WP at another scale. Economic productivity and opportunity cost of water make the undertaking far more complex. Nevertheless, the major drivers at each scale are:

- At the basin level:
  - competition among uses (Agricultural, domestic, environmental, ….)
  - conflicts between countries
  - equity issues (upstream – downstream users)
- At the national level, drivers are:
  - food security
  - hard currency
  - socio-politics
- At the farm level, one driver:
  - maximizing economic return (crop and allocation selection)
- Figure 5 shows the unit water productivity, in kg mass, for different crops and also for beef meat.
- At the field level, the driver is:
  - maximizing biological output (maximizing resources productivity)
- At the plant level, the driver is:
  - maximizing nutrient content and quality of harvest.

Table 1 presents the return of one cubic meter of water in Aleppo, northern Syria for different crops.

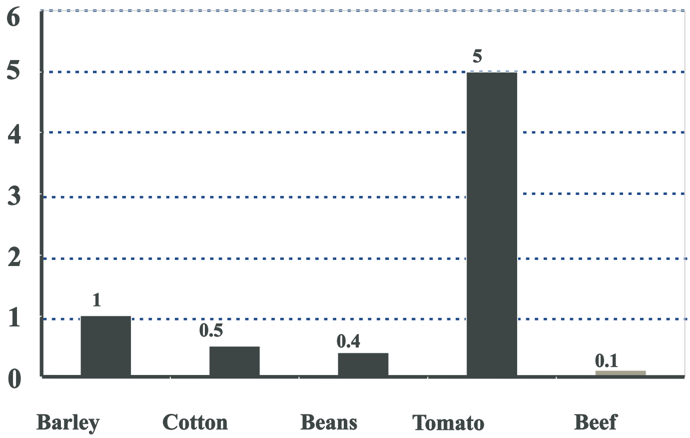

Figure 5. Comparison of water productivity for different crops in addition to beef.

Table 1. Return of one cubic meter of water for different crops, Aleppo, Syria.

	Wheat	Beef	Lentils	Olives	Tomato
Water (Kg)	0.1	0.09	0.05	1.6	4.5
Energy (Cal)	3500	210	2121	2300	900
Protein (gr)	105	30	150	20	50
Money ($)	0.15	0.3	0.24	2.0	1.0
WUE (kg/m3)	1.0	0.1	0.6	2.0	5.0

WP issues to be tackled

It is important to note that WP is not only scale and user specific, but also site and management specific. One cubic meter of good water is expected to produce more biomass than that of the water of low quality. Also, one cubic meter of water is expected to produce more biomass in a cool region than in a hot dry environment. Soil type, water quality, crop variety, production input, water and crop management are among the factors impacting WP. Policies, values, and market prices have their influence on the assessed values of WP. For meaningful comparison of WP at different locations and/or environments, there is need to normalize the values of WP.

It is important, however, that water quality, not only quantity, be defined when talking about water productivity. Table 2 shows the productivity equivalence of one cubic meter of water, but with different qualities. Figure 6 shows wheat grain yield versus evapotranspiration at different regions of the world. The Figure illustrates significant variability in yield due to differences in biophysical conditions (particularly evaporation and other climatic conditions) among sites in addition to differences in management of natural resources. Variability due to management practices gives hope for potential improvement in water productivity especially at low yield domain.

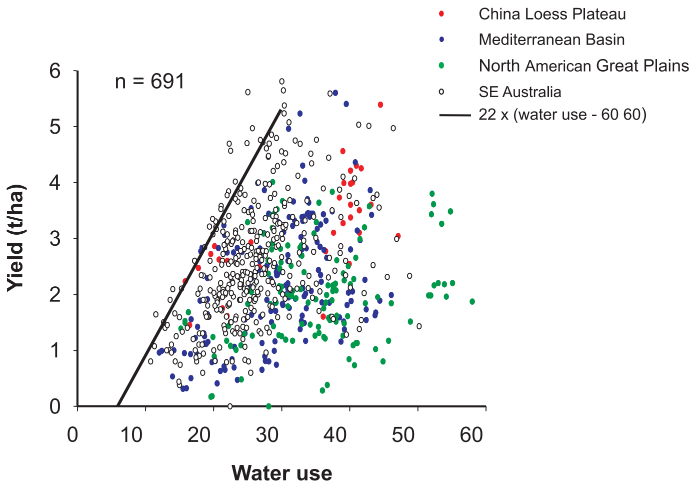

Figure 6. wheat grain yield versus evapotranspiration at different regions of the world, indicating the potential for WP improvements. Source (Sadras and Angus, 2006)

Table 2. WP Equivalence (volume of low quality water whose return is equivalent to the return of one cubic meter of fresh water) for different crops and water quality.

EC (dS/m)	Wheat	Barley	Tomato	Beans
1.0	1	1	1	1
2.0	1	1	1	1.25
4.0	1	1	1.25	3.2
8.0	1.2	1	3.2	10
12.0	1.72	1.25	10	??????

There is a pressing need to standardize the methodology for assessing and evaluating WP with time over different levels (scales). It is difficult to arrive at any useful conclusion by comparing WP based on ET with that based on Irrigation water. The links among water productivity values at different scales need critical study and evaluation. The role of irrigation system and water delivery and scheduling need further investigations.

Tradeoffs between Water and Land Productivities

In conventional irrigation, water is applied to maximize crop yield (maximizing production per unit of land). This is the case when water is not limiting, rather when land is limiting. In the dry areas, land is not, any more, the most limiting factor to production rather water is increasingly becoming the limiting factor. It is, therefore, logical to conclude that since water is more limiting factor, then the objective should be to maximize the return per unit of water not per unit of land. This should yield higher overall production, since the saved water can be used to irrigate new land with higher production. However, high water productivity does not come without high yield. Fortunately, both water productivity and yield increase at the same time as improvement to on-farm management is introduced, but this does not continue all the way. At some high level of yield (production/unit of land) incremental yield increase requires higher amounts of water to achieve. This means that water productivity drops as yield increases above certain levels. Figure 7 shows the relationship between yield increase and water productivity increase for *durum* wheat under supplemental irrigation in Syria. Generally, maximum water productivity occurs at sub-optimal crop yield per unit area. This is provided the relation is not a straight line, which is not always the case.

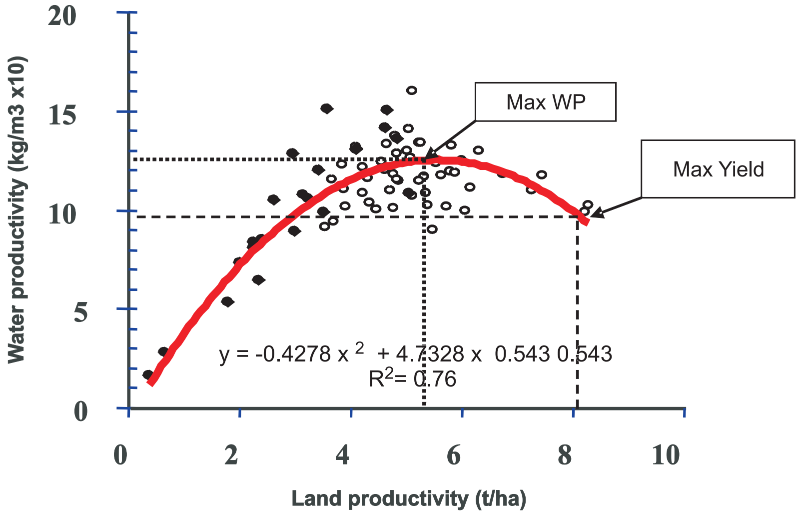

Figure 7. Relationship between water productivity and grain yield for durum wheat under supplemental irrigation in Syria (Oweis et al 1998a).

The association of high WP values with high yields has important implications for the crop management for achieving efficient use of water resources in water scarce areas (Oweis et al., 1998). However, attaining higher yields with improved WP should ensure that increased gains in crop yield are not offset by increased costs of inputs and running costs. The curvilinear WP-yield relationship emphasizes the importance of attaining relative high yields for efficient use of water. A policy for maximizing yield and/or net profit should be looked at very carefully under water scarcity conditions. Guidelines for recommending irrigation schedules under normal water availability (Allen et al., 1998) may need to be revised when applied in areas with limited water resources.

Approaches for Improving WP

It is well observed that there are significant variations in the yield of a certain crop among regions, basins, districts and even in the same project. There is also large gap between potential yield and actual yield on the same site. Therefore, benchmarking is necessary for an effective methodology or approach to improve yield and/or water productivity. Causes and factors limiting present WP to attain potential levels should be identified and mitigated. Furthermore, integration is vital for any successful approach aiming to improve WP, particularly on basin level. Integration is the scientific way to look at and study a given problem from all aspects. Without integration, sustainability will be jeopardized. Moreover, it has been widely accepted and proven that participation of all beneficiaries and stakeholders is an essential success factor for any project targeting WP improvement. Such projects should involve the community as a participant and as a target. People should be involved from the very beginning of the project; they understand and are convinced that the project is theirs and it is for their good. Otherwise, the project will soon be doomed to failure. No doubt, WP improvement projects are of long-term, they need time and resources. Agriculture and irrigation are not only sciences, but also are arts that are inherited over centuries. Therefore, farmers, who are used to traditional farming practices, are difficult to change and abandon.

Winning Ways for Improving Agricultural WP

There is a great scope for improving the productivity and use efficiency of water in water scarce regions. Research findings have shown that substantial and sustainable improvements in water productivity is attainable, but can only be achieved through integrated natural resources management approaches. On-farm water-use efficient techniques if coupled with improved irrigation management options, better crop selection and appropriate cultural practices, improved genetic make-up, and timely socio-economic interventions will help to achieve this objective. Conventional water management guidelines designed to maximize yield per unit area need to be revised for achieving maximum water productivity instead. Appropriate policies on farmers' participation and water cost recovery are necessary for adopting improved management options.

Increasing the productivity per unit of water consumed:

1. ***Changing to crop varieties*** that can provide increased yields for each unit of water consumed, or the same yields with fewer units of water consumed.
2. ***Crop substitution*** by switching from high- to less-water-consuming crops, or switching to crops with higher economic or physical productivity per unit of water consumed.
3. ***Deficit, supplemental, or precision irrigation***. With sufficient water control, higher productivity can be achieved using irrigation strategies that increase the returns per unit of water consumed.

4. ***Improved water managemen***t to provide better timing of supplies to reduce stress at critical crop growth stages leading to increased yields or by increasing water supply reliability so that farmers invest more in other agricultural inputs leading to higher output per unit of water.
5. ***Optimizing non-water inputs***. In association with irrigation strategies that increase the yield per unit of water consumed, agronomic practices such as land preparation and fertilization can increase the return per unit of water.
6. ***Policy reform and public awareness***. Policies related to water use and valuation should be geared towards controlling water use, reducing water demand, safe use and disposal of water, and encouraging the collective approach in using and managing water by users. These policies must be balanced, workable and feasible, otherwise they will be difficult to implement and/or enforced.

Reducing non-beneficial depletion:

1. ***Reducing evaporation from water applied*** to irrigated fields through specific irrigation technologies such as drip irrigation, or agronomic practices such as mulching, or changing crop planting dates to match periods of less-evaporative demand.
2. ***Reducing evaporation from fallow land*** by decreasing the area of free water surfaces, decreasing non- or less-beneficial vegetation and controlling weeds.
3. ***Reducing water flows to sinks***—by interventions that reduce irrecoverable deep percolation and surface runoff.
4. ***Minimizing salinization of return flows***—by minimizing flows through saline soils or through saline groundwater to reduce pollution caused by the movement of salts into recoverable irrigation return flows.
5. ***Shunting polluted water to sinks***—to avoid the need to dilute with freshwater, saline or otherwise polluted water should be shunted directly to sinks.
6. ***Reusing return flow*** through gravity and pump diversions to increase irrigated area.

Reallocating water among uses

1. ***Reallocating water from lower- to higher-value uses.*** Reallocation will generally not result in any direct water savings, but it can dramatically increase the economic productivity of water. Because downstream commitments may change, reallocation of water can have serious legal, equity and other social considerations that must be addressed.
2. ***Tapping uncommitted outflows***
3. ***Improving management of existing facilities*** to obtain more beneficial use from existing water supplies.
4. ***Policy, design, management and institutional interventions*** may allow for an expansion of irrigated area, increased cropping intensity or increased yields within the service areas.

5. ***Reducing delivery requirements*** by improved application efficiency, water pricing, and improved allocation and distribution practices.
6. ***Adding storage facilities infrastructures*** to store and regulate the use of uncommitted outflows, which is usually the case during wet years, could be considered so that more water is available for release during drier periods. Storage may take many forms including reservoir impoundments, groundwater aquifers, small tanks and ponds on farmers' fields.

Deficit irrigation

When water is limiting production, the rules of scheduling should be modified for improved water productivity. In intensive irrigation development, all efforts including research and advancement in technology development are geared towards achieving maximized yield per unit of land. However, in water scarce areas, water, not land, is the most limiting factor to improving agricultural production. Irrigating for less than maximum yield per unit land (deficit irrigation) could save substantial amounts of water for irrigating new lands and hence producing more food from the available water. Deficit irrigation is not the only practice that has shown good potential, but other ways are available to modify water management principles to achieve more water-efficient practices. New guidelines for crop water requirements and irrigation scheduling to maximize water productivity are yet to be developed for the important crops in the dry areas.

Water harvesting

The drier environments, "the steppe", occupy the vast majority of the dry areas of the world. The disadvantaged people generally live there. The natural resources of these areas are subjected to degradation and the income of the people who depend mainly on grazing is continuously declining. Due to harsh conditions, people are increasingly migrating from these areas to the cities, with associated high social and environmental costs.

Precipitation in the drier environments is generally low compared to the basic needs of crops. It is unfavorably distributed over the crop-growing season and often comes with high intensity. As a result, rainfall in this environment cannot support economical dryland farming. In the Mediterranean areas, rain usually comes in sporadic, unpredictable storms and is mostly lost in evaporation and runoff, leaving frequent dry periods during the crop growing season **(**Figure 8**)**. Part of the rain returns to the atmosphere, directly from the soil surface by evaporation after it falls, and part flows as surface runoff, usually joins streams and flows to swamps or to "salt sinks", where it loses quality and evaporates; a small portion of it joins groundwater. The overall result is that most of the rainwater in the drier environments is lost with no benefits and/or productivity (Oweis et al., 1999).

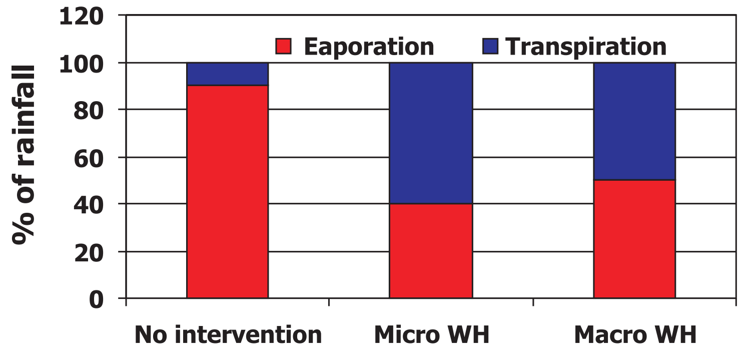

Figure 8. Role of water harvesting in shifting nonproductive water evaporation into beneficial transpiration.

Water harvesting in agriculture is based on the principle of depriving part of the land of its share of rainwater (which is usually small and non-productive) and adding it to the share of another part. This brings the amount of water available to the target area closer to the crop water requirements so that economical agricultural production can be achieved and thus improving the water productivity. Thus water harvesting may be defined as *"the process of concentrating precipitation through runoff and storing it for beneficial use"*.

Capturing rainwater and using it efficiently is crucial for any integrated development. Without water harvesting intervention, all rainwater and land production are lost, while part of the land and most of the rainwater are in production and beneficial. Thus, rainwater productivity is immensely increased. Notable wealth of indigenous knowledge on water harvesting is a available and documented. Indigenous systems such as *jessour* and *meskat* in Tunisia, *tabia* in Libya, *cisterns* in north Egypt, *hafaer* in Jordan, Syria and Sudan and many other techniques are still in use (Oweis et al., 1999 and 2001). Water harvesting may be developed to provide water for human and animal consumption, domestic and environmental purposes, as well as for plant production. Water harvesting is also effective in combating land degradation and desertification

Unfortunately, the introduction of systems which have been tested under various climatic, soil, land-tenure and socioeconomic conditions are usually not accepted by the target groups. The most significant problems and constraints hindering the integration of water harvesting in the agricultural production are:

- Technology inadequate to the requirements of the country/ region/ area;
- Lack of acceptance, motivation and involvement among beneficiaries;
- Lack of adequate hydrological data and information for confident planning, design and implementation of water harvesting projects;
- Insufficient attention to social and economic aspects such as land tenure,
- unemployment and return of water harvesting system;

• Lack of effective involvement of the national research centers and extension services;
• Inadequate institutional structures, beneficiary organizations (associations, cooperatives) and government training programs for farmers, pastoralists and extension staff;
•Absence of a long-term government policy.

Supplemental irrigation

Shortage of soil moisture in the dry rainfed areas often occurs during the most sensitive growth stages (flowering and grain filling) of the crops. As a result, rainfed crop growth is poor and consequently the yield is low. Supplemental irrigation (SI) can, by using a limited amount of water, if applied during the critical crop growth stages, result in substantial improvement in yield and water productivity. Therefore, supplemental irrigation is an effective response to alleviate the adverse impact of soil moisture stress during dry spells on the yield of rainfed crops. Unlike full irrigation, the timing and amount of SI cannot be determined in advance owing to rainfall randomness. Supplemental irrigation in rainfed areas is based on the following three basic aspects (Oweis and Hachum, 2003):

1. Water is applied to a rainfed crop that would normally produce some yield without irrigation.
2. Since rainfall is the principal source of water for rainfed crops, SI is only applied when rainfall fails to provide essential moisture for improved and stable production.
3. The amount and timing of SI are scheduled not to provide moisture-stress-free conditions throughout the growing season, but to ensure a minimum amount of water available during the critical stages of crop growth that would permit optimal instead of maximum yield.

Average WP of rain in producing wheat in the dry areas of West Asia and North Africa (WANA) ranges from about 0.35 to 1.00 kg grain/m^3. However, water used in supplemental irrigation can be much more efficient. ICARDA found that a cubic meter of water applied at the right time (when crops suffer from moisture stress) and good management could produce more than 2.5 kg of grain over the rainfed production. This extremely high WUE is mainly attributed to the effectiveness of a small amount of water in alleviating severe moisture stress during the most sensitive stage of crop growth. This stress usually causes a collapse in the crop development and seed filling and reduces the yields substantially. When SI irrigation water is applied before such conditions occur, the plant may reach its high potential.

In comparison to the productivity of water in fully irrigated areas (rainfall effect is negligible), we find greater advantage with SI. In fully irrigated areas with good management, wheat grain yield is about 6 t/ha using a total amount of 800 mm of water. This makes WP about 0.75 kg/m^3, one third of that under SI with similar management (Figure 9). This suggests that water resources are better allocated to SI when other physical and economic conditions are favorable.

Deficit irrigation is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction in order to maximize the productivity per unit of water used. One important merit of deficit supplemental irrigation is the greater potential for benefiting from unexpected rainfall during the growing season due to the higher availability of storage space in the crop root zone. Results on wheat, obtained from farmers' fields trials conducted in a Mediterranean climate in northern Syria reported significant improvement in SI water productivity at lower application rates than at full irrigation. Highest water productivity of applied water was obtained at rates between 1/3 and 2/3 of full SI requirements, in addition to rainfall.

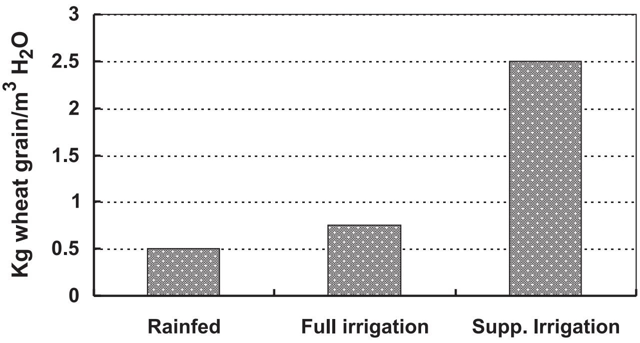

Figure 9: Productivity of one cubic meter of green water (rainfed), of blue water (full irrigation), and of blue water as supplemental irrigation for a basically rainfed wheat.

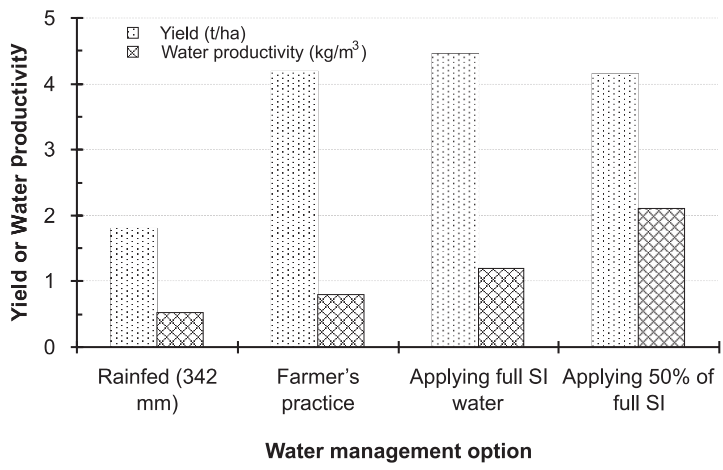

Figure 10: Yield and water productivity for wheat under different water management options for a four hectares farm in northern Syria.

In northern Syria, water-short farmers apply half the amount of full SI water requirements to their wheat fields. By doing so, the area under SI is doubled using the same amount of water, and the total farm production increases by 33 percent. Research in the WANA region has shown that the application of only 50% of full supplemental irrigation requirements causes a yield reduction of only 10-15%. When there is not enough water to provide full supplemental irrigation to the whole farm, the farmer has two options: one is to irrigate part of the farm with full SI leaving the other part rainfed, and the other is to apply deficit irrigation to the whole farm. Under limited water resource availability of 50% of the full SI requirements, SI deficit irrigation proved to be the winning option by farmers. A farmer having a 4-hectare farm would on an average produce 33% more grain from his farm if he adopted deficit irrigation for the whole area, than if full irrigation was applied to half of the area (Figure 10).

In the highlands of WANA region, frost conditions occur between December and March and put field crops into dormancy. Usually, the first rainfall, sufficient to germinate seeds, comes late resulting in poor crop stand when the frost occurs in December. Rainfed yields, as a result, are much lower than when the crop stand pre-frost is good. Ensuring a good crop stand in December can be achieved by early sowing and applying a 50 mm of supplemental irrigation in October. SI, given at early sowing, dramatically increased wheat yield and water productivity. Applying 50 mm of SI to wheat sown early has increased grain yield by more than 60%, adding more than 2 t/ha to the average rainfed yield of 3.2 t/ha (Ilbeyi et al. 2006). Water productivity reached 4.4 kg grain/m^3 of consumed water compared to water productivity values of wheat of 1 to 2 kg/m^3 under traditional practices (Figure 11).

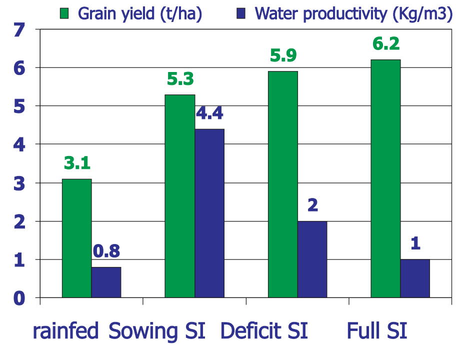

Figure 11. Impact of early sowing of wheat on yield and water productivity in the highland of Turkey.

Changing current land use

Due to increased water scarcity, globalization and climate change, current land use and cropping patterns should be modified if more food is to be produced from less water. Water is likely to be the major constraint and new land use systems that respond to external as well as internal factors must be developed based on available water. This should include adopting water efficient crops, varieties, and sound combinations of crops in the farming system.

Precision irrigation

Improved technologies that already exist may at least double the amount of food produced from present levels of water use, if applied in the field. Implementing precision irrigation, such as micro- and sprinkler irrigation systems, laser leveling and others techniques contribute to substantial improvement in water application and distribution efficiency. It is true that water lost during conveyance and on-farm application is not an absolute loss from a basin perspective, but its quality may deteriorate and its recovery comes at a cost. To account for these losses, the size of the irrigation system will significantly increase and this again comes at a very high cost. Policies to implement and transfer these technologies are vital. There is a need to provide farmers with economic and more efficient alternatives to on-farm water management practices with incentives that can bring about the needed change.

WP Improvement and the Environment

Now, it has been globally understood and accepted that *environment* is a water-using sector, which is strongly linked to the sustainability of water resources development and management. This is a complex issue for both rich and poor countries. It is technically challenging and often entails difficult trade-off among social, economic, and political considerations. One of the important achievements in the water resources issue, in recent years, is the clear and firm inclusion of environmental water requirements in the picture of the water resources assessment and budget at various levels: global, regional and basin-wide.

Strategies to reduce poverty should not lead to further degradation of water resources and ecology. Since we accept that environment is one of the water-using sectors, a valid question that should be answered is *what is the fair share for it*? Estimates of irrigation withdrawal in 2025, taking into consideration the environment, anticipate that irrigation withdrawals need to be reduced by 7% from 1995 level in order to sustain ecosystems. It looks that tradeoff between environmental water needs and that for food production will be unavoidable. There are many options that have been proposed for solving this complex and paradox problem. The two most promising options are increasing water productivity and upgrading rainfed systems through the implementation of highly efficient tested-techniques and improved water management practices – all at lowest environmental cost.

Policies and Institutions Issues

The critical issue in improved water management in the area is lack of appropriate policies and poor implementation. Changing from supply to demand management require incentives and change in the attitude of the people. Valuating water is essential if efficiency is to improve. Socio-political constrains do not allow water pricing, but alternatives to pricing can be developed. Water trading through goods is an old practice. It can be used in countries with extreme water scarcity to reduce inefficient water use, but agricultural practices of rural communities should be protected. Water management institutions such as user associations and community cooperatives are weak in the region and need strengthening. They should be allowed to participate in the decision making regarding water issues. Their capacity is also poor and training is essential to improve skills and participation. Linkages between various organizations and disciplines would help integration and exchange of experiences. It is about time for these vital changes in order to unlock the potential of water management in agriculture.

Time for Change

Increasing water productivity is the more viable option to cope with water scarcity. Substantial increase in WP, however, requires shift in thinking to sustainably increase water productivity in agriculture through integrated and participatory water resource development and management. For example, one of the greatest limitations to adopting water harvesting works is the lack of clear land ownership. This is public, tribal or other forms. Changes are required to provide incentive for people to invest in this promising water management intervention. Therefore, it is essential that substantial changes be made in the way water is managed to help alleviate poverty, promote economic growth and overcome potential conflicts. The changes needed include:

- The emphasis from land to water with new guidelines for water management.
- Water allocation to more water-efficient techniques
- Current land use, cropping patterns and germplasm to be more water-efficient
- The way water is valuated to truly reflect the scarcity conditions.
- Trade policies to import goods with high water demand for production.
- The attitude towards regional cooperation.
- Policies to address water scarcity issues

Conclusions

In the dry areas, water is the most limiting resource for improved agricultural production. Maximizing water productivity, and not yield per unit of land, is therefore, the more viable strategy. Under such conditions, more efficient water management techniques must be adopted. Supplemental irrigation is a highly efficient practice with great potential for increasing agricultural production and improving livelihoods in the dry rainfed areas. In the drier environments, rainwater productivity is extremely low. Water harvesting can make agriculture feasible and improve rainwater productivity in plant production and other beneficial uses. Socioeconomic and environmental benefits of this practice are far more important than increasing agricultural water productivity. Substantial and sustainable improvements in yield and water productivity can only be achieved through participatory and integrated farm resources management. Improving water productivity in water-scarce areas requires a change in the way agriculture is practiced. More efficient irrigation practices must be adopted. On-farm water-productive techniques, if coupled with improved irrigation management options, better crop selection and appropriate cultural practices, improved genetic make-up, and timely socioeconomic interventions will substantially improve water productivity. The major changes needed to achieve this objective includes: Water allocation to more water-efficient crops/techniques, more water-efficient land use, water valuation to truly reflect its value, trade policy to import high water demand goods, regional corporation for combating water scarcity and new policies to address water scarcity issues.

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IV. COUNTRY REPORTS

WATER USE EFFICIENCY IN EGYPT

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1. Introduction

Amongst natural resources in Egypt, water is the most critical. Scarcity and misuse of freshwater pose a serious and growing threat to the sustainable development and protection of environment. Water resource management and water availability are among the most important political, social and economical issues of the 21st century in Egypt (Harsh et al., 1989; Krug, 1989; Medany et al., 1997).

Competition for limited freshwater sources is growing among households, industry and agriculture. Water resources are becoming scarcer due to great consumption to cope with population growth demand and also due to increasing pollution. However, a realistic approach to water problem in Egypt is limited to improving management and allocation practices, as well as upgrading and modernizing water delivery systems. Water resources development and management must go in line with energy policies and strategies for resources conservation efficiency.

During the next 25 years, substantial quantities of freshwater supplies will be diverted from agriculture to industry, tourism, and households. Efforts must be intensified to collect fundamental water databases, organize them into usable and accessible form, and disseminate to the stakeholders participating in water management.

Engineering studies and system management are required before recommendations are made for selecting the proper irrigation system, integrated crop management plans and planting dates. However, particular soil type, crop species and climatological status would affect efficiency of irrigation water.

The use of high value crops and techniques of water saving such as protected agriculture and soilless culture may be a future pillar for a sustainable and economically-viable water management system in Egyptian agriculture.

1. The Climate and Water Resources of Egypt

Egypt has a total area of about one million km^2, with long costal areas on the Red sea and the Mediterranean.

The main agricultural area in Egypt does not exceed 3.3% (3.5 ha) of the total area and is confined to the narrow strip along the River Nile, in addition to the Nile Delta which is located between the Damietta east tributory and Rosetta tributary on the west.

Egypt lies in the moderate climatic zone, characterized by hot and dry weather in the summer, and warm winter. Table 1 illustrates some examples of weather parameters in some Egyptian regions. The mean annual rainfall of 18 mm ranges from 0 mm/year in the desert to 200 mm/year in the northern costal region.

Table 1. Weather Conditions in some Egyptian Regions

Location	November to March					April to October				
	Temp (Cº)				Rain	Temp (Cº)				Rain
	max	min	Av.	RH%	mm	max	min	Av.	RH%	mm
Alex	25.0	15.8	16.5	69	179	33	21	22.5	69.0	13
Suezs	24.5	12.5	17.0	66.5	18	31.5	19.0	25.0	60.5	5
Cairo	25.5	16.1	17.5	60.0	22	34.0	20.0	22.5	58.0	1
Sharkia	33	3.9	19.3	55.4	0.7	45.0	16.0	26.5	43.9	2.8
Asyout	23.5	9.5	15.5	65.5	6	34.0	18.5	25.5	45.5	1.0
Aswan	26.5	13.0	19.0	37.5	-	38.0	22.5	29.5	29.0	3

Irrigated agriculture is practiced in Egypt since the dawn of history. The ancient Egyptians cultivated the lands and established the first system on earth which combined between natural flow of the River Nile and level of taxes to be collected from citizens. The Romans exported grain from Egypt to most of surrounding countries. Irrigated agriculture had a major boost during the rule of Mohammed Ali who managed to jump with the cultivated area from 2.5 million feddan (1 feddan = 0.42 ha) at cropping intensity of less than 100% to more than 5 million feddan and cropping intensity of more than 150% during the period 1810–1850.

In the second half of the 19th century, the rate of progress was slower. However, the country managed to establish a major development hydraulic project, the excavation of Suez Canal.

The construction of Aswan Dam and number of head regulators on the main Nile River and its branches, namely Isna, Nag Hammadi, Assiout, Delta, Zifta and Edfina barrages during the 1st half of 20th century. The construction of the High Aswan Dam in the mid 1960s declared the complete control of Egyptians on the Nile water.

Irrigated agriculture in Egypt is not only a business from which 40% of the work force get their earnings, but also it provides the country with its food basket and natural fiber.

2. Water Resources in Egypt

Egypt is gift of the River Nile. Life and inhabited area is concentrated in the Nile Valley and Delta; close to water. The share of Egypt from Nile water is fixed according to the 1959 Agreement signed with Sudan at 55.5 billion cubic meter per year (BCM/yr), making the per capita share of water around 2000 m^3/yr. This share has dropped to less than 1000 m^3/yr at present. If the rate of population growth remains at the existing level of about 2%; this share is expected to be as low as 500 m^3/yr by the year 2025.

Groundwater is the second resource and is found in a number of aquifers (some are shallow while others are deep,varying from renewable or non-renewable). Shallow aquifers include that underneath the Nile Valley and Delta, which are fed by seepage from the surface irrigation water. For this reason, it is considered more as a store rather than a resource. These aquifers are used for conjunctive use to supplement the irrigation of areas at the tail end of canals where shortage of water may take place occasionally.

Withdrawal from these aquifers stands now at 3–4 BCM/yr. Shallow aquifers are also found in coastal areas where rain water infiltrates the sand dunes and stands at small quantities over saline water reservoirs.

Major deep aquifers are in the eastern and western deserts, they are mainly non-renewable. Less than 1.0 BCM/yr is withdrawn from deep aquifers at the present time and expected to reach 3 BCM/yr in the near future.

Although rainfall and flash floods are minor resources; however, they are considered together with groundwater in the desert as vital resources because Nile water is not available there.

Use of desalination plants is growing in Egypt because the Nile water conveyance to eastern and western ends of the country is proving to be costly.

3.1 Water Allocation

Agriculture consumes more than 80% of the country’s water budget (about 50 BCM/yr). Domestic and municipal use accounts for about 7BCM/yr; while industry consumes more or less 5 billion. In order to cope with the shortage of water, recycling of water is a fixed policy. All drainage water in the upper part of the country returns back to the main course of the River Nile. Around 4 BCM/yr of drainage water in the southern part of Delta is reused. This figure is planned to increase to 7 BCM/yr in the very near future.

Fisheries and fish farms are among the consumptive users of water. Non-consumptive uses include generation of hydro-power and navigation.

3.2 Water Quality

The Nile water quality is very fresh and clean, with salt concentration not exceeding 200 mg/l (ppm) upstream of Aswan High Dam. Urban and industrial pressure on Nile water starts immediately downstream. Upstream of the Delta Barrage, salt concentration becomes around 300 mg/l and at the end of the irrigation network, salinity hits the 500 mg/l mark.

Drainage water ranges between 500 – 1000 mg/l in the upper Egypt, it becomes between 1000–2000 mg/l in the southern part of the Delta and may reach the high level of 5000–7000 mg/l in northern part of the Delta. Agricultural drains do not only carry agricultural drainage only, but also treated and untreated domestic sewage and industrial effluent are carried by these drains. The result is some 12 BCM of drainage water being disposed to the Mediterranean either directly or through the coastal lakes every year.

3.3 Water Use in Agriculture

Cropping Pattern

Winter crops include alfalfa or berseem (a fodder crop) which is either kept longer for 6–7 cuts or shorter for 3–4 cuts. Usually short berseem is followed by cotton, while long berseem is followed by maize or rice. The second major winter crop is wheat; third is beans and vegetables; minor areas are cultivated with sugar beet, onions, garlic, flax and others. Major summer crops are cotton, maize and rice. While vegetables, sorghum, sunflower, sesame, soybeans are minor summer crops which are normally planted between March and June. Some Nile crops are planted in August and these are mainly maize and vegetables.

Agricultural Water Use

The country's annual abstraction from Lake Nasser is designated to be 55.5 billion m^3 according to the 1959 Agreement. On the other hand, about 200 mm of winter rainfall precipitates along Egypt's northern cost where a seasonal agricultural activity takes place depending on this limited water resource. The amount of rainfall decreases southwards leaving little chance for rain-fed farming .The existence of groundwater aquifers in Western Desert and Sinai are mostly deep and non renewable (El Quosy and Ahmed, 1999).

Table 2. Major Crops and their Cultivated Areas

Crop	***Cropping Pattern Area (000 feddan)***
Long berseem	*1800*
Short berseem	*600*
Wheat	*2500*
Barley	*450*
Beans	*320*
Vegetables	*460*
Others	*270*
Total Winter Crops	*6400*
Cotton	*750*
Maize	*1750*
Sorghum	*350*
Rice	*1400*
Vegetables	*630*
Others	*520*
Total Summer Crops	*5400*
Nili Maize	*330*
Nili Vegetables	*270*
Others	*100*
Total Nili Crops	*700*
Sugarcane	*300*
Fruits	*1000*
Total perennials	*1,300*
Total Cropped Area	*13,800*

It is expected that water demand particularly for agriculture which consume more than 85% from total available water, would be tremendous. The gap between supply and demand in the future will widen, the difference is expected to be a deficit of almost 21 billion m^3 by the year 2025. The country has to develop a series of harsh measures for covering of this large deficit through:

- Implementing upper Nile projects for reducing evaporating/seepage losses and the development of low cost techniques for desalination of brackish water.
- Improving water use efficiency both for the irrigation of agricultural fields, for domestic uses as well as for industrial requirements. Agriculture, being the largest consumer, should bear the hardest measures such as rehabilitation of conveyance and distribution networks, the use of modern irrigation systems, recycling of land drainage and treated waste waters, change of cropping patterns, use of short duration varieties of crops, use of drought-resistant and low-quality water tolerant crops etc.
- Conservation of water bodies from the effect of pollutants and contamination through the improvement of treatment technology in one hand and the use of separate conveyance networks for low quality water on the other.

Therefore, irrigation has to be protected in order to grow crops. Drip irrigation was introduced in early 1970's, and several foreign and national companies constructed irrigation projects in Egypt. Drip irrigation is used successfully to grow crops on newly-reclaimed areas in the western and eastern deserts.

Table 3. Egyptian Water Resources in 2000

Source Nile	**Water Use (billion m^3)**
Releases from Aswan Dam	57.9
Productive use	46.9
Municipal	3.5
Industry	1.4
Old land consumptive use	35.1
New land consumptive use	3.9
Power and navigation	3.0
Losses	11.0
Sea and terminal lakes	10.0
Evaporation and seepage from canals	1.0
Nile water use efficiency	81%
Irrigation efficiency	67%
Cropping intensity	200%
Crop consumptive use	2269 m^3/ ha
Rain	1.4
Aquifers	3.6
Total	62.5

Source: Hanna and Osman, 1996.

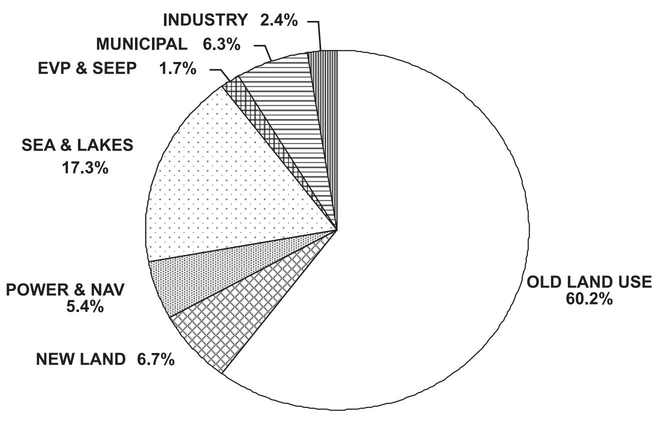


Figure 1. Water Consumption Pattern in Egypt (Source: USAID, 1987).

In April 1997 the Government published its socioeconomic development plans for the next 20 years. The Cabinet of Ministers documented a 5-Year Plan which aims to expand the percentage of Egypt's populated area from nearly 4% to 25%, through the establishment of new industrial and agricultural communities in Sinai and the New Valley of the western desert.

Soil Properties

Table 4 below shows the distribution of Soil Productivity Classes between 1976 to 1995 and the area and extent of each class.

Table 4. Classification of Cultivated Soils Depending upon Productivity during 1976–1995 (1000 ha)

Soil Productivity	1976-1980		1981-1985		1986-1990		1991-1995	
Class	Area	%	Area	%	Area	%	Area	%
First	884	38.3	1329	25.8	332	12.5	1026	31.26
Second	899	39.0	885	35.2	1243	46.7	1229	37.44
Third	384	16.7	205	8.1	768	28.9	579	17.64
Fourth	98	4.3	76	3.0	231	8.7	142	4.32
Fifth	41	1.8	24	0.9	87	3.2	307	9.34
Total	2306	100	2518	100	2661	100	3282	100

Irrigation Methods

The following methods of irrigation are common in Egypt:

* *Conventional Surface Methods*:

Surface irrigation system represents over 80% of Egypt irrigated area.

* *Modern and Sprinkler Irrigation Methods*

Sprinkler system have the advantage of significantly reducing the number of operators directly involved, and thus protection measures can be enforced, and controlled more easily as compared with conventional hand- operated or portable sprinklers.

* *Drip Irrigation Systems*

Might be the one method to be recommended for irrigation with treated effluent, particularly if filtration prevents clogging.

* *Bubbler Irrigation*

It is a localized irrigation technique with regulated flow developed for irrigation fruit trees; which can perform better than trickles and mini sprinklers.

* *Sub-Surface Irrigation*

This system allows the water to be supplied to the root zone with reduced evaporation losses from the soil applying the proper water quantity; and it prevents deep percolation beyond the root zone.

The Extent and Location of Egyptian Irrigated Agriculture
The agricultural land base of Egypt totals about 3.5 million ha. Old lands are representing 75% of agricultural area, and 25% for new lands. The following points should be taken into consideration:

- Due to the increasing population, much greater than current capacity of the national cultivated acreage, per capita share for both cultivated and cropped area is gradually decreasing from 0.48 to 0.12 and from 0.68 to 0.21 feddan (1fed. = 0.42 ha) in the years 1907 and 2000, respectively (Fig. 2).
- Most of the cultivated areas (about 82%) are mainly in the old land of Nile delta and valley. Horizontal expansion in irrigated soils was nearly 18% during the period 1982–1996.

In spite of the increasing of overall cultivated area by 355,462 ha during 1976–1990, first class soils were decreased from 38.3 to about 12.5%. This finding might be due to, raising water table, poor drainage, soil degradation, intensive cultivation, chemical fertilizers, pesticides and housing schemes above agricultural soils.

4. Crop Yields and Water Use Efficiencies

Water resources problems are often associated with low water use efficiency. Hamdy and Lacirignola (1999) reported that agriculture is the most important water use activity. It is also probably the sector least efficient in water use. Low irrigation efficiency can be primarily attributed to water mismanagement, in addition to technical problems of conveyance, distribution, or on-farm application as well as poor maintenance of the irrigation structures. The phrases *efficient water use* or *water use efficiency* is intrinsically ambiguous in relation to crop production. It may mean saving water from a given supply for crop use, or increasing production per unit of water evaporated from soil and/or transpired from the plants in the field (Abou-Hadid, 2002).

For agronomists, Gregory (1991) reported that water use efficiency is commonly defined as:

- WUE = Yield per unit area/ Evapotranspiration in m^3 Abou-Hadid (2002) summarized the main factors affecting water use efficiency as follow:
- Water delivery system; irrigation system; crop shape and morphology; climate factors; management options; economic consideration; techniques for predicting the yield and social / political factors.

Attributing WUE values to the unit of irrigation cost is one of the methods that is used to describe the efficiency of producing crops by using irrigation methods. In this case, the resulted value is known as “Economical Irrigation Productivity” (EIP) (El-Gindy, *et. al*, 2001), with a unit of kg/Egyptian pounds. PIE expresses the relation between the crop yield and the consumed water in an economical way.

Under Egyptian conditions the following notes are considered:

- Water use efficiency (WUE) reflects the capability of consumed water in producing crop yield and refers to the obtained yield per each unit of consumed water during the growing season.
- National water consumed by irrigated crops in 1998 was estimated to be about 37.5 BCM. While the water delivered was nearly 60 BCM. Therefore, the average irrigation application efficiency (Ea) at the national level was 62.5% (Alaam, 2002).

For the same crop, WUE differs among regions due to the variation in both yield and consumptive water use (CU). The following figures can be reported as values of WUE at the old lands (which are the main areas for some main crops): 1m^3 water produces 1.27 kg corn, 0.32 cotton, 6.26 tomato, 9.84 bersem, 1.38 wheat, 0.84 barley, 0.88 faba bean, 7.56 sugar beet, 5.65 potato, 4.86 onion, 2.15 pepper and 4.09 kg cucumber.

The effect of irrigation cost on WUE is shown in Figs 7 and 8. According to the definition of the term WUE, higher WUE value means better water usage and less water losses under certain conditions. Where as, at the same conditions of high WUE, the EIP value could be low, this due to the value of irrigation costs. For example, while the WUE of winter tomato crop (6.5 kg/m^3) is higher than the WUE of cabbage (5.1 kg/m^3), the EIP of cabbage (135 kg/LE) is higher than tomato (124 kg/LE) at the same conditions. This is due to the higher irrigation cost of tomato as compared with cabbage.

- It is preferable to notice that the dominant irrigation system in Egypt is surface especially in the Nile delta and Valley (i.e., in the old land). While pressurized irrigation systems are implemented in the new land.
- The obtained WUE of the vegetable crops cultivated under protected cultivation are significantly higher than the values obtained under open field conditions. For example; WUE of strawberry is 17 kg/m^3, cantaloupe is 29 kg/m^3, Tomato is 16 kg/m^3, melon is 24 kg/m^3, Lettuce is 59 kg/m^3, pepper is kg/m^3, and for cucumber is 31 kg/m^3.

4.1 Changing the Crop Pattern to Save Water

The proposed strategies are:

- Rice and sugarcane are the most water-consuming crops. Therefore, replacement of some areas of sugarcane by sugar beet, which requires less water, could be implemented.
- Reducing the rice areas to 294,000 ha, which is the minimum limit for protecting the Delta from seawater intrusion. This reduction in area along with growing short duration rice varieties is expected to result in savings of more then 3.5 billion m^3 (BCM) of water per year.
- Decreasing the gap between the net return from winter and summer cultivation.
- Defining a crop pattern for each region according to its climatic conditions, soil type and water quantities and penalizing violators.

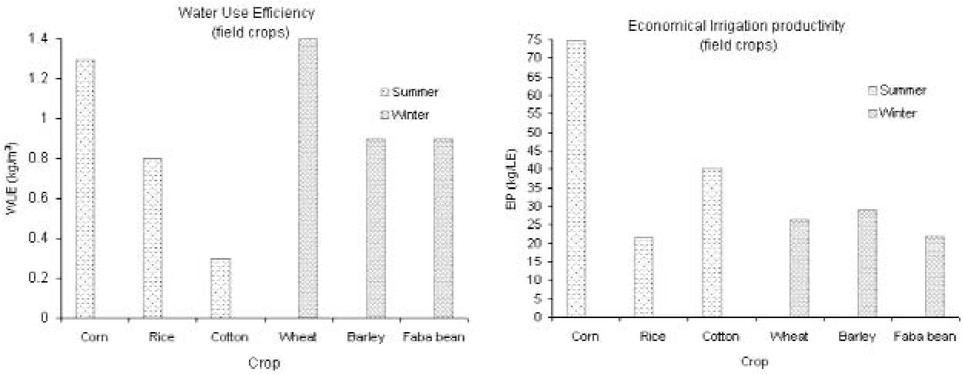


Figure 2. Water Use Efficiency (WUE) and Economical Irrigation Productivity for some Main Field Crops

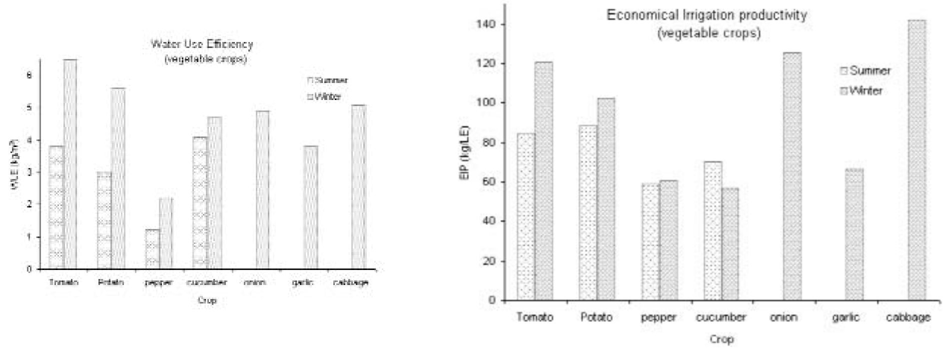
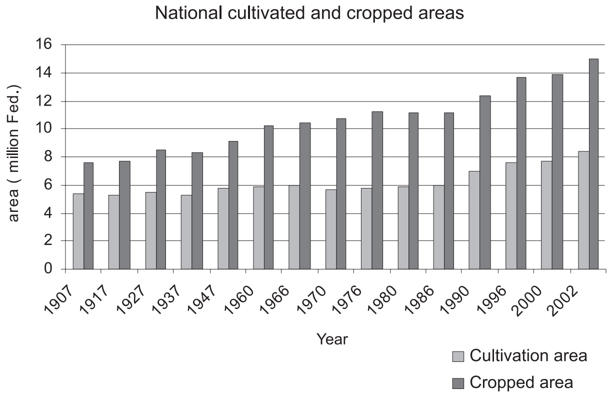


Figure 3. Water Use Efficiency (WUE) and Economical Irrigation Productivity for Vegetable Crops at Major Regions

4.2 Irrigated Crops and their productivity

The annual total cropped area is estimated at 6.3 million ha. (2000), giving a cropping intensity of about 180%, crop production contributes about 68% of the total value of agricultural GDP. The value of field crops, however, is estimated at about 66% of the total crop production value. The value of vegetables and fruits are estimated at 17% and 15%, respectively, of the total crop production value.

Two main groups are labeled concerning crop production; they are winter and summer crops. Following are the subsequent productivity and country production over years for some of the main crops as shown in Fig. 3 and 4 (Agricultural Statistics, MALR ,2002).



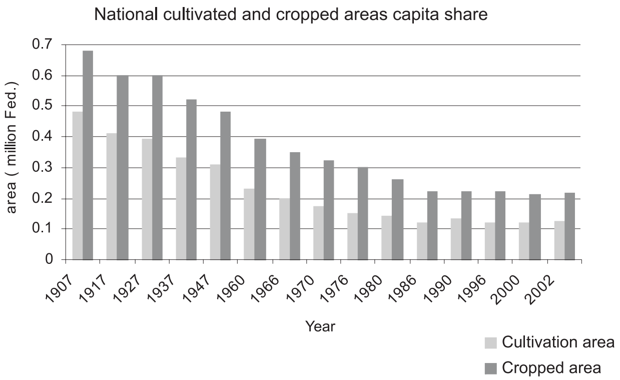


Figure 4.Cultivated and Cropped Areas and Per Capita Share during 1907

5. Policies Related to Improving Water Use Efficiency

5.1. Socioeconomic aspects

Most of the Egyptian farming communities are living below poverty line. The obvious reason is that most land holdings are so fragmented to extent that the average holding is less than one feddan. This situation can be attributed to two main reasons:

a. The agrarian reform adopted by the 23 July Revolution which split the land owned by big landlords and distributed it to landless farmers.
b. The heritage system in which land is usually divided between sons and daughters when the father or the mother dies.

One other main reason for farmers' low income is the cheap price of agricultural products, which is mainly due to the low income of average citizen who cannot afford expensive food items. The cheap output together with the expensive inputs creates a situation in which farmers are subsidizing the national economy.

Farm inputs include seeds, fertilizers, pesticides, harvesting/ picking, labor, energy (for lifting water) and more important the rent of land which has doubled10 times during the last five years. All other inputs are not subject to any subsidy and they are all sold in the free market.

In view of above situation, it is fairly difficult to charge farmers for any other extras including water. On the contrary the farmers are enjoying subsidized bread, fuel, electricity, potable water like any other citizens.

5.2. Water Management: Policies and Strategies

Up to the recent times water management in Egypt was carried out by a quite central fashion. The Ministry of Water Resources and Irrigation (MWRI), being the public body responsible for water distribution in the country, prepares and implements dynamic water policies to cope with the rapid change in the society's needs for water. There are mainly the fast growing population and the need to raise their standard of living.

Working in close cooperation with the Ministry of Agriculture and Land Reclamation (MALR), the MWRI allocates the water between the stakeholders according a water balance between supply and demandr. The growing population puts more pressure on the demand side while the supply is fixed. The solution is always twofold:

Increased productivity per unit volume of water, and
Increased efficiency of the water supply system.

In old lands, increased productivity per unit volume of water is managed through the introduction of subsurface drainage, land leveling, night irrigation, short-season crop varieties, irrigation improvement projects, deep plowing, improved seeds, …etc. These measures are called *vertical expansion*. The *horizontal expansion* is to add new lands reclaimed from desert areas. Since the construction of the High Aswan Dam, Egypt added new areas close to 2 million feddans of desert lands located on the fringes of the Nile Valley and Delta. In 1997 the country's water policy called for the reclamation of 3.4 million feddans up to the year 2017. By then the total cultivated area would be around 11 million feddans which can hardly be exceeded at the present water quota of the country.

Egypt is maintaining excellent relationships with the Nile Basin Countries and the opportunity to develop water resources in the basin for the benefit of all the riparian countries appears to be promising.

Increasing efficiency of the supply system includes:

- Reduction of evaporation from Lake Nasser through efficient regulation of its operation rules,
- Reduction of losses from the conveyance network through canal lining, aquatic weeds control, tightening of gates, reducing tail end losses, etc.
- Reduction of losses on the farm level by reducing surface runoff through land leveling and reducing deep percolation.

The fact that the water multiplier in Egypt has reached 150–200% level is a major factor in increased efficiency.

The overall efficiency of supply in Egypt is touching 75% which is high for a gravity irrigated system.

It is mandatory in newly reclaimed lands to use modern irrigation systems (drip and sprinkler). This partially has increased the efficiency. However, one of the major limitations of continuous reuse of water is soil salinization. The second limitation is the pollution of soil and water environments which appears to be extremely difficult to control.

The MWRI has local offices down to the district level. The average area covered by the district offices is between 30 and 40,000 feddans. Prolonged discussions are taking place to transfer the management of irrigation at its lowest level *(mesqa)* to farmers. Some 2000 Water Users Associations have been formed already. Some of them are functioning successfully. Further discussion upgrade to Farmers' Federation which is composed of leaders of mesqas on the same distributors' canal, ambitious groups call for handing over the management up to the level of irrigation districts to farmers. The opposition to these ideas is based upon the fact that going up on the scale brings other stakeholders to the scene such as potable water supply, fish farming and navigation which makes the matter more complicated than the farmers' capability. However, farmers participation is high on the government agenda and it is not expected to stop since the government cannot any longer bear to carry out both managing at this very low level and taking care of major aspects like development of water resources and pollution control.

Based upon the recommendations of international organizations, Egypt is strongly biased towards the application of integrated water resources management, demand management, cost sharing/recovery systems and the reform of institutions from top to bottom.

5.3 Importance and Degree of Autonomy for Water Users Associations (WUAs)

Creation of much closer working relationship between water suppliers and beneficiaries which can be reflected in the following issues:

- Reduction of financial and operational responsibilities of Ministry of Public Works and Water Resources.
- Improved mesqas reduce evaporation and seepage losses and increase water delivery efficiency.

- Equity of distribution between head and tail reach farmers.
- Reduce size of canals by shifting from rotation to continuous flow, which can add to the area of cultivated lands.
- Less number of pumps and lower pumping costs.
- Reduce irrigation timing and allow for more flexibility in irrigation.
- Eventually all these actions would increase crop yields.

5.4 Governmental Efforts to Improve Agricultural Water Management

i. Sugarcane Water Conservation

As part of the Government's efforts to promote improved water conservation and management ; both Ministeries of Agriculture and Water Resources are working together to reduce the amount of water applied to agricultural production while maintaining high levels of productivity and improving farm incomes. Considerable efforts concentrated on the sugarcane crop because it uses the most water of any crop in Upper Egypt.

A minimum of 3.0 BCM of water is applied to about 1,050,420 ha of Sugarcane (traditional irrigation quantity applied average 12,000 m^3 of water per feddan/yr). To reduce the amount of water consumed by this crop, A Working Group was formed consisting of members from the above two ministries, the Sugarcane Council, the Sugarcane Companies, with a goal to develop and implement a policy of improved irrigation by using less water while maintaining current levels of production from the crop.

In 1977 Sugarcane Working Group implemented a pilot program to install a piped on farm- irrigation system on 315 ha of privately-owned and operated sugarcane farms in the Governorates of Minia, Luxor, and Qena. The improved irrigation system is expected to reduce water application down to 8–9,000 m^3 per feddan, while maintaining current levels of production. The improved irrigation system has shown a reduced water use for sugarcane by 20% to 25%. There are increased sugarcane yield, ranging from 10% to 25%; improved water quality and efficiency of water use; improved drainage; improved fertilizer efficiency; increased production area of land by up to 10 %; improved weed control. In addition, some considerable time and cost savings associated with irrigation, such as reducing need for diesel fuel to operate irrigation pumps and lower hired labor costs. The improved irrigation system requires farmers to substitute for the traditional system of flood irrigation used on all other crops in the Nile Valley, a more structured and efficient system including;

Subsoil plowing; LASER leveling of the field prior to pipes installation; installation of a new high capacity water pumps; and connecting main pipes to above- ground perforated pipes (PVC or aluminum) with valves to control water flow.

ii. LASER Land Leveling

LASER land leveling has a positive effect on increasing agricultural crops yields and save irrigation quantity by 10 to15%. This technology started since 1984 and has been expanding in Egypt on a large scale. Both Ministries of Agriculture and Water Resources are working together to enhance the technology of LASER land leveling by private contractor and Government rental station. LASER land leveling is widely implemented in paddy field in Delta.

iii. Irrigation Improvement Project (IIP)
The Irrigation Improvement Project is designed to respond to the technology transfer challenge to improve water management for Egyptian farmers to meet two major Goals:

A. To increase agricultural production, and
B. To save water through improved irrigation practices.

The demonstration program of this Project is under implementation since 1997. The demonstration includes laser land leveling, gypsum treatment, soil leaching and applying various improved crop management practices. The IIP showed large improvements in the conveyance efficiency of the branch canals and Mesqas (from 60% to 90%) and in the uniformity of water distribution along the mesqa (farm canal).

6. Constraints to Improve Water Productivity

Fast rate of population growth stands as one of the major constraints to country's development plans in all sectors. Agriculture is not an exception to this fact. However, even with the existing circumstances there is still plenty of room for improvement. The major obstacles to this improvement are as follows:

6.1 Water allocation

Egypt has important relative advantages, such as the central location, modest weather and trained labor. The country should concentrate more on the production of vegetables, fruits, ornamental, aromatics and alike. This can only be achieved in the presence of proactive marketing policy, strong private sector, good commercial ties…etc.

Considering competition among activities, return of water from agriculture is small compared with activities like industry and tourism. A small portion of water directed from agriculture can support tremendous industrial and tourism activities.

6.2 Water valuation

One of the fixed policies of Egyptian Succession of Governments is the negative reception of the idea of water pricing. The reason is that farmers who are being at the bottom of the society cannot afford any extra burden represented by water price, especially as they are subsidizing the national economy by selling fairly cheap farm products. Potable water as well as water supply to industry are sold at subsidized prices affordable to the average citizen. However, waste in water use in all aspects is clear. It seems that using better tariffs in which minimum charge is imposed upon small consumers and higher charge on large consumption could be an incentive. Same applies to irrigation; this can be done by fixing a quota per feddan and charging for any extras. Penalizing for water waste either by deviating from the fixed areas and locations of water consuming crops (rice, sugarcane and banana) or by applying excessive irrigation gifts should also take place.

6.3 Water pollution

- Pollution is the major negative impact caused by unplanned urbanization and industrial extension. It should be pointed out that separate fresh water networks need to be completely separate from the sewage or industrial effluents collection systems.

The way out of this problem is three-folds:

1. Increase of treatment capacity (potable water supply for more than the capacity of sewage treatment plants),
2. Reduce potable water supply and lower pressures until sewage treatment plants catch up with supply, and
3. Force industry to treat water locally inside factories. It is important to consider the applications of the “Polluter Pay Approach", which could solve the problem.

6.4 Water Resources Development

Only 5% of the Egyptian water budget is local while some 95% comes from sources outside the country’s boundaries. Maintaining friendly relationship with Nile Basin Countries help in converting slogan of water wars into shared vision and shared benefits. However, the possible alternative is desalination. The relative advantage in this respect is the extended shares of country on the Mediterranean, Red Sea and its two gulfs; as well as the possibility of generating renewable energy (solar, wind, waves, etc.) and the existence of huge reservoirs of brackish water. These three factors may lower the cost of desalination to affordable levels.

6.5 Farmers’ Participation

Farmers’ participation is a very important aspect in the way of better use of water. Although, this exercise is more than 20 years old since the idea started, yet, the progress is fairly small.

The reasons behind that are: Government is not offering sufficient support to juvenile associations; benefits of the exercise to the farmers in not clear (in view of the fact that water has no price); and the service providers as individuals or organizations are still not there.

6.6 Institutional Reform

Egypt has just started the complete modernization of its water system since few years ago. The existing central organization not only in the Ministry of Water Resources but also in other ministries and intuitions needs to change in order to cope with the new changes. The first step towards implementation of an integrated water resources management plans started with the Irrigation Improvement Project (IIP) in which the old system in old lands is renewed. Also, drainage projects in which more than 4 million feddans are covered with subsurface drainage and more than 6 million feddans are covered with open drainage. The second step was to improve the software by introducing the Project through local offices for supervising irrigation, drainage, groundwater, survey and mechanical-electrical works within their districts.

6.7 Private-Public Partnership (PPP)

This is a major challenge to the irrigation system which is very central, very public and is supported by a real old bureaucracy. Unfortunately, water projects are not rewarding in respect to their small and long term returns. However, if water is valuated properly, then such Irrigation Improvement Project will certainly be in the center of events.

6.8 Public Awareness

In order to transfer a society from being fully run by state and public authorities to private sector activities; it is needed to change people's mentality. This can only be achieved through strong public awareness programs capable of slowly but surely taking care of this task.

7. Conclusions

In Egypt, irrigation is the main parameter in the agricultural sector and for the whole national economy. Almost all cultivated lands are under irrigation, making Egypt one of unique cases.

Tremendous efforts should be paid towards the maximum usage of each drop of water.

Two parallel programmes ought to be implemented: *first* is upgrading the conveyance efficiency of the irrigation channels network; and *second* introducing an effective on-farm irrigation management.

The overall objective of an effective on-farm irrigation management is to maximize crop yield per unit of applied water. This target could be achieved through several instructing:

- Determination of the accurate applied irrigation water.
- Irrigation scheduling should be based on the actual crop water needs.
- Irrigation method ought to be chosen depending upon local conditions of soil, water, crop and environment.
- Cultural practices for rationalizing irrigation water at farm level such as good leveling and growing short duration varieties especially for high water-consuming crops such as rice.
- Public awareness and Water User Association (WUA's) are vital keys to spread and transfer knowledge and technologies among irrigation stakeholders.
- Use of marginal waters (brackish) for crop production in desert areas and for city beautification and greening purposes (specially using treated sewage water).

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WATER USE EFFICIENCY IN IRAN ISLAMIC REPUBLIC: Status, Challenges and Opportunities

F. Abbasi†, N. Heydari[1] and F. Sohrab‡

1. Introduction

Increased water scarcity and competition for water resources from other sectors made the need to improve agricultural water use efficiency as a priority. The main objective is to ensure adequate food for future generations with the same or less water quantity available to agriculture. Aavailable information indicates that there is a wide gap between actual and attainable crop water productivity, especially in rainfed agriculture. Quantifying crop water productivity reveals gaps in knowledge regarding the best ways to increase crop water productivity. Most of these gaps relate to our inability to fully quantify all flow components in the domain of interest, their interactions with the plants, agricultural inputs and the environment in the process of producing marketable yields. This country report reviews the status of water resources in Iran, briefly presents the water use efficiency (WUE) and irrigation efficiency within the country, raises the problems and gives suggestions to improve WUE in Iran.

2. Background

Agriculture plays a key role in the economy of Iran. It accounts for 18% of the Gross Domestic Product (GDP), one-fourth of employment, more than 85% of food requirements, 25% of non-oil exports, and 90% of raw materials for industries. The agriculture sector scored an average growth rate of 5.1% over the National Development Plans.

Out of the 165 million ha of the country's land area, about 37 million ha are suitable for irrigatation and dry-land agriculture including: 20 million ha irrigated and 17 million ha dry-land. About 18.5 million ha are currently devoted to horticulture and field crops production. This total cultivated area is distributed as follows: 6.4 million ha are under annual irrigated crops, 2 million ha horticultural crops and about 6.2 million ha are under annual dry-land crops and the remaining 3.9 million ha are fallow. Rangeland areas are about 102.4 million ha, including 90 million ha as pastures and 12.4 million ha are forests.

Islamic Republic of Iran (IRI) falls within the arid and semi-arid. The average annual precipitation for the country is 252 mm (one-third of the world average). However, 179 mm of rainfall is directly lost through evaporation. In other words, 71% of precipitation is lost

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due to evaporation, while annual potential evaporation varies between 1500 to 2000 mm (Fig. 1). In the past 6 years, particularly in 2000, some parts of the country suffered from severe drought, which affected most of the Near East countries.

The altitudes vary from -40 to 5670 m above the sea level and have a pronounced influence on the diversity and variation of the climate. Although most parts of the country can be classified as arid to semi-arid, the country, however, enjoys a wide range of climatic conditions. Both latitude and altitude have a major influence on climate in the various regions. This is shown by the spatial variation of annual precipitation (50 mm in the central desert and 1600 mm in Gillan province, situated in the southern coast of the Caspian Sea (Fig.2). Temperature varies from -44 °C in Bodjnoured located in the central Zagrus range mountains to 56 °C in the south along the Persian Gulf coast. Distribution of rainfall in Iran is very irregular and non-equitable. The north, west, and south-west region cover only 30% of the country's total area but receive nearly 56% of the country's total rainfall. While the central and eastern parts cover 70% of the country area, they receive only 43% of total precipitation (Table1).

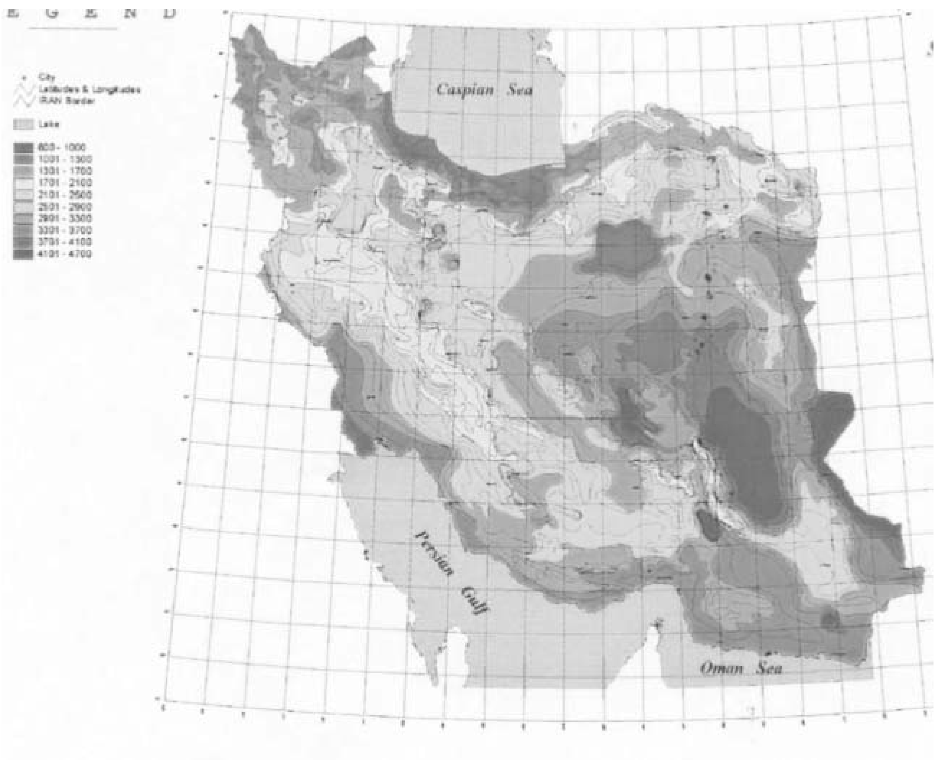

Figure 1. Iso-evaporation Map of Iran

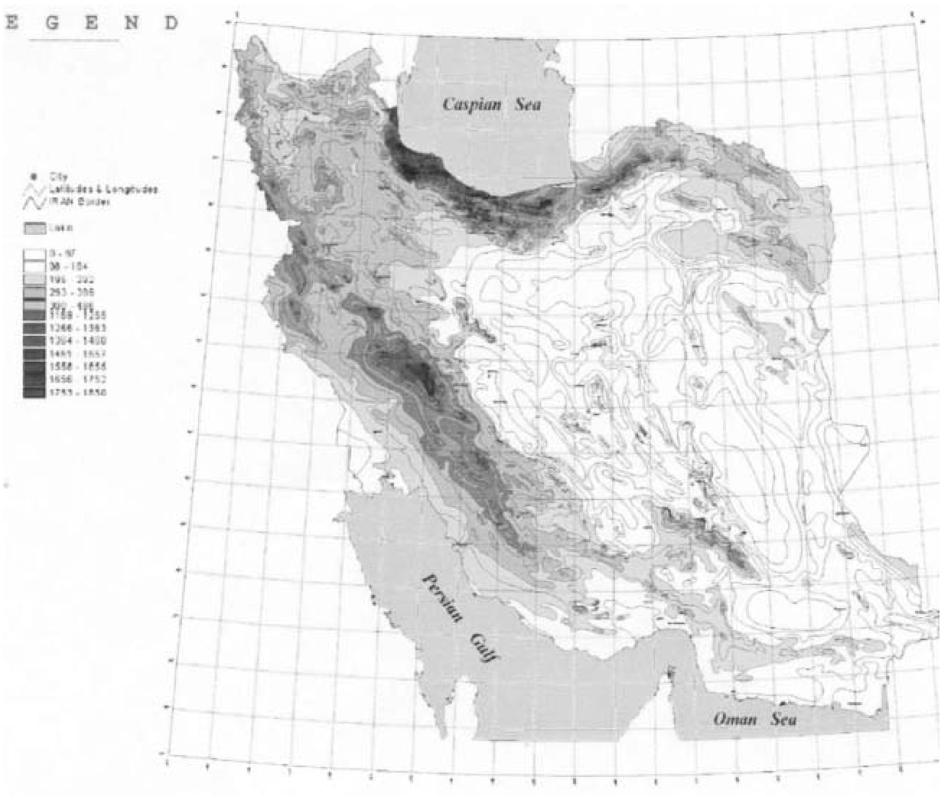

Figure 2. Average Annual Precipitation in Iran

Table 1. Spatial Distribution of Precipitation in Iran

Annual Precipitation (mm)	Area (km^2)	Percent (%)
<50	100,000	6
50-100	285,000	17
100-200	456,000	28
200-300	370,000	23
300-500	280,000	17
500-1000	130,000	8
>1000	18,000	1
Total	1,648,000	100

3. Water Resources

The main source of water in Iran is precipitation in the forms of 70% rainfall and 30% snow, with a total annual water resources of about 413 billion cubic meter (BCM). As mentioned before, about 71.6% of the total rainfall (295 BCM) is directly evaporated. Considering 13 BCM of water entering from the borders (joint border rivers), the total potential of renewable water resources is estimated to be 130 BCM.

Currently, the total water consumption is approximately 88.5 BCM, out of which more than 93% is used in agriculture, while less than 7% is allocated to urban and industrial consumptions (Table 2). Under the present situation, 84 BCM of water is utilized for irrigation , serving 8.2 million ha of irrigated agriculture (horticulture and field crops). About 3.0 million ha of these areas are under irrigation networks, 4.7 million ha by means of traditional networks and less than 1.1 million ha are under fully equipped net works or pressurized irrigation systems.

Surface water resources provide 37.5 BCM water for different consuming purposes (about 42% of the total water consumed) in the country. The importance and existence of groundwater was explored by Iranians thousands of years ago. The traditional method of groundwater extraction is called Qanats, which brings water to surface by gravity. In recent years more than 50,000 of various types of wells were dug for extraction of groundwater from the aquifers. About 58 percent of total water consumption in the country (51 BCM) is extracted from groundwater resources. Figure 3 shows spatial distribution of groundwater use within the country.

Due to inefficiency of traditional irrigation methods and the poor efficiency of water conveying systems; about 60% of the valuable water is lost and in practice only 40% of available water is utilized in agricultural production.

Table 2. Estimated Consumption of Water by Different Sectors in Iran

Consuming Sector	Consumption (BCM)	Percent of total (%)
Agriculture	82.50	93.22
Urban	5.60	6.32
Industry	0.03	0.03
Miscellaneous	0.37	0.43
Total	88.50	100.00

3.1 Irrigation Efficiency

A common perception is that irrigation efficiency in the Asian and Pacific regions is fairly low, at about 30%. More than 60% of the world's irrigated areas are in Asia, two thirds of it in India and China. From the early 1960s to the end of the 1990s, the irrigated area doubled in size, worldwide. The issues shaping the development of agriculture include water scarcity, over exploitation of groundwater, increasingly severe environmental problems, and a decline in the contribution from agriculture to rural incomes.

The need to produce more food and other agricultural products with less water and to enhance the efficiency of consumed water are becoming a global concern. Irrigation system efficiency is one of the major factors affecting the water use efficiency.

The overall irrigation efficiency in Iran varies between 31 to 57% for the different provinces (Table 3). It is lower than the average of the world irrigation efficiency (45% for developing countries and 60% for developed countries). Based on research results in the country, the high application efficiency was obtained by drip irrigation followed by sprinkler and furrow irrigation systems being about 85, 69, and 55%, respectively. Naturally, the lowest application efficiency was reported in traditional surface irrigation systems. Surveys indicate that the trend of irrigation efficiency over the last two decades in Iran is positive. Application efficiency was estimated to be 48.7 and 64.6% over the last two decades. Comparison of irrigation efficiency between the fields under private and state management systems shows that irrigation efficiency is essentially the same. The values of irrigation efficiencies indicate that in average, consumption of irrigation water in Iran compared to world application is relatively high. Comparison of applied irrigation water in Iran and in the World for some crops is given in Table 4.

Table 3. Measured Values of Irrigation Efficiency in some Provinces in Iran

Province	**Irrigation Efficiency (%)**		
	Application	**Total***	**Total****
Khorasan	50.3	32.2*	42.8**
Kerman	47.7	30.5	40.5
Esfahan	36.3	23.2	30.8
Fars	55.7	35.6	47.3
Khozestan	47.6	30.5	40.5
Mazandaran	44.5	28.5	37.9
East Azerbaijan	40.5	25.6	34.0
Tehran	43.5	27.8	36.9
West Azerbaijan	59.6	38.1	50.6
Markazi	59.3	38.0	50.5
Kermanshah	50.0	32.0	42.5
Hamedan	58.5	37.4	49.7
Ardabil	61.9	39.6	52.6
Gillan	53.4	34.2	45.4
Chahar-Mahal-Bkhtyari	43.3	27.7	36.8
Golestan	52.5	33.6	44.8
Kohkilueh -Boirahmad	51.5	33.0	43.8
Gazvin	66.8	42.8	56.8

Based on measured *64% and ** 85% network irrigation efficiency.

Table 4: Comparison of Average Application Water for Different Crops in the World and Iran

Crops	World (m^3/ha)	Iran (m^3/ha)
Wheat	4,500-6,500	6,400
Melons	7,000-10,500	17,900
Sugar-beet	5,500-7,500	10,000-18,000
Rice	4,500-7,000	10,000-18,000
Sugar-cane	15,000-25,000	20,000-30,000
Corn	5,000-8,000	10,000-13,000

The International Water Management Institute (IWMI) has reported that the average net irrigation requirement in Iran for cereal and field crops is 5,100 and 8,100 m^3/ha, respectively. Ministry of Energy, which is in charge of water allocation in Iran estimated the average amount of irrigation requirement to be 5,200 m^3/ha. The average of the figures, which has been published by different consulting engineers, is 5,900 m^3/ha. Considering these figures, the overall irrigation efficiency in Iran would be something between 48 to 55% which is somewhat different than the values that are presented officially or non-officially by various sources. This is mainly due to deficit irrigation that farmers practice naturally due to water limitations.

Irrigated area in Iran is about 8.4 million ha, partly suffer from severe to moderate water stress. Half of the irrigated area is equipped with the modern irrigation systems and operated by governmental organizations. It seems that irrigation efficiency in such systems is somewhat lower due to mainly free availability of water, which released from dams, and there is no incentive for farmers to save the water. The other half is operated by private sector and the water is supplied from groundwater resources. In this case, the irrigation efficiency is also low. The rest of the irrigated farms in Iran, which are under severe to moderate water stress, belongs to the small farm holders who in fact do not save water but their irrigation efficiency is somewhat high. Irrigation efficiency in these farms is estimated to be 55-65%. The likely reason is due to the fact that those farmers under-irrigate their fields.

3.2 Water Use Efficiency

Water use efficiency (WUE) is simply defined as the amount of production per unit of water. Obtaining more production with the same amount of water will increase WUE. A key to mitigate the problem of water scarcity in Iran would be increasing the WUE. High values of WUE in irrigation has not mainly been from a certain irrigation system but from increased crop yields due to better management. By proper water management, converting traditional irrigation systems to modern systems, and completion of irrigation networks; the irrigation efficiency is expected to be increased up to 50 to 60%. In this case the area of the irrigation networks may increase from 2.5 million ha to 3.5-4.3 million ha.

In order to have reliable information about WUE of major crops within the country under different farm management and for the purpose of agricultural production planning from limited water resources, some field studies were conducted in different regions (Kerman, Hamedan, Ardabil, Golestan, and Khuzestan provinces). In field trials, total crop production and gross volume of water applied to field by the farmers were measured in each irrigation event. Then the crop WUE in kg/m^3 was determined for each crop in each region. WUE for wheat, sugar beet, sugarcane, potato, maize, cotton, alfalfa, barley, and chickpea was 1.01, 0.94, 0.31, 2.25, 6.46, 0.73, 1.48, 0.56, and 0.18 kg/m^3, respectively. Overall, WUE in Iran was estimated to be 0.8 kg/m^3 in year 2000 and currently is somewhat higher being about 1 kg/m^3.

The genetic characteristics of the crop are the primary factor determining the crop WUE. The secondary factors that affect crop WUE in various ways are the reaction to water deficit. For instance, WUE for wheat crop in Khorasan province of Iran is about 0.5 kg/m^3 which is quite low compared to a similar environment like Imperial Valley in California or even Bhakra in India. The average WUE for different crops in Iran is shown in Table 5. As a rule of thumb, a reasonable level of wheat productivity is about 1 kg/m^3. Therefore, if demand for grain grows by 50% in the country by 2020, one way to meet this demand is to increase WUE by 50%.

Table 5. Water Use Efficiency of Certain Crops at Different Regions of Iran

Crop	Irrigation method	Yield (kg)	Applied Water (m^3/ha)	Water Productivity (kg/m^3)
Wheat	furrow-border	5,460	9,900	0.55
Barley	furrow	6,090	6,120	1.00
Sugarbeet	furrow-border	37,700	14,500	2.60
Potato	furrow	37,100	5,140	7.21
Maize	furrow	7,000	1,080	0.65
Alfalfa	Basin-border	10,500	11,660	0.90
Beans	furrow	5,100	5,600	0.91
Sesame	furrow	1,432	7,000	0.20
Tomato	furrow	16,000	4,800	3.33
Lettuce	furrow	4,100	8,600	4.77

In order to fulfill food requirements, WUE should be increased to about 1.6 kg/m^3 in the next decade. This implies that the institution, structure and procedures of water allocation in agriculture sector should be modified. This would call for emphases on special prioritization, policies, modernization, and productivity management.

To elaborate more on importance and role of water and to draw the necessary attention for improving WUE in future, the main agricultural criteria in index year (2005) and long horizon are presented in Table 6.

Table 6. Main Agricultural Criteria of Iran at Index Year (2005) and Long Horizons

Criterion	Year	
	2005	**2020**
- Population (million)	70.0	89.0
- Allocated water to agriculture sector (BCM)	82.5	100.0
- Total products of the irrigated land (million ton)	85.0	160.0
- WUE (kg/m^3)	1.0	1.6
- Expected increase in allocated water (%)	–	20.0
- Expected growth in agricultural products in irrigated land (%)	–	238.0
- Ratio of the allocated water to agriculture sector from total water (%)	93.0	93.0

As shown in Table 5, possibility of increasing water resources is very limited being about 20% after 15 years. However, agricultural products of the irrigated land have to be increased by 88% in 2020. This implies that current WUE of 1 kg/m^3 has to be increased to about 1.6 kg/m^3 by 2020.

3.3 Dryland Agriculture

Rainfed agriculture covers extensive lands in Iran where wheat and barley are the major crops grown. Other rainfed crops include pulses, oilseed, tea, citrus, vegetables, grapes and figs. It is most likely that high dependency on irrigated-agriculture would not be able to meet the food and feed demands in future. Nearly 10 percent of the country's total agricultural products come from rainfed areas. Areas under rainfed wheat and barley were 3.95 and 1.11 million ha in 1997-98 and 4.032 and 0.87 million ha in 2003-2004, respectively. According to the Ministry of Jihad-e-Agriculture, the total production of rainfed wheat and barley were, 4.69 and 0.816 million ton in 2003 and 2004, respectively. Low and variable rainfall, high evaporation rates, long dry periods, relatively low soil fertility, poor seed quality and improper agronomic practices by the farmers are contributory factors to low yields in the rainfed areas. Presently, the national average yield of wheat and barley under rainfed condition are 832 and 934 kg/ha, respectively. Rainfed wheat yield is about one quarter of the irrigated fields, i.e., 3200 kg/ha.

Rainfall variability and uncertainty as a major constraint to rainfed production system, deters the farming community from appreciable involvement. The prevailing high risk in rainfed agriculture should not continue, particularly at the face of an ever-increasing population and demand for more food. New ways and methods of production should be sought and adopted in order to increase and stabilize crop production in these areas. Optimum amount of supplemental irrigation and single irrigation have shown promising results in this respect and may well prove to be a key solution in the realization of potentials of the dryland areas in the production of food for the future.

On-farm water-productive techniques if coupled with improved irrigation management options, better crop selection and appropriate cultural practices, improved genetic make-up, and timely socioeconomic interventions will help to achieve this objective. Conventional water management guidelines should be revised to ensure maximum water productivity instead of land productivity.

A review of literature and research in the past indicates that the relation between rainfall amount and crop yield in dry-farmed zones of Iran, remained a subject of interest since decades. Mirnezami (1972) concluded that rainfall is the most important factor limiting the yield of rainfed wheat in Iran. He stated that a threshold value of 295 mm of rain is necessary for a satisfactory yield. In the same study, the correlation coefficient of the linear relationship between wheat yield and six different moisture indices were in the range of 0.928-0.981. Hashemi (1973) found a positive correlation coefficient of 0.78 between dryland wheat yield and the total annual rainfall in different parts of Iran, excluding the Caspian Coast and area with annual rainfalls greater than 600mm. His analysis shows a lower and more variable response of yield as rainfall approaches 400 mm, the consultants prepared a map of the country showing the suitable areas for supplementary irrigation. However, they did not give the criteria used for such planning. ICARDA initiative for supplemental irrigation potentials in Iran and in the Near East and subsequently the Rabat Workshop, were the major development in relation to a concrete scientific output on this topic in the Region (Perrier and Salkini, 1987).

Literature review reveals that the following points could be helpful in assessing the potential of using supplemental irrigation and single irrigation in Iran.

- Supplemental irrigation and single irrigation aims at stabilizing yield and preventing or minimizing risks due to temporal variability of rainfall. It is a compensatory action practiced when rainfall has been less than the long-term average for a period of time long enough to threaten economical reduction in rainfed crop production.

- More than 90 percent of the country average annual rain falls during October to April. About one-third of the time during 32 years, the rain falls below the average value of the record. It is generally believed that the country is prone to a drought period every 5-7 years. Supplemental irrigation could help in saving great losses of the yield at this time particularly, and improving the yield during average rainfall years.

- Iran has many microclimates. This means that the countrywide average rainfall may not necessarily reflect the local conditions in a particular rainfed area. As such, even in a year judged as “normal” on the basis of countrywide average, certain rainfed regions may be suffering from inadequate precipitation. Therefore, the situations suitable for application of supplemental irrigation are more frequent than what the countrywide average rainfalls may indicate.

Rainfall in the Near East rainfed areas, especially in the dominant Mediterranean-type climate, is characterized by low annual amount, unfavorable distribution over the growing season and large year-to-year fluctuations.

Shortage of soil moisture in the dry rainfed areas occurs during the most sensitive growth stages (flowering and grain filling) of cereal and legume crops. As a result, rainfed crop growth is poor and yield is consequently low. The mean grain yield of rainfed wheat in the Region is about one ton per ha, but ranges from 0.5 to 2.0 ton/ha depending on the precipitation amount and distribution, and on agronomic factors such as soil fertility and crop variety. These yield levels are far below the yield potential of irrigated wheat (over 4 to 5 ton/ha). Supplemental irrigation can, using a limited amount of water, if applied during critical crop growth stages, result in substantial improvement in yield and water productivity.

Research results from the Dryland Agricultural Research Institute (DARI) and others, as well as harvest from research stations and farmer's fields, showed substantial increases in crop yield in response to the application of relatively small amounts of single and supplemental irrigation water. This increase covers areas with low as well as high annual rainfall.

Furthermore, using irrigation water conjunctively with rain was found to produce more wheat per unit of water than if used alone in fully irrigated areas, where rainfall is negligible. In fully irrigated areas water productivity in producing wheat ranges from 0.5 to about 0.75 kg/ m^3, which is about 1/3 of that under Supplementary irrigation. This difference suggests that allocation of limited water resources should be shifted to the more efficient practice (Oweis, 1997).

In water-scarce areas, water, not land, is the primary limiting factor to improved agricultural production. Accordingly, maximizing yield per unit of water, and not yield per unit of land, is a more viable objective for on-farm water management in the dry farming systems. Improving water productivity in water-scarce areas requires a change in the way agriculture is practiced. Conventional guidelines designed to maximize yield per unit area need to be revised with a view to achieving maximum water productivity. Appropriate policies related to farmer participation and water cost recovery are needed to prompt the adoption of improved management options.

More efficient irrigation practices must be adopted. Supplemental irrigation (SI) and single irrigation are options with great potential for increasing water productivity in rainfed areas. Scarce water now used for full irrigation could be reallocated to supplement rainfed crops for improved water productivity. However, to maximize the benefits of SI other inputs and cultural practices must also be optimized.

4. Policies and Institutions

As already noted, the major consumer of water (more than 93%) in Iran is agricultural sector. Increase in economical value of water is one of the major objectives in the economic development plans of Iran. Increase in the economical value of water will be possible when the yield or return per specific volume of water increases. For this reason it is preferable to use the supplied water for producing of commodities with higher economical efficiency, or to use in the regions where it returns more economical value.

Based on above discussions, over the last years determination of optimal and economical cropping pattern for each region, determination of crops' water requirement, and volumetric allocation of water have been considered by the authorities within the country as the major activities to increase WUE. For optimal use of allocated water to the farmers, the following policies have been adopted over the last years by the government:

More supervision of water resources and volumetric allocation of water to the farms based on crops' water requirement and an estimated irrigation efficiency,
According to the established law in 1983, water charge for regulated surface waters is between 1-3% of value of the cultivated crops,
Based on the established law in 1993, water pumping from 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 groundwater supervision,
Subsidizing policies for water consumed and supervision charging for those farmers whose yields are higher than average,
Termination of water allocation to those farmers who in two successive years consumed water more than permissible level,
Encourage policies for those farmers who use less water and maintain their production in acceptable level using proper management practices,
Equipping and renovation of lands including land leveling, land consolidation, drainage and land reclamation, construction of irrigation networks and lining of the traditional canals and expansion of pressurized irrigation systems have been some other activities made by the government.

7. Challenges

The major threatening issues concerning water use efficiency include frequent droughts and decreasing water supply to agricultural sector, improper allocation and non-optimum use of available water, and problems arising from the weak implementation of policies, as well as the rather slow adoption of available technologies for improved water use efficiency. To address these concerns, water use efficiency must be enhanced through various holistic and integrated approaches. These include technological advances, innovative participatory approaches, and appropriate policies and support services in irrigation system management to ensure wider application and sustainability of efforts at the community or farmers' field level. Water for irrigation has now become a major limiting factor in agricultural production nearly everywhere. The irrigated area has been expanding, while at the same time there has been a growing demand for water for industrial and urban uses. Decrease in the supply of available water, has sharpened concerns over the allocation and optimal use of available water.

8. Conclusion and Recommendations

The focus of crop WUE improvement is on farmers: how farmers gain timely access to water, how they use it efficiently for crop production, and how they produce more food with less water under circumstances of actual or economic water scarcity. Suggestions on improving water use efficiency at farm level focus on:

1. Use stress-tolerant crop varieties that produce more marketable yield per unit of water consumed;
2. Adopt farming practices that optimize water use, i.e., performing a proper crop rotation and economic cropping pattern;
3. Employ management techniques that give farmers timely access to water; and
4. Introduce policies and institutions that help farmers to take advantage of the above advances.

Progress towards these comments will come partly by taking lessons learned in one crop or river basin and generalizing them to others, and partly by original research into novel ideas. However, the rate of farmers' adaption of these technologies has been slow. Too often in agricultural research the lead-time from study to field impact is decades.

The challenge ahead lies in developing institutions that can integrate management of ground and surface water irrigation; integrate management of irrigation at the farm, irrigation scheme, and basin levels; allocate water fairly among competing uses and users, including environmental services; and address the problems of irrigation development, including the impact of using wastewater on the environment and human health.

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WATER USE EFFICIENCY IN AGRICULTURE IN JORDAN

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SUMMARY

Jordan is an arid country covering about 90 000 km^2 with an average rainfall of approximately 8.4 billion m^3. About 94% of the area receives less than 200 m of annual precipitation appearing as surface and ground water. In 1980, irrigation water share of total use was 78% while in 1991 the share decreased to 74% and it is projected to decrease further to 53% by 2010.

Jordan is one of the 10 most water-deprived countries in the world. Lack of water will be one of the most serious challenges to Jordan's future economic growth. With population expected to double by 2029, the already low availability will be halved.

The increasing gap between limited water supply and increasing demand in Jordan requires careful policies and programmes to conserve and manage water properly. Water conservation is a means of enhancing water availability by managing both supply and demand. Generally, this can be addressed by enhancing the efficiency of use through the utilization of improved water saving technologies and management practices, and the behavior modification of current practices through, in part, public awareness programs.

Improving WUE is a critical aspect of comprehensive water resources management. Technological options include use of better technologies and improvements in management skills. Irrigation efficiency is quite variable, worldwide, and among the highest reported is 85%. If the Jordanian target is set to reach 75% in the next 10 years for example, a total of about 35 MCM/year may be saved for either irrigation or other usage, of which about 25 MCM will be available in the Jordan Valley.

In order to raise the irrigation efficiency, surface irrigation channels were converted into pressurized piped systems. Modern water management information systems are used in the management of water resources and irrigation conveyance and distribution systems.

Policies and strategies for exploiting the growth potential of irrigated agriculture ensuring efficient utilization of water resources through maximizing the efficiency of water storage, conveyance, distribution and on-farm application. Thus reducing the current water shortages confronting irrigated agriculture. This implies developing suitable water storage structures both on and off-farm in order to minimize evaporation and seepage losses, converting from open canal conveyance and distribution systems to close-pipe systems in the Jordan Rift Valley and replacing existing surface basin or furrow irrigation with drip systems.

1. Background

Access to sufficient high quality water is fundamental for all human, animal and plant life as well as for all economic activities. At the global level, plenty of water is available. But to meet the demand, water has to be supplied where and when it is needed. These spatial, temporal, and qualitative characteristics pose the greatest challenge to meeting the fusing demand in all sectors. Water quality and competition between uses are therefore critical issues for the future of water use. There is no single "magic bullet" to solve this complex problem. Increase in water supplies, and especially storage is needed; as well as water demand management, including not only economic instruments but also education and other efforts to change behavior.

Today an estimated 40 % of agricultural products and 60 % of the world's grain are grown on irrigated land. Irrigation accounts of around 70 % of water withdrawals worldwide and over 90 % in low-income developing countries. But water constraints may make expanding irrigation to feed an additional 1.5 billion people by 2025 almost impossible.

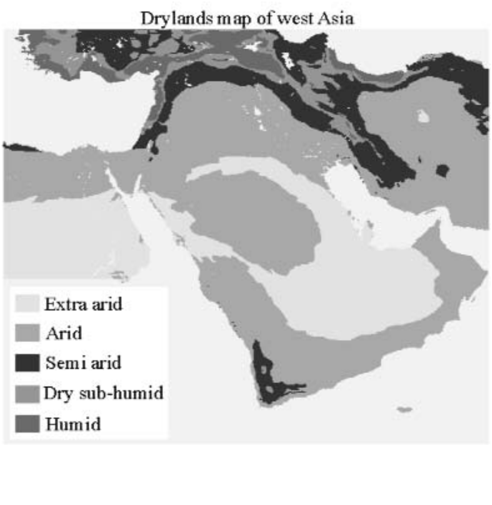
Water for agriculture is critical for food security. However, water for irrigation may be threatened by rapidly increasing nonagricultural uses in industry, household, and the environment. Therefore, new investments in irrigation, water supply systems, and water management should be introduced in order to meet part of the demand.

The high economic and environmental costs of developing new water resources limit supply expansion. *Whether water will be available for irrigation or not* remains an urgent question for the world so that agricultural production can provide food security.

1.1 Aridity

At the global scale the world is divided into six aridity zones., according to the ratio of mean annual precipitation to mean annual potential evapotranspiration. Drylands include arid, semi-arid, and dry sub-humid areas in which this ratio ranges from 0.05-0.65. Areas where the ratio is less than 0.05 are hyper-arid zones and the areas where the ratio is greater than 0.65 they are humid zones.

Drylands cover almost 54 million km^2 of the globe. Semi-arid areas are most extensive followed by arid areas and then dry sub-humid lands. These aridity zones spread across all continents, but are found most predominantly in Asia and Africa.



The aridity map of Middle East shows that 25.5 % are classified as Extra-arid zone, 69.8 % are considered as drylands (arid, semi-arid and dry sub-humid areas), then only 4.7 % of Middle East area are classified as humid area.

Climate change will have a significant impact on water resources and their management. Climate change will amplify its substantial destabilizing effect on the hydrological cycle and will have a pervasive influence on the future demand, supply and quality of fresh water resources in the region. It will add pressure on water and environment resources and coastal systems currently under stress.

As a result of the temperature rise, the water demand will increase. The evaporation from water bodies will reduce the available supply and the increased evapotranspiration from crops and natural vegetation as well as the water demand for irrigation or industrial cooling systems will add pressure on water resources.

1.2. Increased Scarcity of Irrigation Water

Total global water withdrawals for agricultural, domestic, and industrial use are projected to increase 23 percent from 1995 to 2025. Projected withdrawals increase 28 percent in developing countries.

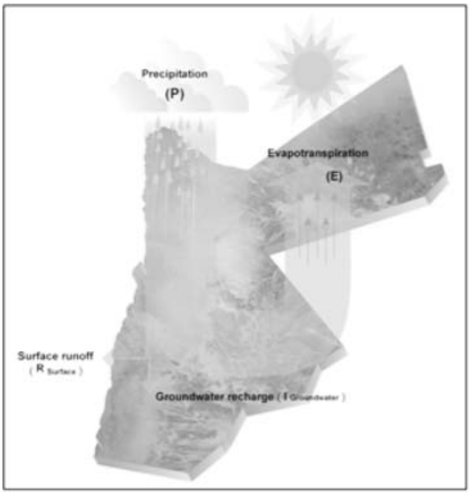
Global consumptive use of water will increase by 16 percent, the vast majority in developing countries, where consumptive use across all sectors will increase by 18 percent. Non –irrigation water demand will increase by 62 percent world wide, 96 percent in developing countries, and 22 percent in developed countries. Consumptive use of water for irrigation worldwide will grow only 3.9 percent, which is significantly lower than the 12 percent increases in the rate of water use to meet full demand for irrigated crops. Of critical importance, the slow growth in irrigation water supply, especially in developing countries, will be due to water supply constraints and high non-irrigation demand, which will increase water scarcity for irrigation.

Table 1. Water Withdrawal and Consumptive Use in 1995 and 2025 (km^3)

Countries	Water Withdrawal		Water Consumption		Irrigation Consumption		Non-Irrigation Consumption	
	1995	2025	1995	2025	1995	2025	1995	2025
Developed countries	1,144	1,266	436	476	286	271	168	205
Developing countries	2,762	3,528	1,364	1,609	1,162	1,214	202	395
world	3,906	4,794	1,800	2,085	1,430	1,485	370	600

2. Water Resources in Jordan

Jordan is an arid country covering about 90 000 km^2 with an average rainfall of about 8.4 billion m^3. About 94% of the area receives less than 200 m of annual precipitation. In 1980 irrigation water share of total use was 78% while in 1991, decreased to 74% and it is projected to decrease further to 53% by 2010.



Water Resources in Jordan

The water problems have periodically emerged since the 1960's as full fledged socioeconomic crises when severe short falls in supply have failed to meet domestic and agricultural demand. Non-adequate management of the water crisis and absence of appropriate water policies have resulted in a failure to generate solutions for water shortages.

Daily per capita share of water in Jordan is considered to be one of the lowest, both according to world averages, and the averages in neighboring countries. The per capita water availability dropped below 200 m^3/capita/year. This is far below the benchmark level of 1000 m^3/capita/year often used as an indicator of water scarcity and expected to reach 100 m^3/capita/year in 2025.

2.1. Water Policy Framework

"Policies and strategies for exploiting the growth potential of irrigated agriculture ensuring efficient utilization of water resources through maximizing the efficiency of water storage, conveyance, distribution and on-farm application. Thus reducing the current water shortages confronting irrigated agriculture. This implies developing suitable water storage structures both on and off-farm in order to minimize evaporation and seepage losses, converting from open canal conveyance and distribution systems to closed-pipe systems in the Jordan Rift Valley and replacing existing surface basin or furrow irrigation with drip systems.

Pricing publicly developed and managed water to reflect the importance and scarcity in Jordan establishing an irrigation time schedule for the Jordan Valley on the basis of crop water requirements. To enable the government to provide farmers with irrigation water at the proper time and desirable quality, a demand driven water supply system will be set up. Exempting the imported materials required for the local manufacture of water saving technologies from customs duties, in order to minimize the production costs of such equipment. Enforcing regulations relating to the licensing of groundwater wells, and monitoring ground water extraction and recharge of main ground water aquifers to ensure the sustainability of the water supply with regard to quality and quantity".

2.2 Terrain and Climate

Jordan comprises three distinct regions, each with its own climate:

i. The highlands are a mountainous and hilly region whose altitude ranges from 1969-5249 feet above sea level, and comprises the vast majority of Jordan's arable land. Fruit trees, vegetables and cereals are planted in the rain fed highlands.
ii. The Rift Valley (The Ghor), reaches over 1312 feet (400 metres) below sea level at the Dead Sea. The Rift Valley has fertile soil and is relatively rich in water resources. Generally, there is warm weather all year round that is ideal for farming. About half of the agricultural produce of the kingdom is grown there.
iii. The rest of the country, which accounts for two thirds of the Kingdom, is semi-arid, with very low rainfall. This region is home to the bedou (nomadic Bedouins) of Jordan, with traditional sheep and goat herds which provide meat for the rest of the country.

Jordan's climate is characterized by hot-dry conditions during summer and moist-cold condition during the end of October to the beginning of May and the rest of the year is hot and very dry.

3. Irrigated Agriculture in Jordan

3.1 Overview

Currently irrigated agriculture is the largest water consumer constituting around 65% of the overall uses compared to only 35 % for municipal, industrial and tourism purposes. The dependence on rain for irrigation, and seasonally fluctuating agricultural production, creates a heavy reliance on agricultural imports, though Jordan does manage to export some agricultural products. The majority of Jordan's agricultural products (over 60%) are grown in the Jordan Valley.

Agricultural production also takes place in the highlands (mostly it is cereals and field crops, and seasonally, fruits and vegetables). In the late 1960 and 1970, the Government began developing pilot projects in the desert and the upland of Jordan using groundwater. According to the Ministry of Agriculture estimates the total irrigated area in the country is estimated at 76 000 ha, consisting of: 42 000 ha in the upland and the southern desert and 33 000 ha in the Jordan Valley (Shatanawi et. al. 2003).

More than 60% of the irrigated area in the country is located in the Jordan valley. For this, the Government with assistance of international financing institutions had implemented irrigation projects in the Valley by constructing King Abdullah Canal (KAC) with a total length of 110.5 km. The Government gave special concern to provide adequate amounts of irrigation water during drought years; therefore five dams were constructed during the period of 1968 till 1992. Constructing these dams provided more irrigation water for the Jordan valley,

During the last 10 years, the Government invested in converting all the open canals of irrigation systems in the Jordan Valley into a pressurized pipe network system, and establishing another four dams, to make total capacity of all 9 dams at about 217 MCM.

Comparing the available water with the cultivated area, less than 660 mm/dunum are available (a donum is 0.1 ha). This amount of water should be used with most efficient cultivation practice and precise water irrigation water management to achieve high productivity in the Jordan Valley

3.2 Productivity and Estimated Water Use Efficiency of Irrigated Agriculture

The total area of production under irrigation in Jordan increased from an average of 53 800 ha in 1984/86 to 71 700 ha in 1990/92. In terms of production, the average production of crops on irrigated land during 1990-92 was 1.3 million tons. The production from rainfed lands was 0.26 million tons, from a total crop production of 1.6 million tons, or about 16 % of the total production.

Table 2. Average Contribution of Irrigated and Rainfed Sectors to Agricultural Production (1990/92).

Commodity	Total Production		Irrigated Prod.		Rainfed Prod.	
	(1000 M Tons)	%	1000 MT	%	1000 MT	%
Vegetables	1082	69	1046	66.5	35	2.2
Field Crops	159	10	37	2.4	122	7.8
Fruit Trees	332	21	228	14.5	104	6.6
Total	1573	100	1311	83.4	261	16.6

Source: Ministry of Agriculture (MOA), Department of Agricultural Economics and Statistics, Statistical Reports.

- Vegetables accounted for 69% of the total production, of which irrigated lands accounted for 67% and rainfed lands 2% of the total. Within the irrigated lands, 80% of the production came from vegetables and the rest from fruit trees.
- The average value of production of crops produced on irrigated lands in 1990-92 was about Jordanian Dinar (JD) 229 millions and that on rainfed lands about JD 59 millions, (Table 4). Irrigated agriculture contributed 79.5% and rainfed lands 20.5% of the total value of crop production (JD=1.4 US$).

Table 4. Contribution of Irrigated and Rainfed Agriculture to Production Value of Vegetables, Field Crops and Fruit Trees, 1990/92, (Value Million JD).

Commodity	Total Value	Irrigated		Rainfed	
		Value	%	Value	%
Vegetables	159.2	154.7	53.8	4.5	1.6
Field Crops	24.3	4.9	1.7	19.4	6.7
Fruit Trees	104.0	69.0	24.0	35.0	1.2
TOTAL	287.5	228.6	79.5	58.9	20.5

Source: Ministry of Agriculture (MOA), Department of Agriculture Economics and Statistics, Statistical Reports.

- During 1990-92, the production of crops in the Jordan Valley amounted to 610 000 tons and that in the uplands 701 000 tons, for a total of 1.3 million tons, (Table 5). Vegetables accounted for 80% of the total volume of production, with vegetable production in the uplands accounting for 46% of the total and the Jordan Valley 34%.
- In terms of total vegetable production (irrigated and rainfed) for Jordan, the uplands produced almost 57% of the vegetables in the country and the Jordan Valley a little more than 43 %, a reversal of the situation that existed just a few years ago.

Table 5. Contribution of Jordan Valley and Uplands to the Irrigated Production of Vegetables, Field Crops and Fruit Trees, 1990/92.

Commodity	**Total**		**Jordan Valley**		**Upland**	
	(1000 MT)	**%**	**1000 MT**	**%**	**1000 MT**	**%**
Vegetables	1046	80	449	34	597	46
Field Crops	37	3	4	1	33	2
Fruit Trees	228	17	157	12	71	5
Total	**1311**	**100**	**610**	**47**	**701**	**53**

Based on the year 2000, the following tables provide some estimates of the water use efficiency for vegetable crops and fruit trees cultivated in Jordan. Reference crop evapotranspiration (ETo) was calculated according to Penman-Monteith Equation, and values of crop coefficients (Kc) were computed according to FAO Irrigation and Drainage paper no. 24 - Crop Water Requirements.

Table 6. Water Use Efficiency (WUE) for Vegetable Crops Cultivated in Jordan.

Crop	Area (1000 ha)	Production (1000 ton)	Productivity (ton/ha)	ETc (m^3/ha)	WUE (kg/m^3)
Tomato	14.24	618.9	43.5	5500	7.91
Eggplant	1.84	60	32.6	3000	10.87
Squash	3	59.1	19.7	3000	6.57
Cucumber§	1.02	84.4	82.7	3600	22.97
Bell-pepper	1.16	24.6	21.2	3600	5.89
Beans	1.54	18.4	11.9	3500	3.40
Cauliflower	1.74	44.9	25.8	2000	12.90
Cabbage	1.45	42.1	29	2000	14.50
Onion	3.76	81.9	21.8	4500	4.84
Potato	3.64	126	34.6	3000	11.53
Lettuce	1.02	22.7	22.3		
Spinach	0.23	3.7	16.1	2000	8.05
Broad beans	1.17	14	12	2000	6.00
Garlic	0.77	15	19.5	4700	4.15
Carrot	0.69	18.6	27	3500	7.71
Jews-mallow	0.12	3.3	27.5	1600	17.19
Okra	0.96	4.9	5.1	2400	2.13
Watermelon	3.12	237.6	76.2		
Melon	2.13	48.3	22.7		

§Cucumber under intensive cultivation (Greenhouses).

Table 7. Water Use Efficiency (WUE) for some Fruit Crops Cultivated in Jordan.

Crop	Area (1000 ha)	Production (1000 ton)	Productivity (ton/ha)	ETc (m^3/ha)	WUE (kg/m^3)
Olive	85.93	184.8	2.2	4000	0.55
Grape	14.56	67	4.6	6000	0.77
Citrus	6.65	181.6	27.3	7500	3.64
Banana	1.8	47.2	26.2	12000	2.18
Apple	5.5	109.4	19.9	7000	2.84
Pear	0.78	4	5.1		
Quince	0.09	0.7	7.8		
Palm trees	0.52	4.3	8.4		
Almond	1.4	4.8	3.4		
Peach	2.98	20.7	6.9	6700	1.03
Apricot	1.41	10.5	7.4		
Prunes	1.92	9.6	5		
Cherries	0.38	2.3	6.1		
Figs	1.59	7.1	4.5		
Pomegranate	0.87	6	6.9		
Guava	0.21	2	9.5		

3.3 Water Conservation and Efficiency Measures

The increasing gap between limited water supply and increasing demand in Jordan requires careful policies and programs to conserve and manage water properly. Water conservation is a means of enhancing water availability by managing both supply and demand. Generally, this can be addressed by enhancing the efficiency of use through the utilization of improved water saving technologies and management practices; as well as the behavior modification of current practices through public awareness programs. Water conservation by the Ministry of Water and Irrigation is expected to bring immediate and sizable water savings. Financially, conservation and efficiency measures will help to reduce the need for expensive water supply projects that are primarily designed to provide additional water.

Water conservation and efficiency improvement play a major role in mitigating the problem of water scarcity and shall be given the proper consideration in the Kingdom's water resources development and management programs. Therefore, the Ministry of Water and Irrigation will endeavor to undertake all the necessary measures leading to the establishment of comprehensive programs for water resources conservation, reduction of water losses, and improvement of water use efficiency in all sectors.

Table 8. Estimated Water Supply and Requirements (MCM/Year)

Year	Total Requirements	Total Estim. Supply	Deficit
1998	1205	898	-307
2005	1321	1042	-279
2010	1436	1250	-186
2015	1536	1283	-254
2020	1647	1287	-360

3.4 Water Losses

Due to limited water resources; Jordan Valley Authority (JVA) had established a pressurized system for the conveyance of irrigation water. This system allows farmers to convert from conventional irrigation methods to modern drip and sprinkler systems. The pressurized system will also enable the JVA to keep the irrigation water in the network for 24 hours (continuous flow). Recently, most of the water that is delivered to farm gate is conveyed through pressurized pipelines. A total of 29,000 ha are equipped to receive water from the irrigation distribution network and now it is estimated to be more than 33,000 ha.

According to available data, about 60% of on- farm irrigation systems is trickle type and only 32% is surface irrigation (Shatanawi and Hadadin, 1993). Irrigation management efficiencies for CJV is reported to vary from 34% to 90%. Conventional surface irrigation systems were found to have an average irrigation management efficiency of 70% (Shatanawi et.al. 1995).

According to previous studies, the main factor contributing to low irrigation management efficiencies was attributed to lack of knowledge by farmers concerning crop water requirements and scheduling of irrigation water. Distribution uniformity of trickle system caused by emitters clogging problem as a result of unsuitable filtration system, and poor hydraulic design of the irrigation network.

4. Irrigation Water Use Efficiency

The overall efficiency of water used in Jordan was estimated in 1991 at 65 %. This means that 35% of the water withdrawn is lost. Among the highest reported efficiency worldwide is 85%. If the Jordanian target is set to reach 75% in the next 10 years, a total of about 35 MCM/year may be saved, out of which about 25 MCM will be available in the Jordan Valley.

The overall irrigation water use efficiency is the product of conveyance, on farm and application efficiency.

The conveyance efficiency is enhanced by improvements in the conveyance systems and the on-farm efficiency is enhanced by improvements brought to on-farm irrigation systems. The application efficiency is enhanced by adequate knowledge of crop water requirements over the growing season that depend on the local environment. Enhancement of this efficiency further requires a more sophisticated on-farm water management, based on reliable crop water requirements data.

The use of sprinklers in Irrigation is decreasing and being replaced by drip irrigation which is more efficient. Drip and surface irrigation in the Jordan Valley along with sprinkler systems in the south mainly seem to be used, this could continue or change with the use of recycled waster water resources.

4.1 Measures Taken to Optimize Water Use Efficiency

The following measures on the supply and demand sides have been taken by JVA to increase water use efficiency:

a) Building of Karameh Dam. This dam was constructed in 1994 at Wadi Malha, to the west of Karameh in the Jordan Valley, with an estimated yield about 35 MCM for agricultural use.
b) Raising of Kafrein Dam project that started in 1995 will increase the capacity of the existing dam by 4.6 MCM.
c) The conversion of remaining areas from surface to pressure pipe systems saving about 20 MCM/year.
d) Irrigation Water Delivery Scheduling Pilot: under this pilot program, farmers will be able to order water for delivery any day and in any quantity, up to a set maximum,

throughout the crop season. The aim of this pilot program is to give farmers more control over their water delivery schedules, this benefit comes with more responsibility.

e) Repair of canal linings along the northern 94 km of King Abdallah Canal (KAC) have been underway since the beginning of 1995.

f) The automated water management control system of the Jordan Valley, consists of three phases. Phase I included the computerization of the irrigation management system and data bank. Phase II included the updating of Phase I hardware to meet additional requirements, and the development of new hardware and software for many units:

   A parallel project, was launched with the interim phase to implement a Water Measurement Network along the Canal, including the installation of 14 Measurement Stations and the automation of four Check-Gates.

g) Since the horizontal expansion is limited, increasing cropping intensities in wet years are being considered by the farmers in the valley. The Jordan Valley Authority is encouraging the farmers for intensive winter cultivation.

h) Due to the limited water resources and water quality constraints, the cropping pattern of new projects will be directed towards the use of salt-tolerant crops like dates, and semi-tolerant crops like early producing seedless grapes which offer good net income.

i) An on-going USAID-financed project is being carried out under the administration of the Ministry of Water and Irrigation. One of its components is to deal with research and extension of the farm water arrangement.

j) A GTZ-financed study was carried out in 1994, for the Recovery of Operation and Maintenance Costs of Irrigation Water in Jordan, was completed mid-1994. As a result of the study's recommendations, a new tariff for irrigation water has been adopted since 1995.

4.2 Use of Information Tools and Technologies for Water Management

Efforts to encourage and enhance indigenous water research targeted at the improvement of resource management, enhancing the understanding resource economics, and adapting the research findings in other environments to local conditions, including but not limited to, crop water requirements, minimizing evaporation and controlling evapo-transpiration. Resource management aims at achieving the highest possible efficiency in the conveyance, distribution, application and use. It shall adopt a dual approach of demand management and supply management. Tools of advanced technology shall be adopted to enhance the resource management capabilities.

Improving WUE is a critical aspect of comprehensive water resources management. Technological options include use of better technologies and improvements in management skills.

However, irrigation management efficiency could significantly be increased by improving technical background of farmers especially, on crop water requirements and irrigation scheduling. This will save water and help expansion of irrigated areas, as well as to enhance environment quality.

i. Low Flow Drippers
Micro Dripping is an irrigation method that enables a very low flow rate, close to one tenth the flow of ordinary drippers. The nominal flow rate of each Micro Dripper may be as low as 0.2 liters/hour and this low flow is resulting in better wetting distribution in the ground.

The slower infiltration in the soil allows the plant to develop a wider roots pack. A better matching between the watering rate and the sucking rate of the plant is therefore achieved.

ii. New Instrumentation
Options to improve the productivity of irrigation include land leveling and efficient sprinklers to apply water more uniformly; surge irrigation to improve water distribution; low-energy precision application sprinklers to cut evaporation and wind drift losses; furrow diking to promote soil infiltration and reduce runoff; and drip irrigation to cut evaporation and other water losses and to increase crop yields.

Changes in water management systems are also important. For example, irrigation systems could be improved through better timing of water releases. Farmers could adopt water-conservation technology and use better information and communication technologies to reduce non-beneficial irrigation, apply water uniformly to crops, and reduce stress. Farmers could also plant more drought-resistant crop varieties or varieties that use water more efficiently. In addition, they could adapt better soil management and other conservation practices.

iii. Genetic Engineering
Plant varieties developed as a result of genetic engineering research can be favored for introduction into Jordan's markets. Maximizing resistance to pests, salinity and adverse conditions are features that are needed. Additionally, the maximization of crop yields is another beneficial feature of such varieties.

***Some early fruits of transgenic agriculture*:**
Sentinel Crops: A recent innovation is a plant intended not for food but for quality control. It contains a gene derived from a luminescent jellyfish, but in all other ways it is identical to the food crop it is planted alongside. When these sentinel plants experience a lack of water, they literally glow in the dark. The farmer then knows that his crop must be watered or whether irrigation can be postponed.

iv. Reduced need for fertilizers
Some plants, primarily legumes (peas and beans) have a symbiosis with the nitrogen fixing bacteria. The plants provide nodules on their roots that protect the nitrogen fixing bacteria, which then enrich the soil around those roots. This permit the legumes to grow luxuriantly without nitrate fertilization and it makes the soil fertile for other plants growing in the same soil later. The technique of *crop rotation* is one of the oldest techniques of agriculture. Scientists hope to be able to transfer the genes which direct the formation of the nodules to other crops. If this is successful, the need for Nitrogen fertilizers would be dramatically reduced.

Unlike nitrogen, there is no short-term likelihood that scientists will find a genetic engineering way to replace fertilizers that provide phosphates. The best hope for phosphate replacement would be to breed or engineer plants that make more efficient use of the phosphate available to them.

A genetic transformation of wheat which promoted increased synthesis of glucine dehydrogenase was 29% more effective in utilizing the same amount of fertilizer as the unmodified variety.

v. Treated Waste Water Reuse
Treated wastewater effluent is considered a valuable water resource for irrigation. This is deemed by the supply-demand imbalance of drinking water, the arid climatic conditions of the country and the deficit in the trade of food commodities. Therefore the Government of Jordan has imposed that all new wastewater treatment projects must include feasibility and design aspects for treated wastewater reuse. *Jordanian Standards JS 893/2002 for Reclaimed Domestic Wastewater* is based on reuse categories. Untreated wastewater is prohibited to be discharged to the watercourses or to be used for irrigation by the Jordanian law.

Presently, there are 19 Wastewater Treatment Plants serving most of the major cities and towns in the country, treating about 96 MCM per year 2003 (Influent). The quantity of treated wastewater was about 85 MCM per year (Effluent). About 63% of the total population of Jordan have access to wastewater collection and treatment system. The amounts of wastewater treated constitute around 13 % of the water used for irrigation (2003). Where the 87% of the Irrigation water is surface and ground water.

Naturally, wastewater quantity increases with more population increase. therefore, by 2020 when the population is expected to be 9.9 million, some 240 MCM per year of wastewater is expected to be generated.

The Ministry of Water and Irrigation strategy is to fully use the wastewater effluent for restricted irrigated agriculture. Implementing this strategy necessitates that the qualities of the wastewater effluents meet the *Jordanian Reclaimed Domestic Wastewater Standards* and WHO Guidelines for Irrigation Water Quality.

The Wastewater Management Policy Paper No. 4 “Management of Wastewater” issued in June 1998 focuses on the management of wastewater as a water resource and includes, amongst others, development, management, wastewater collection and treatment as well as the reuse of wastewater and sludge in the agriculture, pricing, selected priority issues, standards and regulations.

vi. Land Use Management and Water Harvesting

Significant amount of rainfall is lost in these regions due to evaporation and runoff. Therefore, appropriate water harvesting schemes could save 10 to 15% of the total amount lost (which is about 6.6 Billion m^3). Jordan will be able to increase ground water recharge and double the agricultural production. The expected amount of harvested water is almost equal to the available amount of water that is being used in the country during 1994.

In the late 1960's, different water harvesting techniques, such as cisterns, hafirs and earth dams were widely used in Jordan. In the highland of Jordan, most of fruit trees production depends only on the rainfall. In an effort to encourage Jordanian farmers to adopt more production and stable-land use system, the Jordanian Government through the Ministry of Agriculture and some other official agencies and in cooperation with international organizations, initiated several programmes for soil and moisture conservation and water harvesting projects. Some of these projects are listed below:

- Jordan Highland Development Project
- Zarqa River Basin Project
- Balama Project
- Al Muwaggar Project
- Jordan Arid Zone Productivity Project
- Water Harvesting Prediction Optimization Model
- Saklah Project
- Al-Hammad Basin Project:

vii. High- tech Irrigation Systems

a. Irrigation Management Information System (IMIS) Project
   The objective of this project is to develop a package of Irrigation Management Information System (IMIS) which can provide irrigation personnel (farmers) with real time estimates of irrigation requirements and scheduling. The project will help to initiate and sustain a technology transfer program concerning the issues of when to irrigate and how much irrigation water to apply on-farm level to maximize water use efficiency.

b. IRRIMED Project
   The objective of this project is to support efficient management for water used for irrigation as well as to test scenarios for long term sustainable policies. Accurate knowledge of water demand and use by irrigated agriculture is a key to an effective water management strategy. Therefore, this project will bring researchers together with man-

agers and other stakeholders to jointly evaluate research results and needs and set research priorities, The general scientific objective is the assessment of temporal and spatial variability of water consumption of irrigated agriculture under limited water resources condition.

5. National Research Work

Applied research on water topics is adopted and promoted. Such topics as water economics, resource management, crop water requirement, use of brackish water, irrigation technologies, farming practices, crop yields, moisture storage and the like were introduced and implemented by different governmental institutions.
Efficient water use through environmentally sound production of high quality vegetables for domestic and export markets.

5.1 Ministry of Agriculture Projects

(i) Expanding Date Palm Cultivation under Saline Conditions in Jordan
(ii) Fertigation Project in Jordan
(ii) Development of Agricultural Resources in Wadi Zarqa (Maeen).
(iv) Development of Agricultural Resources –Yarmouk Basin.
(v) Development of Agricultural System within Watersheds.
(vi) Education and Information Program to Improve on- Farm Water Use Efficiency Program (Kafa`a)

5.2 Ministry of Water and Irrigation Projects

(i) Improved Water Resources Management
(ii) Integrated Management of Agriculture inputs in the Jordan Valley
(iii) Introducing of Water Harvesting Techniques in the Range lands.
(iv) Irrigation Optimization in the Jordan Valley
(v) Jordan -Valley Development Project:
(vi) Use of Reclaimed Water in the Jordan Valley.
(vii) Water Efficiency and Public Information for Action
(viii) Water Quality and Environmental Improvement in the Jordan Rift Valley
(ix) Water Quality Improvement and Conservation Project
(x) Water Resources Management in Irrigated Agriculture.

6. Technology Transfer and Role of Extension Services in Water Saving

Technology transfer and adaptation to local conditions are primary targets for development activities and adaptive research.

Public awareness is primarily a means of informing and educating water users about the seriousness of the water situation in Jordan. In so doing, it is a tool for managing water demand and can be used to help rationalize water consumption and encourage conservation at the household, business, or farm level. Public awareness programs could substitute for other demand management methods, including raising water prices, introducing water saving devices, and rationing water supply, which may be less acceptable to the general public.

Carrying out public awareness programs is important, because any significant changes in how water is conserved or protected will require public support and participation.

6.1 National organizations involved in water awareness activities:

- Governmental Organizations:
    - Ministry of Water & Irrigation
    - Ministry of Agriculture
    - National Center for Agricultural Research & Technology Transfer (NCARTT):
- Non-governmental organizations (NGO's):
    - Jordan Environment Society
    - Royal Society for the Conservation of Nature
    - Jordan Hashemia Fund for Human Development
    - Noor Al-Husein Foundation
    - Agricultural Engineering Association - International Organizations:
    - Global Environment Facility (GEF)
    - Water Education and Public Awareness for Action
    - Inter Islamic Network on Water Resources Development and Management (INWRDAM)-Jordan

6.2 Tools Used to Raise Awareness

Media tools like TV-films, TV-spots, radio messages, newspaper, advertisement and others are the usual tools.
Public awareness campaigns and activities at local community level including training workshops, seminars, forum, lectures, meeting and others were conducted.

- Publications and printed materials like: posters, brochures, pamphlet, books, coloring books, guidelines and others.
- Demonstration sites focus on water conservation and management.
- Campaigns materials like pens, T-Shirts, hats, labels, and others.
- Exhibitions.
- Animations, poems, songs and others.

7. Suggestions on Water Strategy and Policy

Strategies should stress on the need for improved resource management with particular emphasis being placed on the sustainability of present and future uses. Special care shall be given to protection against pollution, quality degradation and depletion of resources. Furthermore, achieving the highest practical efficiency in the conveyance, distribution, application and use should be a primary goal.

Dual approach of demand management and supply management, with tools of advanced technology should be utilized to enhance the resource management capabilities.

The interactive use of multiple resources should be targeted to maximize the usable flows, and maximize the net benefit from the use of each water unit . In conjunction with this, there should be targeting the minimum cost of operation and maintenance. In addition, the cost of production of future industrial, commercial, tourism and agricultural projects being measured should also be considered in terms of their requirements of units of water. Performance efficiency of water and wastewater systems and their management should be monitored and rated, as well as the improvements on performance to be introduced with due consideration to resource economics.

In Jordan, policies and strategies are set for exploiting the growth potential of irrigated agriculture ensuring efficient utilization of water resources through maximizing the efficiency of water storage, conveyance, distribution and on-farm application. Thus reducing the current water shortages confronting irrigated agriculture. This implies developing suitable water storage structures both on and off-farm in order to minimize evaporation and seepage losses, converting from open canal conveyance and distribution systems to closed-pipe systems in the Jordan Valley and replacing existing surface basin or furrow irrigation with drip systems.

Pricing publicly developed and managed water to reflect its importance and scarcity in the country, through establishing an irrigation time schedule for the Jordan Valley on the basis of crop water requirements. To enable the Government to provide farmers with irrigation water at the proper time and desirable quality, a demand- driven water supply system will be set up. Exempting the imported materials required for the local manufacture of water-saving technologies from customs duties, in order to minimize the production costs of such equipment. Enforcing regulations relating to the licensing of groundwater wells, and monitoring ground water extraction and recharge of main ground water aquifers to ensure the sustainability of water supply with regard to quality and quantity.

Regarding water policy, the Government is focusing on rational allocation and use of water. Initiatives include the development of management plans for surface irrigation systems in the Jordan Valley and for groundwater basins (e.g., full utilization of the existing Deir Allah pumping scheme and conservation of the Disi fossil aquifers); modernizing and upgrading surface and groundwater monitoring systems; protecting water resources from pollution; managing groundwater to ensure sustainable yields for renewable aquifers; adopting a progressive pricing system to secure the financial viability of water delivery agencies; and establishing a strong institutional framework for the implementation of water management policies. In 1994, a bill was presented to the Parliament reflecting progressive water tariffs

8. Challenges

Jordan's political stability and economic prospects depend heavily on Jordan's ability to manage its scarce water resources. The problem has two dimensions. The *first*, and most obvious, is the deficit in total supply; while the *second* and equally important dimension is management of the resources available in an integrated manner.

Water deficit has been treated in some cases as if water was abundant. Hence, water prices have been minimal and demand was excessive. Two-thirds of the Kingdom's water goes to low-value agricultural crops, while higher value demands for urban consumers, industry and tourism receive much less portion. Furthermore, half of Amman's water supply is "lost" in the city's old distribution network.

Securing a reliable supply of water, adequate quantity and quality, is one of the most challenging issues facing Jordan today. Planning and policy formulation for the supply and utilization of water resources will be based on comprehensive and reliable data, including data on water quantity, quality, and utilization

It has become both politically and socially very difficult to reduce the total irrigated area allocated to present users. (Ministry of Water and Irrigation, 1998). This is a big problem for the authorities, because as the population increases water resources are needed elsewhere for both municipal and industrial needs. However, there is work going on to look into growing crops which are more resistant to salinity and drought. Yet, these are still at the research stage, as human health and the environmental impact have to be taken into consideration.

Finally, one could recommend to stress efforts to increase supplies, as well as a better balance for the demands of agriculture, domestic use, industry and the environment through economic measures, regulation, and campaigns to motivate and equip users to conserve water.

Technological and institutional approaches must be combined to accomplish these goals. Achieving such a coordinated approach to water is challenging, but essential for feeding the people, and to reduce poverty in our region.

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Annex
GROUND WATER MANAGEMENT POLICY

1. Background

Groundwater in the Hashemite Kingdom of Jordan occurs in a renewable and nonrenewable form in 12 distinct basins. The exploitation of groundwater in ancient times was done through the exploitation of springs where groundwater emerges to the surface, and through the artificial means of tapping the aquifers by drilling shafts. Archaeological remains in the Jordan Rift Valley indicate the sinking of such shafts at different angles. They date back to the Nabatean era (300 B.C - 106 A.D) and the Roman era thereafter. Jordanians continued to harness the spring water for different purposes. In the Ottoman era (1516-1916), the use of water was regulated and water rights were kept by the district administration in an official register. Legislation for water acquisition and use in the Hashemite Kingdom started in 1938, and due consideration was given to of the prior water rights recognized by the previous Ottoman administration.

Modern technology to access groundwater aquifers was introduced to the Kingdom in the late 1950s legislation to regulate the exploitation of groundwater resources and to have it supervised by government was soon introduced. The country had its population doubled as it hosted the first wave of Palestinian refugees in 1948. It united with the West Bank in 1951 in one Hashemite Kingdom. Free movement of people, goods, and services was normal and added more to the population. The increase in population occurred in and around urban areas, which intensified the demand for urban water. Springs that had been the source of urban water could no longer cope with the increased demand. Streams that emerged from them dried up with adverse environmental consequences. Tube wells were drilled to pump more water from the aquifers for urban supply purposes.

Demand also increased for food. Permits were issued to interested developers to drill wells for agricultural development. The drilling and abstraction of groundwater were monitored and controlled until the outbreak of the 1967 war and its aftermath. Government control weakened, and many wells were drilled without permits. The relaxation of Government controls thereafter continued primarily because of the institutional instability and the shifting of institutional responsibilities.

Today, each of the 12 water basins has wells and pumps installed in them capable of abstracting more water than the safe yield of each. The average annual abstraction from all basins exceeds the renewable average of recharge and currently stands at 159% of that average. The over pumping ratio ranges between 146% in minor aquifers to 235% in major ones. This cannot be tolerated, and decisions have been taken to remedy the situation.

WAJ assumed the responsibility of groundwater administration, management and development. The concerned directorate of NRA and that of the JVA were transferred to WAJ in

1984. Both WAJ and JVA came under the umbrella of a newly founded Ministry, the Ministry of Water and Irrigation, (MWI) in 1988.

Currently, MWI/WAJ is in charge of groundwater administration and management in addition to its responsibilities for providing municipal water supplies to all population centers in Jordan, and the collection and treatment of their wastewater. MWI/WAJ receives applications for drilling licenses and abstraction permits, and issues such licenses and permits in accordance with the groundwater legislation. MWI/WAJ also supervises drilling, abstraction, and makes arrangements for the lease of land and use of groundwater for agricultural purposes in remote arid areas. Recently, MWI has stepped up the activities of groundwater resources studies on a national scale.

2. Conditions of Groundwater Aquifers

There are eleven renewable groundwater reservoirs in the country. Their sustainable yields vary from one reservoir to another, and their combined sustainable yield is 275 million cubic meters per year.

The majority of the reservoirs are being utilized at rates exceeding their sustainable yields. Some are of particular concern because they are the most over utilized aquifers. The combined abstraction rate of all renewable reservoirs approaches 437 MCM per year, a rate equal to 159% of their sustainable yield.

The over pumping from one aquifer in the 1960s and 1970s caused its loss due to high salinity ratios. It is feared that this unpleasant experience will be repeated in some other aquifers if they are not rescued through proper management.

There are extensive non-renewable reservoirs in the sandstone formation underlying almost the entire area of the country. The water quality of these reservoirs varies and is known to be fresh in the Disi-Mudawara area.

Qualities elsewhere have been sparsely investigated and preliminary findings indicate brackish water qualities. More work is needed to investigate these reservoirs.

The use of fresh fossil waters from the non-renewable reservoir in Disi-Mudawara started in the early eighties for municipal and industrial purposes in the city of Aqaba. This was followed by the use of the same aquifer (Disi) for agricultural purposes. Future use of this aquifer is earmarked for municipal purposes for the city of Amman, and pumping for agricultural purposes is being reduced.

3. The Policy

Objective
The objective of this policy is to outline in more detail the statements contained in the document entitled: "Jordan's Water Strategy". The policy statements set out the Government's policy and intentions concerning groundwater management aiming at development of the resource, its protection, management and measures needed to bring the annual abstractions from the various renewable aquifers to the sustain-able rate of each.

On Resource Exploration
1. Plans and implementation measures for the exploration of groundwater resources shall be prepared and updated. Theoretical investigation and field operations in the form of drilling, sampling and logging shall be conducted continually.
2. Assessment and re-assessment of the sustainable yields of groundwater reservoirs shall be made in light of the accumulation of data and information
3. Monitoring of each reservoir shall be conducted through a network of observation wells. Such crucial data as the groundwater table, the draw down as a result of development, the physical, chemical and biological characteristics and their changes will be collected.
4. MWI/WAJ personnel will implement groundwater-exploration will be conducted as a priority. The service can be out-sourced when deemed necessary or required by any partnership with others in this activity.
5. Equipment, hardware and computer software needed for groundwater investigation and exploration shall be maintained by MWI/WAJ. Drilling services can be out-sourced when needed and so will be the maintenance of software packages.
6. Advanced methods and tools for investigation including LandSat imagery shall be employed, and cooperation with other countries in this field will be promoted.
7. A comprehensive program to assess the potential of brackish groundwater shall be conducted. Brackish groundwater will be used to augment water supply for domestic use through desalination in due time and specified localities. They also may be used for agricultural purposes where appropriate.
8. Compilation of oil and gas drilling data as well as geophysical data shall be made to gain better understanding of the potential of the deep aquifers.

On Monitoring
9. A network of observation wells shall be installed in each of the groundwater reservoirs or parts thereof for the purpose of monitoring the conditions and performance of the reservoirs in response to development and abstraction.
10. A groundwater reservoir can be divided into sub-units for the purposes of monitoring and control of abstraction.
11. Advanced technology shall be employed in the monitoring processes including the installation of water meters, remote control devices, telemetry, automation and field central controls.
12. Data collected in the monitoring process shall be formatted for storage in and retrieval

from computer files. Hard copies and computer back-up copies shall be maintained at all times.

13. Analysis and interpretation of data shall be made by a specialized group of professionals and their aides, and results published in special reports by MWI/WAJ.
14. Logistics for the field teams shall be secured, and their working conditions improved to the best affordable levels.
15. MWI/WAJ shall evaluate, update and redesign the groundwater-monitoring plan to cover all aquifers with emphasis on the overexploited and polluted aquifers.
16. A special monitoring network of industries and olive presses will be adopted and installed for those with potential pollution to groundwater.

On Resource Protection, Sustainability and Quality Control

17. Recharge areas of aquifers shall be protected to the maximum extent possible. Conflicts arising out of urbanization shall be addressed and mitigation measures specified for the urban planners to have them included in the urban planning process.
18. Recharge areas shall be protected against pollution caused by whatever means including solid and liquid waste disposal, mining, land fills, brine disposal, agricultural inputs and the like.
19. Drilling of wells and abstraction of groundwater from them shall be prohibited without a drilling license and an abstraction permit issued by WAJ.
20. Withdrawal from wells shall not exceed the abstraction permit rate under penalty of substantial fines and / or revoking the abstraction permit and the closure of the well. Over-abstraction from aquifers shall be reduced to sustainable levels in accordance with a time-phased plan.
21. The laboratories of the Water Authority of Jordan shall be equipped with the latest technologies and equipment to match the requirements of good quality controls and assurance. Monitoring of groundwater qualities shall be made, hazards identified and mitigation measures specified and implemented.
22. Withdrawal from non-renewable fossil aquifers shall be made carefully and after elaborate studies and investigations. A lifetime will be assigned for each of these aquifers and an abstraction rate specified accordingly.
23. The MWI will co-operate with planning and environmental authorities to have polluting industries and solid waste dumps located outside the protection zones of aquifers.
24. The MWI shall co-operate with the Ministry of Agriculture and its arm of extension service to regulate the type and application rate of fertilizers, pesticides, and sludge used within the area of aquifer recharge.
25. MWI/WAJ in liaison with other authorities will seek to restrict storage of chemicals, waste materials and sewage treatment works within the inner circle protection zone.

On Resource Development

26. Development of groundwater reservoirs shall be commenced only after careful studies are made of the potential of each, and observation wells installed in carefully chosen locations to monitor the reservoir during exploitation. Wellfields shall be distributed with a proper distance between wells to minimize sudden drawdown of water levels.

27. Development of deep groundwater aquifers shall be carefully made. Abstraction from them shall be gradual with periodic assessment of quality and quantity.
28. Potentials of reservoirs shall be based on the natural rate of recharge. These can be augmented through means of artificial recharge induced through proper designs.
29. Natural rainwater and treated effluent of wastewater are considered primary sources for artificial recharge. Monitoring of recharge facilities and their maintenance shall be made periodically.
30. Development of groundwater reservoirs shall not be allowed without a license issued by MWI/WAJ. Private developers and public entities shall all be required to apply for any development they intend to undertake.
31. Inflow into and outflow from each groundwater reservoir shall be determined as accurately as possible before any permit is issued for the development of that reservoir.
32. Artificial underground storage, especially in the alluvial fans of the Jordan Valley shall be investigated.
33. Groundwater mathematical models shall be developed or updated for all regional aquifers of the basins to predict their yield under various pumping scenarios.
34. New nonrenewable groundwater sources shall be allocated to municipal and industrial uses as a first priority.
35. MWI/WAJ shall encourage the use of groundwater conjunctively with surface water in places where such joint management has the potential for increasing the benefits of water use.
36. MWI/WAJ shall encourage the use of marginal groundwater quality for agricultural uses especially when such use may relieve pumping from fresh groundwater aquifers.

On Priority of Allocation

37. Priority of allocation of groundwater shall be given to municipal and industrial uses, to educational institutes and to tourism. These purposes are deemed to have the higher returns in economic and social terms.
38. Priority shall also be given to the sustainability of existing irrigated agriculture where high capital investment had been made. In particular, trees irrigated from groundwater shall continue to receive an amount sufficient for their sustainability with the use of advanced irrigation methods.
39. Expropriation of use rights arising from legal use of groundwater, or of water rights established on springs rising from groundwater reservoirs shall not be made without clear higher priority need, and against fair compensation.
40. Priority shall be given to the use in irrigated agriculture of the reservoirs whose water quality does not qualify them for use in municipal and industrial purposes.
41. Priority for use in agriculture shall also be given to the cases where supplementary irrigation from the groundwater reservoir is possible.
42. A contingency plan shall be made and updated for the purpose of allocating the water from privately operated wells for use in the municipal networks.

On Regulation and Control

43. Campaigns shall be waged against illegal drilling of tube wells, and wells thus drilled

shall be stopped, rigs confiscated and legal action taken against violators.

44. Comprehensive groundwater basin management plan for each aquifer shall be developed as part of the National Water Master Plan.
45. Water meters installed on groundwater wells shall be read on quarterly basis to make sure that abstraction from the wells does not exceed their allocations, specified in the permits.
46. Prohibition of well licensing for agricultural purposes will be sustained. Only high priority purposes shall be entertained for licensing.
47. Fees and charges will be used as an instrument to control groundwater over-pumping.

On Legislation and Institutional Arrangements

48. Legislation and institutional arrangements for the development and management of groundwater resources shall be reviewed from time to time. Shortcomings shall be addressed and institutional arrangements shall be updated, adjusted or restructured.
49. Effective laws shall be reviewed from time to time with the intention of updating their provisions to match the requirements of changing times. By-laws issued under the applicable laws shall also be updated to serve the purpose of performance efficiency. Institutional set-up shall be reviewed in parallel, updated, adjusted or restructured to improve performance.
50. Close co-operation will be maintained with the other organizations whose activities may directly impact the performance in the water sector.

On Research, Development and Technology Transfer

51. A study and research activity shall be entrusted with a specialized unit within MWI. The unit will be entrusted with technology transfer responsibilities.
52. Due emphases will be made on the efforts targeting human resources development.
53. Training centers will be reinforced and upgraded. Cooperation with outside centers and agencies will be promoted.
54. International and regional cooperation shall be pursued in the fields of research, development and technology transfer in ground-water exploration, management, quality control, and economics shall be promoted. Exchange of information and experience shall be maintained with regional and international parties.

On Shared Groundwater Resources

55. Legal research shall be made on the sharing of groundwater aquifers and their protection.
56. Efforts shall be made and sustained to establish Jordan's rights in shared groundwater resources through international agreements.
57. Regional data exchange on shared groundwater resources shall be encouraged.
58. Cooperation with neighboring countries for the optimal and sustainable use and management of the shared groundwater resources shall be sought.
59. Special attention will be paid to the monitoring, assessment and development of shared groundwater resources.

On Public Awareness

60. Workshops and seminars for well owners will be organized to promote groundwater conservation and raise efficiency of groundwater use.
61. Training programs for Ministry staff shall be conducted to build capacity for public awareness campaigns related to groundwater use and protection.
62. MWI/WAJ in cooperation with other concerned agencies shall maintain a program to educate farmers on the importance of groundwater protection and shall promote technology transfer related to groundwater use in irrigation.
63. Cooperation with other concerned agencies shall be maintained to encourage the reuse of groundwater in beneficial purposes.

On Private Sector Participation

64. The role of the private sector in the development of fresh groundwater resources shall be reduced where reduction of abstraction is sought. The private sector shall be encouraged to co-operate in the rehabilitation of aquifers where needed.
65. The private sector shall be encouraged to develop aquifers of marginal water quality for use in irrigation. It shall also be encouraged to develop fossil and renewable aquifers in remote areas for agricultural uses with the intention of promoting technology transfer and the creation of job opportunities.
66. Desalination of brackish groundwater by the private sector shall be promoted. Care shall be given to the environmental impacts of such activities, particularly the safe disposal of brines.

IRRIGATION WATER POLICY

1. Background

The Hashemite Kingdom of Jordan has been facing a chronic imbalance in the population - water resources equation, which imbalance is manifested by a substantial in deficit in the foreign trade in food commodities ($110 per capita in 1997), and by rationing of municipal water that is serviced to the population twice a week. The total renewable freshwater resources of the country amount to an average of 750 MCM per year. The population in 1997 was around 4.4 million people, growing at an annual rate of 3.6%. The per capita share was 160 cubic meters per annum in 1997 and declines at a rate equal to that of the population increase.

The production of food in semi-arid countries like Jordan is hardly possible without irrigation. The irrigated areas are located in the Jordan Valley (some 33,000 hectares), and in the Plateau (some 44,100 hectares). Some 400,000 hectares are fit for dry land farming, but it is practiced on half of this potential because of the insecurity associated with erratic rainfall and other reasons. Irrigated agriculture, however, provides most of the agricultural production in the Kingdom and offers the higher percentage of agricultural jobs and other jobs in support services.

Because of the huge imbalance in the population - water resources equation, the treated wastewater effluent is added to the water stock for use in irrigated agriculture. It will constitute a substantial percentage of the irrigation water in future years.

2. Development of Irrigated Agriculture

Irrigated agriculture has been practiced in the Jordan Valley since the dawn of civilization. Their Archaeological remains tell of the construction of water storage facilities and irrigation networks by the Nabateans before the Christian era in the Jordan Rift Valley and elsewhere. Irrigation was developed in the Rift Valley by channeling the uncontrolled perennial flow of side wades and rivers through well-developed water conveyance systems and irrigation techniques.

Formal development and a rebirth of irrigated agriculture in Jordan started in the early 1950s in the Zarqa Triangle with irrigation from the uncontrolled flow of the Zarqa River. The Deir Alia agricultural experimental station was established at that time. The more serious effort was planned in 1954 - 1955, and implementation commenced with grant assistance from the United States towards the East Ghor Canal Project, renamed in 1986 as the King Abdallah Canal Project. The Project was implemented between 1959 and 1966 with USAID grant funds, and between 1968 - 1970 with support from the Kuwait Fund, between 1975 and 1980 with loan funds from USAID, IDA and KFW, and between 1983 and 1988 with loan funds from KFW, and, south of the Dead Sea with loan funds from the

Kuwait Fund, the Saudi Fund and the Government of Italy. The older parts of the project were upgraded by conversion of surface canal networks to pressure pipe distribution networks between 1986 and 1996 with loan funds from the Arab Fund and the Government of Japan.

Five storage dams have been built in the process; they serve as important feeders to the King Abdallah Canal. The Canal itself was rehabilitated between 1994 and 1998 with funds from the EIB.

The total area thus developed in the Jordan Valley, under the responsibility and supervision of successive Government agencies, is about 33,000 hectares. About 8,000 more hectares of arable lands remain to be irrigated north of the Dead Sea, and some 2,000 hectares south of the Dead Sea. A potential exists for irrigated agriculture in Wadi Araba with groundwater sources and surface water sources.

More development has taken place on the plateau using groundwater sources. The private sector was behind all that development, with the exception of small and scattered irrigation projects supervised by Government agencies in the 1960s. The total area thus irrigated amounts to about 44,100 hectares.

3. The Policy

Objective

The following policy statements detail the long-term objectives outlined in the Water Strategy. It is to be noted that this policy addresses the irrigation water and does not extend to the issues of irrigated agriculture. It addresses in more detail water-related issues of resource development: agricultural use, resource management, the imperative of technology transfer, water quality, efficiency, cost recovery, management and other issues. Linkages with energy and the environment are accorded a separate chapter. This policy is compatible with the Water Strategy and is in conformity with its long-term objectives. Most of the provisions of this policy are being exercised, and some others are needed to maximize the benefit from irrigation water, and improve the social returns from its uses. While the policy is national, its implementation is vested in the respective Government agencies as stipulated by applicable laws. Of particular importance is the role of the Ministry of Water and Irrigation and the Ministry of Agriculture.

On the Role of Irrigated Agriculture

1. Irrigated agriculture is a trade of Jordanian ancestry practiced in the Jordan Rift Valley and on its escarpment. Archaeological irrigation networks and facilities are standing evidence. Irrigated agriculture contributes to the production of food, and provides job opportunities in direct and indirect agricultural employment and supporting services. It also enhances the environment and helps arrest desertification.

On Sustainability of Irrigated Agriculture

2. Existing areas of irrigated agriculture shall be accorded the chances for sustainability. No diversion of its waters to other uses shall be allowed without providing a replacement source fit for agricultural use unrestricted by health and public health considerations, and unduly hampered by chemical constraints.
3. Sustainability of agriculture shall be compromised only if it threatens the sustainability of use of ground water resources. Potential pollution of underlying aquifers or the depletion thereof is among the reasons that can prompt such compromise.
4. Irrigation water sources shall be protected against pollution that degrades water quality, is hazardous to the environmental integrity of soils, or can endanger animal health, particularly livestock. In this regard the adoption of biological control methods shall be promoted in lieu of the use of pesticides. Where desalination of brackish water is practiced, particular attention will be paid to the disposal of brine especially when such practice is done within the catchments area of dams.
5. Close coordination shall be maintained with the Ministry of Agriculture and its research and development arm and with other related institutions with the aim of enhancing on-farm irrigation efficiencies and maximizing the agricultural output of a unit of land area per unit flow of irrigation water.
6. Surplus surface water during the wet season shall be provided to farmers through the irrigation networks free of charge to leach soils especially those farms that are irrigated with treated wastewater in the dry season.
7. Drainage networks shall be installed in irrigated areas where natural drainage is not sufficient to serve the purpose. Disposal of drainage water shall be made in an environmentally friendly manner. Maintenance of such networks shall be accorded attention similar to that paid to the maintenance of irrigation networks.

On Resource Development and Use

8. For irrigation purposes, and in light of the tight water situation, wastewater is considered a resource and cannot be treated as "waste." It shall be collected and treated to standards that allow its reuse in irrigation unrestricted by health and public health considerations or unduly constrained by high salinity contents.
9. In remote sparsely populated areas, and after satisfying the local municipal and industrial needs from unallocated water resources, water resources shall be allocated to agricultural production including livestock. Such development shall be planned and implemented in an integrated social and economic fashion in order that communities can be formed, settled and developed.
10. Maximum use shall be made of rainfall for crop production, and supplementary irrigation shall be employed to maximize production including increasing cropping intensities.
11. The use of brackish water in irrigation shall be pursued with care. Soil salinity resulting there from shall be monitored and its buildup managed and mitigated. Land shall be managed with the attention it deserves as a non-renewable resource.
12. A revolving development plan for water resources, including irrigation resources, shall be adopted. The use of modern techniques made available by software development will be employed for the purpose.

On Technology Transfer and Adaptation

13. Despite the high percentage of agricultural water uses, the quantities used fall short of the needs. Higher agricultural yields shall be targeted and the transfer of advanced technology shall be endorsed and encouraged. The transformation of traditional irrigation and farming practices into modern methods shall be endorsed and promoted.
14. Such advanced methods as drip irrigation, spray irrigation, micro-sprinkler irrigation are favored over less efficient methods. Local manufacturing of these systems will be encouraged.
15. Irrigation water conveyance and distribution shall be made through the installation of pressure pipe networks. Maximum use shall be made of gravity-generated pressures to operate these systems.
16. Operation of the irrigation network will be improved to have the water filling the network for 24 hours. Such operation will enhance the benefits that accrue from drip irrigation. While in a rotation system the drip irrigation pipes act as on-farm conveyor, 24-hour operation has the advantage of operating the drippers as designed.
17. Plant varieties developed as a result of genetic engineering research shall be favored for introduction into Jordan's markets. Maximizing resistance to pests, salinity and adverse conditions are features that are needed. Additionally, the maximization of crop yields is another beneficial feature of such varieties.
18. Leasing of Government lands with permits to use water resources not earmarked for higher priority uses, especially in remote areas, shall be encouraged with the view of introducing advanced agricultural practices. Cooperation with advanced countries through technical co-operation shall be sought and promoted to advance technology transfer and adaptation.

On-Farm Water Management

19. Crop water requirements in the various micro-climatic zones of the country shall be experimentally determined, taking into consideration the prevailing different water qualities.
20. Farmers shall be encouraged to monitor soil moisture on their farms to determine the timing for irrigation water application. The rate and duration of the application shall be adjusted to match the crop water requirements.
21. In as much as is practical, investments on the farm to provide overnight water storage facilities shall be discouraged through providing a continuous supply of irrigation water in the distribution networks.
22. Along with water management, farmers should be able to manage such other agricultural inputs as chemical fertilizers with the irrigation water.
23. Night application of irrigation water, especially in the dry season, shall be encouraged to reduce evaporation losses.
24. Automation of on-farm irrigation networks and their operation will be encouraged and training of farmers on advanced water management techniques shall be sought by cooperating with the research and extension service of the Ministry of Agriculture. Cooperation with other countries in this regard and in technology transfer in general shall be pursued.

25. Programs shall be prepared to raise the public and farmers awareness of the availability of reused water, its rational and economic use and on the impacts of its quality.

On Irrigation Water Quality

26. Irrigation water quality shall be monitored through sampling at the sources and from the conveyance and distribution network. Farmers shall be alerted to any degradation of water quality. This is important so that they can plan the use of such water for the suitable farming purposes.
27. Where marginal quality water, such as treated wastewater effluent, is a source of irrigation water, care should be taken, to the maximum extent possible, to have the quality improved to standards that allow its use for unrestricted irrigation. This can be achieved through blending with fresher water sources.
28. The same applies to the potential use of drainage water or brackish water sources. However, farmers should be informed of the potential quality of irrigation water so that their choice of crops is made with the necessary background information and knowledge.
29. Soil salinity and water chemical contents are also constraining factors. Where its salinity is combined with water salinity, the environment of the root zone can cause high stress. Care shall be taken in providing testing services to farmers, and in promoting extension service in such zones where soil salinity and irrigation water salinity produce hostile roots environments.

On Management and Administration

30. Government agencies have been responsible for the development of water resources in the Jordan Valley and for the construction of the irrigation network. The Jordan Valley Authority (JVA) is the legal successor of these agencies and has been in operation since May 1977. It is the agency amongst them that has lived longest. The JVA is, as the predecessor agencies had been, responsible for the operation and maintenance of irrigation facilities, from the source (dams, rivers, springs) to the destination (farm gate).
31. Piped irrigation networks shall be the standard method of irrigation conveyance and distribution. Where possible, gravity pressure shall provide the heads in the distribution networks. Supplementary pumping shall be used where needed.
32. Irrigation water shall be metered at the farm turnout. Digital meters shall be installed at each farm unit for volumetric measurement of in-flowing water.
33. Government shall gradually phase-out of the business of irrigation water distribution, as is feasible, as soon as possible.
34. Pilot irrigation areas shall be designated to test the workability of Participatory Irrigation Management (PIM), where farmers will assume the responsibility of water delivery to their farms. When found successful, PIM will be extended to the Jordan Valley irrigation systems.
35. Development of water resources, including groundwater, outside the Jordan Valley has been the responsibility of the Water Authority, WAJ that since 1983 has been the successor, among others, of the Natural Resources Authority. Private farmers are allowed, by license and abstraction permit from WAJ, to exploit groundwater for all purposes,

including irrigated agriculture. These private farmers operate their irrigation systems, and have introduced advanced irrigation techniques to their operations.

36. Abstraction from all groundwater wells shall be metered, and monitoring of abstraction shall be made periodically to assure conformity with the provisions of the abstraction permits.

On Public Awareness

37. Public awareness campaigns shall be waged to urge the public to protect water resources against pollution, and to bring home the economic and social value of a unit flow of water.
38. The cost of irrigation water development shall be emphasized, and the importance of protection of structures and utilities against vandalism shall be advocated.

On Water Pricing

39. Irrigation water shall be managed as an economic commodity that has an immense social value. Like other water resources, irrigation water is a national commodity owned by society at large without prejudice to existing water rights.
40. Agriculture provides service to society in the form of employment, population distribution, provision of food that would otherwise have to be imported, and enhancing the environment. It is for this reason that agriculture enjoys support from society in the form of tax exemptions and subsidies.
41. The water price shall at least cover the cost of operation and maintenance, and subject to some other economic constraints, it should also recover part of the capital cost of the irrigation water project. The ultimate objective shall be full cost recovery subject to economic, social and political constraints. Due consideration shall be made of any water rights as established by law.
42. Part of the capital cost shall be recovered through the application of a one-time charge against irrigation rights. This is applied as a rate per unit area of the irrigated farm. The size of the portion thus recovered shall not be less that half the irrigation network development cost.
43. Differential prices can be applied to irrigation water to account for its quality.

On Regulation and Controls

44. Planting of crops with high water requirements shall be discouraged. Market forces shall be applied to discourage such plantations.
45. Planting of perennial crops shall be allowed only with permits until such time as the water balance and the operation system show no signs of water stress in any of the dry months.
46. Cooperation with other countries, regional and world wide, shall be promoted to enhance the marketing potential of Jordanian agricultural commodities and the products of its agro-industries.

On Irrigation Efficiency

47. Maximum overall irrigation efficiency shall be a standing target. Government agencies in charge of operation and maintenance shall endeavor to approach this target and maintain it.
48. Automation of irrigation networks shall be pursued, and electronic surveillance and monitoring of irrigation networks shall be employed to reduce losses through leakage and breaks.
49. Preventive maintenance of pumps, motors and valves shall be programmed and conducted periodically. Human resources for proper management of maintenance shall be secured to the maximum extent possible.
50. On-farm automation, although the responsibility of farmers, shall be promoted through extension service and demonstration farms.
51. Programs for manpower training to perform duties of irrigation operations, forecasts and scheduling of irrigation service shall be a standing objective.

On Linkages with Energy and the Environment

52. The use of herbicides that are environmentally friendly shall be encouraged. The savings in evapo-transpiration by unwanted plants is a positive outcome. Similar advantage is gained through the savings in plant nutrition that otherwise will be absorbed by unwanted vegetation.
53. Serious care shall be taken in choosing the technology of wastewater treatment. The treated effluent, considered part of the irrigation water stock, shall be maintained as an environmentally accepted resource that can be safely handled by agricultural labor. It shall not be harmful to wild life or to domesticated animals on the farms.
54. A trade-off shall be made between capital investment, energy requirements for operation, and the losses that will otherwise be incurred in the irrigation water resource. Choice of the optimal configuration shall be based on a thorough analysis of these factors.
55. Maximum use shall be made of the gravity head inherent in the irrigation water sources of the Jordan Rift Valley. Supplementary head shall be generated through pumping interventions to maintain a suitable pressure head at the farm gate.

On Legislation and Institutional Arrangements

56. Legislation and institutional arrangements for the development and management of irrigation water resources shall be periodically reviewed. Gaps shall be filled, and updating of institutional arrangements with parallel legislation shall be made periodically.
57. The role of government shall be fine-tuned and its involvement reduced over time to regulation and supervision. Involvement of stakeholders and the private sector in irrigation management and support will be introduced and expanded.
58. The role of the private sector in the development of irrigated agriculture shall be promoted. Care will be taken to monitor and supervise the use of water resources in that regard.

On Shared Water Resources

59. Shared water resources occur in the Jordan River basin and in ground water resources to the south, east and north, and that are either used for irrigation or are mixed with irrigation water of the Jordan Valley. Priority shall be given to the development and management of shared water resources.
60. The quality and flow rates of water obtained by Jordan shall always be monitored and proper records kept of such data.
61. The establishment of Joint Water committees to co-operate with neighboring countries over issues affecting other riparian shall be promoted.
62. Regional cooperation will be proposed, promoted and sustained with the neighboring countries with which Jordan shares international waters.

On Research and Development

63. Applied research on water topics will be adopted and promoted. Such topics as water economics, resource management, crop water requirement, use of brackish water, irrigation technologies, farming practices, crop yields, moisture storage and the like are among favored topics.
64. Cooperation with specialized centers in the country and outside will be promoted, and raising funds for this purpose will be supported.
65. Technology transfer and adaptation to local conditions will be a primary target for development activities and for adaptive research.

WATER USE EFFICIENCY IN LEBANON

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1. Introduction

The sustainability of water resources in agriculture is one of the major concerns in Lebanon. Agriculture is the largest user of water in the country (up to 70% of the total available water) and, therefore, the agricultural water use efficiency is of great importance. This can be achieved only when a sustainable water management policy is applied at both network and farm levels. Such policy is largely based on the adoption of modern irrigation techniques, such as drip and sprinkler, known to have higher water application efficiency than traditional surface irrigation.

The term efficiency is very often used to express irrigation systems performance. It can be defined by the ratio of water depth delivered by the system to water depth supplied to the system. Another efficiency term often used is water use efficiency (WUE). This is defined by the ratio of crop biomass or grain production to the amount of water consumed by the crop, including rainfall and/or irrigation water applied. The WUE indicators defined by those ratios is useful to identify the best irrigation scheduling strategies for rainfed and irrigated agriculture, and to analyze the water saving performance of irrigation systems and respective management, as well as in comparing different irrigation systems, including regulated deficit irrigation (RDI). The water use indicators are yet far from common usage but they have the potential to be very useful for water resource planning and management at the farm and scheme levels. Therefore, it is necessary to perform a rigorous analysis of on-farm water management practices and their possible improvements in order to develop a sustainable irrigated agriculture, that tend to preserve the environment through a rational use of the scarce water resources.

A number of researchers have analyzed the economics of deficit irrigation in specific circumstances and have concluded that this technique can increase net farm income (Martin et al., 1989; English, 1990). The potential benefits of deficit irrigation are derived from three factors; increased irrigation efficiency, reduced costs of irrigation and the opportunity costs of water. Four levels of applied water could be defined as optimal in one sense or another (English et al., 1990):

• The level of applied water at which crop yields per unit of land are maximized;
The level at which yields per unit of water are maximized;
The level at which net income per unit of land is maximized;
The level at which net income per unit of water is maximized.

Regulated deficit irrigation (RDI) may be implemented during part of the growing season by regulating moisture within a desired deficit range. RDI aims to optimize water use efficiency and therefore maximize the yield returned per unit of water applied. Any minor yield loss which may result from the implementation of a mild moisture deficit/stress under RDI is offset by the benefits of reduced water use leading to a reduction in excessive vegetative growth (Kirnak et al., 2002). A variety of crops have been found to benefit from a RDI strategy including maize, wheat, sunflower, potato, tomato and cotton. Irrigation using drip is typically able to apply smaller quantities of water more frequently, and is better able to maintain soil moisture at the mild deficit required to implement RDI.

The objectives of this study are to describe the problems facing water management at on-farm level in Lebanon. It also aims at setting up a list of indicators that tend to increase water use efficiency. Finally, a case study will be brought for four annual crops; corn, soybean, cotton, and sunflower, grown under limited irrigation conditions.

2. Agricultural and Irrigation Potentials in Lebanon

Lebanon, with its 1,045,200 ha of total area, has a cultivable area of 329,000 ha, or 32% of its total area, of which 177,500 ha could be potentially irrigated. In 2000, the FAO through the Project of Agricultural Census reported a total cultivated area of 247,940 ha distributed over the Lebanese regions, of which 43% are in the Bekaa Valley (Figure 1). Moreover, the percentage of agricultural land per plot size varies from 0.5% of plots having average area less than 0.1 ha, to 16.4% of plots having average area of 2-4 ha, while 9.1% of the agricultural land have average plot size >500 ha (Table 1).

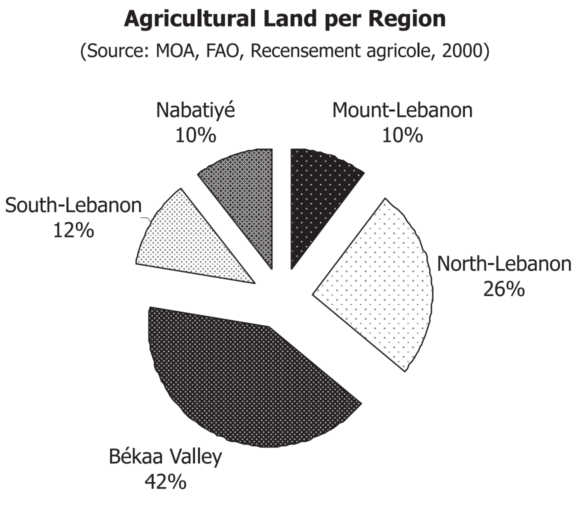

Figure 1. Agricultural Land in Lebanon per Region

Table 1. Agricultural Land and Number of Farmers per Plot Size

Plot size (ha)	Agricultural land (ha)	%	Number of farmers	%
No land	0.0	0.0	4036	2.1
< 0.1 ha	1182	0.5	18126	9.3
0.1 - 0.2 ha	3832	1.5	27689	14.2
0.2 - 0.5 ha	17210	6.9	53749	27.6
0.5 - 1 ha	26422	10.7	37994	19.5
1 to 2 ha	37716	15.2	27434	14.1
2 to 4 ha	406778	16.4	14977	7.7
4 to 6 ha	21971	8.9	4559	2.3
6 to 8 ha	14222	5.7	2079	1.1
8 to 10 ha	9295	3.7	1048	0.5
10 to 15 ha	16977	6.8	1434	0.7
15 to 20 ha	9269	3.7	549	0.3
20 to 50 ha	26518	10.7	911	0.5
> 500 ha	22646	9.1	244	0.1
Total	247,940	100.0	1,94,829	100.0

Source: Ministry of Agriculture, Food and Agriculture Organization of the United Nations, Agricultural Census Project, 2000.

Irrigated land in Lebanon accounts for some 104,008 ha, or 42% of the total agricultural land and the remaining 143,931 ha are under rainfed conditions. Figure 2 reports irrigated land in Lebanon in the different regions. As seen in this figure, the Bekaa Valley accounts by itself to 51% of the total irrigated land in Lebanon. In the irrigation projects operated by the public sector, the poorly maintained distribution canals and ditches suffer from high water losses and low irrigation efficiency (not exceeding 40%). This poor efficiency is also due to poor land leveling. However, the government has plans to implement large scale irrigation projects and to modernize the traditional irrigation networks, which will allow the irrigation of additional 74,000 ha.

Data of the FAO (2000) indicated that 48% (49,924 ha) of the total irrigated land in Lebanon receive water for irrigation from surface sources, while 52% (54,084 ha) are irrigated from groundwater. Note that for surface water sources used for irrigation, only 10 % are conveyed from surface water reservoirs, 12% are pumped directly from the river courses, and 30% from river diversion. Total water use is made upon 68% for agricultural consumption, while domestic and industry consume 28% and 4%, respectively.

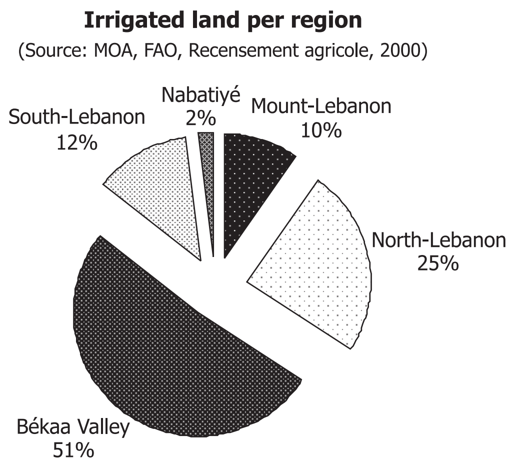

Figure 2. The Percentage of Irrigated Land per Region

Table 2. Irrigated Land and Number of Farmers per Plot Size

Plot size (ha)	Irrigated land (ha)	%	Number of farmers	%
No land	0.0	0.0	4036	2.1
< 0.1 ha	601	0.6	18126	9.3
0.1 - 0.2 ha	1432	1.4	27689	14.2
0.2 - 0.5 ha	5336	5.1	53749	27.6
0.5 - 1 ha	7728	7.4	37994	19.5
1 to 2 ha	11278	10.8	27434	14.1
2 to 4 ha	13597	13.1	14977	7.7
4 to 6 ha	8542	8.2	4559	2.3
6 to 8 ha	5956	5.7	2079	1.1
8 to 10 ha	4451	4.3	1048\	0.5
10 to 15 ha	8800	8.5	1434	0.7
15 to 20 ha	5216	5.0	549	0.3
20 to 50 ha	16726	16.1	911	0.5
> 500 ha	14342	13.8	244	0.1
Total	104008	100.0	194829	100.0

Source: Ministry of Agriculture, Food and Agriculture Organization of the United Nations, Agricultural Census Project, 2000)

2. Agricultural Landuse in Lebanon

Out of the total cultivated area is 247,940 ha, about 51,842 ha are cropped with cereals, 59,514 ha of fruit trees, 52,421 ha with olive, 24,726 ha with industrial crops, and 45,232 ha with vegetables (Figure 3). This makes a total cultivated area of 233,736 ha. The remaining 14,203 ha are left fallow. Add to this cultivated area some 4,995 ha of green houses and tunnels spread all over the country, mainly cropped with vegetables and flowers.

The whole range of extensive cropping down to the very intensive systems is applicable under Lebanese agriculture. Perhaps, the most suitable for the country would be a cropping system which makes the best use of the scarcely available resources in terms of space, time, efficiency and technology. The most apt system would be a very intensive program of production utilizing multiple crops, and using the most effective cultural practices and irrigation technologies. The possibility of intensive cropping becomes a reality and the potential for high productivity could be exploited. Record yields could be obtained from crops under local irrigated conditions. Subtropical fruits and vegetables could be produced in coastal areas. Temperate crops are produced at high mountains and traditional crops in the Bekaa Valley.

- *Multiple cropping:* Farmers try to concentrate on short season crops so they can produce more than one crop annually, for example an early crop of potato is usually followed with a late plantation of the same crop. Lettuce follows winter crops and beans follow early vegetables as lettuce or potato.

- *Inter cropping*: It is practiced in coastal areas more or less representing sequential pattern. For economical purposes and to compensate for the weak profit, farmers try to make the best use of land and the maximum use of the growing season. Many times the risk factor becomes high as they are faced with an early winter or a late spring.

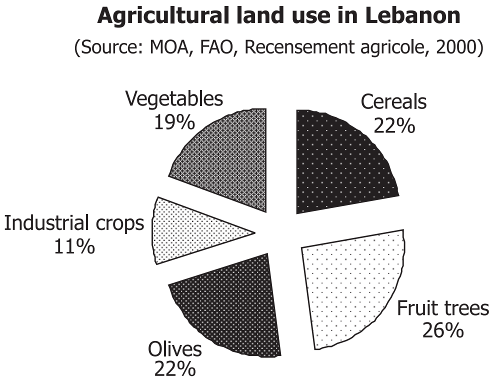

Figure 3. Agricultural Landuse in Lebanon

3. Development of Irrigated Agriculture in Lebanon

Out of the 104,008 ha irrigated lands in Lebanon, 64% receive water from surface irrigation (furrow, basins and flooding), 28% receive water from sprinkler irrigation and only 8% of the irrigated lands receive water from drip irrigation (Figure 4). Furthermore, over the 163,374 of irrigated plots in Lebanon, about 143,328 plots are irrigated with surface irrigation, giving an average plot size of 0.5 ha, while 10,100.0 plots receive water with sprinkler irrigation, with an average plot size of 2.9 ha, while a total of 9946 plots receive water with drip irrigation, with an average plot size of 0.6 ha (Table 3).

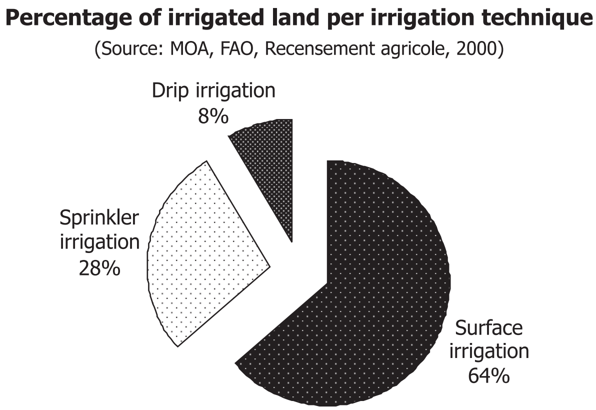

Figure 4. Percentage of Irrigated Land per Irrigation Technique

Table 3: Average Irrigated Plot Size per Type of Irrigation Technique

Irrigation technique	Irrigated land (ha)	Number of plots	Average plot size (ha)
Surface irrigation	66128	143328.0	0.5
Sprinkler irrigation	29042	10100.0	2.9
Drip irrigation	8838	9946.0	0.9
Total	**104008**	**163374**	**0.6**

Source: Ministry of Agriculture, Food and Agriculture Organization of the United Nations, Agricultural Census Project, 2000.

The public irrigation sector in Lebanon, essentially did not change since 1970, consists of 5 large-scale schemes (>1000 ha) and 50 medium and small-scale schemes. Most of those schemes are 25 to 50 years old, poorly maintained and in an advanced state of deterioration. It is estimated that most of the area irrigated by surface water needs rehabilitation. The irrigation schemes are not on the whole regular shaped ones. They follow the contour of the land, and water is supplied by gravity from a series of local springs, or in some other case by diversions via small channels. When water is supplied by local springs with high seasonal variation of water flow, the main constraint is related to water delivery during the irrigation period, which coincides with summer. Where water is being supplied by perennial rivers or artesian springs, the major problem relies on the increasingly costly and unsustainable water extraction due to a poor distribution network.

The amount of water needed for irrigation is based basically on the rate at which irrigation must be applied in order to control the soil moisture deficit caused by the potential evapotranspiration of the crop. It depends on the crop, the soil type and the irrigation method being used. The determination of the amount of irrigation for cultivated crops is important for the design of the irrigation system.

Irrigation efficiency and water distribution uniformity using different irrigation methods remain important issues for agricultural development. Inefficient water use leads to environmental problems with leaching of agrochemicals and aquifer pollution. There are serious concerns in Lebanon about the inefficiency of water use in agriculture. At the scheme level, overall efficiency from worldwide data is between 23 and 42%. At the farm level, irrigation efficiency is an average 50% with traditional irrigation techniques, such as basins and furrow, but could reach 70%-80% when sprinkler irrigation is used, and can exceed 80% when drip irrigation is used.

Irrigation efficiency is the product of storage efficiency, conveyance system efficiency and farm efficiency. Here we are more concerned with farm efficiency. This includes within-farm distribution efficiency, field application efficiency of the irrigation systems and distribution uniformity. The farm distribution system improvement is a straightforward engineering work of lined canals, adequate gates and controls or appropriate pipes. Efficient farm irrigation implies a sound field experience. Drip system has been known to be the most efficient irrigation technique, with comparison to sprinkler and surface irrigation techniques. With an efficient irrigation system:

A larger area could be irrigated,
Competition between water users can be reduced,
The effect of water shortage can be less,
Fertilizers could be added with irrigation water (fertigation),
Less agrochemicals reach ground water, and
Manpower and energy could be saved.
However, in any irrigation scheme, the three components of the overall irrigation efficiency should be improved, i.e., storage efficiency, conveyance efficiency and on-farm efficiency. These three concepts of irrigation efficiency, most important at the farm level, should be well understood to undertake the necessary measurements accordingly.
Moreover, uniformity of water application is necessary to increase efficiency. This implies controlled water application associated with good land preparation and leveling. Adequate design of head and field ditches with appropriate flow rates also remain essential in surface irrigation. For sprinkler and drip systems, good design, operation and maintenance of performing equipment are key factors to be evaluated.

In Lebanese agriculture, the conditions for an approach to promote water use efficiency are fully realized. There is general agreement that water resources are being presently depleted and that this water use should be on better sustainable basis. Scarce water sources are already being used for high-value crops, considering, for instance, the huge increase in protected cultivation area of vegetables, and water-delivery infrastructure is relatively advanced. Although the project is aimed at relatively advanced agricultural developments, it contains options that could be applied also in quite simple water sharing schemes. In order to ensure the right environment for “economically-sound decisions", it is aimed at high value and strategic crops, such as vegetables, orchards, potato, sugar beet, corn and legumes for both human and animal diets. However, agriculture sector complains of the public sector, poor interest and little care. This phenomenon is not new to the farming community as farming is and has been a very risky business depending on climatic conditions, weather changes and marketing problems. Production is becoming more expensive, and farming life becomes more difficult. This can be attributed to many points; among them:

- *Optimal water use is unknown:* Farmers often do not know the precise water needs of crops. What farmers know, however, is that shortage of water equals yield loss, whereas seldom damage is done by over-irrigation. In practice, irrigation is often related to the availability of water resources, regardless of actual water needs. Hence, water stocks are used inefficiently in time and place. If used carefully, limited-water resources may contribute to yield increase when appropriate irrigation methods, based on water saving approach, such as sprayers and drippers, are used.

- *Inefficient management of water services:* In the case of irrigation, farmers must often deal with the constraints due to the need of sharing water within a network. In Lebanon, however, water for irrigation purposes is mostly used individually, without any participative interest to use water collectively from the part of the agricultural communities. This in reality is due on one hand to lack of collective irrigation networks established by the competent authorities, and on the hand to the absence of Water Users Associations, which practically supervise the irrigation operations. These two factors contributed to the disorganization of the irrigation sector and increased the conflict for water in many parts of the country.

- Technological inadequacy: In Lebanon, differences prevail in the technological levels at both the on-farm water management systems and the water conveyance and distribution systems. Adequate technology is a prerequisite both for high irrigation efficiency and for implementation of volume-related incentives.

The general objectives of using modern irrigation techniques, such as sprinkler and drip systems, instead of using the traditional surface irrigation, are to ensure a water saving policy based upon increasing the economic water use efficiency of the irrigated agriculture. This will be achieved by developing and testing a system to assess real water need and optimal water allocation, in combination with context-specific incentives aimed to improve water use efficiency and reduce waste. A specific scientific and technological innovative plan should be developed based on:

A management tool for farmers to determine their actual water needs and to allocate efficiently scarce resources, under the constraints imposed–and incentives offered–by the water services provider;
A tool for managers of water services to assess water deficit and manage it through constraints and incentives.

Case studies, with socioeconomic contexts, should be implemented in target areas to calibrate the following tools:
i. Comparison of water use efficiency of traditional vs. modern technologies, at on-farm level;
ii. Dealing with low vs. high-value crops and different stake-holders;
iii. Water price coupled to advice in order to increase economic water use efficiency at Water Service level.

4. Case Study: Improving Wate ruse Efficiency of some Cultivated Crops

Field studies aiming at examining the response of maize (*Zea mays* L.), Soybean (*Glycine max* L. Merril), cotton (*Gossypium hirsutum* L.) and sunflower (*Helianthus annuus* L.) to deficit irrigation stress were conducted during the period 1998-2003 at Tal Amara Research Station in the Central Bekaa Valley of Lebanon (ltitude 905 m a.s.l). Tal Amara has a well-defined hot, dry season from May to September and very cold for the remainder of the year. Long-run data indicate an average seasonal rain of 592 mm, with 95% of the rain occurring between November and March. Crops were grown on deep and fairly-drained soil, characterized by high clay content (44%).

Hybrid maize (*cv. Manuel*) was sown on 19 May in 1998 and 25 May in 1999 at 10 plants m^{-2}. Soybean hybrid (*cv*. Asgrow 3803) was sown on 10 May 2000 and 25 April 2001 at a density of 12 plants m^{-2}. Cotton (*cv*. AgriPro AP 7114) was sown on 5 May in 2001 and on 13 May in 2002 at a density of 10 plants m^{-2}. Sunflower (*cv*. Arean) was sown on 20 May 2003 and 10 May 2004 at a density of 10 plants m^{-2}.

For maize, crop evapotranspiration (ET_{crop}) was measured using a set of two drainage lysimeters of 4 m^2 surface area (2m×2m) by subtracting the volume of drainage from the irrigation amount. The lysimeters, 1.2 m deep, 24 m apart, aligned N-S, are situated in the middle of 1-ha field (200 m N-S by 50 m W-E) (Karam et al., 2003). For soybean, ET was measured by a weighing lysimeter of 16 m^2 surface area (4m × 4m) and 1.2 m deep, containing the same clay soil as in the drainage lysimeters. Watering of the lysimeter was made upon a 30% soil depletion of the available water in the 0-100 cm soil layer. The weight loss of the lysimeter due to soil evaporation and plant transpiration was measured with load cells and recorded at a 15-minute interval on a computer located near the lysimeter. For cotton and sunflower, ET_{crop} was estimated using the FAO method (Doorendos and Pruit, 1977) by multiplying reference evapotranspiration ($ET_{rye\text{-}grass}$) by crop coefficients (K_c):

$$ET = ET_{rye\text{-}grass} \times K_c$$

Reference evapotranspiration ($ET_{rye\ grass}$) was measured in a set of two rye-grass drainage lysimeters of 4 m^2 surface area (2m×2m) and 1m depth. The lysimeters are 24 m distant, aligned W-E, and located inside the weather station (40 m×40 m), 50 m apart of the experimental plots. Table 4 below illustrates deficit irrigation treatments for the crops under study.

At physiological maturity, all individual plants in the 1m^2 sampling quadrates were harvested to determine above ground biomass production (B) and yield (Y). For maize, grain number per m^2 and the 1000-grain weight were determined. For soybean and sunflower, seed number per m^2 and the 1000-seed weight were also determined. For cotton, yield was determined by weighting lint at dry basis in the sampling areas.

In maize, soybean and sunflower, water use efficiency at grain or seed-basis ($WUE_{g,s}$) was calculated as the ratio of yield at dry basis to crop evapotranspiration (Y/ET), while water use efficiency at biomass-basis (WUE_b) was calculated as the ratio of biomass at dry basis to ET (B/ET). In cotton, water use efficiency at lint-basis (WUE_l) was calculated as dry lint yield to the amount of water evapotranspired from the crop. WUE was expressed in kg M^{-3} (1 kg M^{-3} = 1 g M^{-2} mm^{-1}).

Tables 4 illustrates irrigation treatments of the different crops, while Table 5 shows values of evapotranspiration (ET), yield (Y), biomass (B) and water use efficiency of the crops under well and deficit irrigation conditions.

Grain-related water use efficiency (WUE_g) of lysimeter grown maize was 1.52 kg M^{-3} in 1998 and 1.34 kg M^{-3} in 1999. However, fully-irrigated maize had a WUE_g of 1.68 kg M^{-3} in 1998 and 1.54 kg M^{-3} in 1999. Higher WUEg values of 1.88 kg M^{-3} and 1.87 kg M^{-3} were obtained in 1998 and 1999, respectively, from the I-60 treatment. On a biomass basis, I-100 treatment had values of water use efficiency (WUE_b) of 3.16 kg M^{-3} and 2.46 kg m^3 in 1998 and 1999, respectively, while the I-60 treatment had values of 3.23 kg M^{-3} and 2.97 kg M^{-3}, respectively. On the lysimeter, these values were 3.0 kg M^{-3} and 2.34 kg M^{-3}, respectively.

Seed-related water use efficiency (WUE_s) of the well-irrigated soybean treatment was 0.47 kg M^{-3}, showing no consistent difference with the lysimeter grown soybean. Apparently in this experiment, WUEy of the deficit-irrigated treatments S1 and S3 were 13% and 4% higher than the control. However, the S2 treatment had a WUEs value 17% lower than the control. For the biomass-basis, water use efficiency (WUE_b) of the control averaged 1.06 kg M^{-3}, whereas WUE_b of treatments S2 and S3 were 6% and 9% higher, respectively. No significant difference was found between treatment S1 and the control.

The highest lint water use efficiency (WUE_l) was encountered for cotton in S1 treatment, and averaged 0.62 kg M^{-3}, followed by S2 (0.50 kg M^{-3}), S3 (0.46 kg M^{-3}) and the control (0.36 kg M^{-3}). These values are very close to those obtained by Gilham et al., (1995). At biomass basis, WUEb varied from 2.07 kg M^{-3} in the control, to 1.97 kg M^{-3} in S1 treatment, to 1.96 kg M^{-3} in S2 and 1.93 kg M^{-3} in S3.

Average seed-related water use efficiency (WUEs) of sunflower fully-irrigated control an average of 0.80 kg M^{-3} while WUEs values of the deficit-irrigation treatments were 0.76, 0.81, and 0.87 kg M-3, in S1, S2 and S3, respectively. At biomass basis, WUEb varied from 3.79 kg M^{-3} in the control, to 3.46 kg M^{-3} in S1 treatment, to 3.70 kg M^{-3} in S2 and 4.07 kg M^{-3} in S3.

5. Conclusions

The results obtained in this experiment showed that deficit irrigation at mature seeds in soybean was more profitable compared to full bloom and seed enlargement. Moreover, flowering was the most critical stage of sunflower to deficit irrigation and therefore deficit irrigation at this stage should be avoided, while it can be acceptable at seed formation. For cotton, timing irrigation deficit at first open boll has been found to provide the highest lint yield with maximum WUE, when compared to deficit irrigation at early boll loading and mid boll loading. For maize, deficit irrigated-treatment produced less seed yield but resulted in higher water use efficiency than the well-irrigated control. Moreover, the relationship between yield and ET is an appropriate framework to investigate the pattern of regulated deficit irrigation. Furthermore, these two variables bring forth the variable water use efficiency, i.e., WUE = YET-1, a concept widely used in agronomic and irrigation research.

There are four facets to the problems of water use efficiency: (i) agronomic; (ii) technological; (iii) economic; and (iv) social. These aspects are integrated in the development and practical field evaluation of two decision support tools: for the farmer to assess their real water need, and for the water services to foresee shortages and deal with them. This can be broadly divided into two main parts: (A) Assessment of water needs both at plot level and at network level, which is general; and (B) Coping with scarcity as efficiently as possible, that is context specific. In the first part (assessment) we will implement existing but not readily available knowledge (crop response to water) and innovative irrigation technologies into decision support systems that can be used under conditions and by operators typical of the semi-arid areas. In the second part (efficient management of water resources) we will determine the “optimal” outcome (the conditions that growers will have to share and to bear) that is constrained by the socioeconomic context.

Table 4. Irrigation Treatments of the Different Crops under Study

Crop	Year	Treatment	Period of irrigation cutout
Maize	1998	I-100	No irrigation restriction during the growing period
	and		Deficit irrigation at 40% of crop evapotranspiration
	1999	I-60	(from 6-leaf stage onwards)
Soybean	2000	C	No irrigation restriction during the growing period
	and	S-1	Deficit irrigation at full bloom
	2001	S-2	Deficit irrigation at seed enlargement
		S-3	Deficit irrigation at mature seeds
Cotton	2001	C	No irrigation restriction during the growing period
	and	S-1	Deficit irrigation at first open boll
	2002	S-2	Deficit irrigation at early boll loading
		S-3	Deficit irrigation at mid boll loading
Sunflower	2003	C	No irrigation restriction during the growing period
	and	S-1	Deficit irrigation at early flowering stage
	2004	S-2	Deficit irrigation at mid flowering stage
		S-3	Deficit irrigation at early seed formation

Table 5. Crop Evapotranspiration, Yield, Biomass and Water Use Efficiency of Different Treatments

Crop	Variety	Year	Treatment	ET (mm)	Yield (t ha^{-1})	Biomass (t ha^{-1})	WUE_y (kg M^{-3})	WUE_b (kg M^{-3})
Maize*	Manuel	1998	Lysimeter	952.0	15.2	28.6	1.60	3.00
			I-100	863.0	14.5	27.3	1.68	3.16
			I-60	575.0	10.8	18.6	1.88	3.23
		1999	Lysimeter	920.0	13.4	21.5	1.46	2.34
			I-100	833.0	12.8	20.5	1.54	2.46
			I-60	556.0	10.4	16.5	1.87	2.97
Soybean**	Asgrow 3803	2000	Lysimeter	800.0	3.38	7.96	1.95	4.61
			C	720.0	2.82	6.88	1.81	4.43
			S-1	596.0	2.50	5.66	1.94	4.40
			S-2	632.0	1.76	6.21	1.29	4.55
			S-3	647.0	2.57	6.64	1.84	4.75
		2001	Lysimeter	725.0	3.65	8.23	2.33	5.26
			C	652.0	3.59	7.65	2.55	5.43
			S-1	541.0	3.65	6.53	3.12	5.59
			S-2	580.0	2.93	7.38	2.34	5.89
			S-3	567.0	3.43	7.50	2.80	6.12
Cotton***	AgriPro AP7114	2001	Lysimeter	-	-	-	-	-
			C	577.4	0.4233	2.47192	0.34	1.98
			S-1	473.9	0.6534	1.90098	0.64	1.86
			S-2	537.6	0.5682	2.11622	0.49	1.82
			S-3	542.6	0.5398	2.16691	0.46	1.85
		2002	Lysimeter	-	-	-	-	-
			C	602.2	0.4906	2.80900	0.35	2.16
			S-1	482.9	0.6239	2.16020	0.61	2.07
			S-2	531.8	0.5856	2.40480	0.50	2.09
			S-3	569.6	0.5535	2.46240	0.44	2.00
Sunflower****	Arena	2003	Lysimeter	-	-	-	-	-
			C	688.0	5.46	19.2	0.79	3.39
			S-1	534.0	3.95	16.6	0.74	3.16
			S-2	579.0	4.63	17.6	0.80	3.34
			S-3	629.0	5.59	19.6	0.89	3.68
	Arena	2004	Lysimeter	-	-	-	-	-
			C	769.1	5.26	20.5	0.68	4.18
			S-1	598.0	4.06	16.4	0.68	3.76
			S-2	647.0	4.65	18.2	0.72	4.05
			S-3	700.0	5.41	20.6	0.77	4.46

*Karam et al. (2003)
**Karam et al. (2005)
***Karam et al. (2006)
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REDUCING AGRICULTRUAL WATER DEMAND IN LIBYA THROUGH IMPROVING WATER USE EFFICINECY AND CROP WATER PRODUCTIVITY

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1. Introduction

Similar to most countries of West Asia and North Africa (WANA), Libya has always been in a delicate balance between the limited available water resources and the basic human needs of a subsistence way of life. During the last few decades, however, the introduction of modern ways of resource utilization developed in the highly industrialized western humid zones has shifted the balance towards water resources exploitation at levels far exceeding their rates of renewal. The situation has been exacerbated by unchecked population growth demanding more food and a better standard of living under conditions of scarcity, poor resource management and low production efficiency. To meet these demands, agriculture has been dramatically changing from its traditional rainfed practices into an extensively expanded large scale irrigation and intensively exploited water resources base. The available renewable water resources are insufficient to meet the present rate of expansion on sustainable basis. The deficit between renewal and utilization has been presently satisfied through overdraft and mining of groundwater aquifers and increasing dependence on poor quality water supplies. The result is lower piezometric levels, seawater intrusions, soil salinization and more salt accumulation and pollution of production environments. When the other rising water demands of urbanization and industrialization that compete with irrigated agriculture are considered, the present situation is highly unsustainable and calls for serious interventions and reconsideration of the presently established growth and development models, especially those related to irrigated agriculture that represents more than 80% of the total national water consumption. This report is intended to clarify some aspects of irrigation water management that are potentially promising to get more agricultural production with less water use through increasing water use efficiency and improving crop water productivity.

2. Water Resources Situation in Libya

The Libyan population increased from less than one million in 1955 to 6 million in 2005 and it is expected to reach more than 12 million by 2025 (NASID, 2006). As indicated in Table 1, the total available fresh water supplies on sustainable basis has been estimated at the fixed rate of 2279.5 million m^3 / year (GWA, 2000). According to these figures the national annual average per capita water availability decreased from 2280 m^3 in 1955 to 380 m^3 in 2005 and is expected to reach 190 m^3 by the year 2025. Thus, the whole country is already experiencing water scarcity that is getting more severe with time.

Table 1. Sustainable Water Supplies from all Available Sources in Major Basins of Libya in million m^3 per year (MCM/Y)

Water Basin	Groundwater Resources	Surface Water Resources	Unconventional Water Resources	Total
Jefara Plain	200	52	27.5	279.5
Jabal Alakhdar	200	92	45.5	337.5
Alhamada Alhamra	230	48	50.5	328.5
Kufra and Sarir	563	-	-	563
Murzuk	771	-	-	771
Total	1964	192	123.5	2279.5

Source: General Water Authority (2000).

Table 2. Historical Development and Future Predictions of Water Use by all Sectors in Libya (MCM/Y)

Water Use	Year				
	1984	1995	2000	2010	2020
Agricultural	1978	3080	3860	4525	5790
Industrial	90	145	176	261	386
Municipal	247	364	457	708	1060
Total	2315	3589	4493	5794	7236

Source: General Water Authority (2000).

These national averages, however, mask the spatial and temporal variability of the severity of water scarcity within each water basin. Even within the same basin, water availability varies widely from one location to another. This fact implies that any meaningful irrigation water management strategies should be based on the full understanding of the hydro-climatic components and their interrelationships with agricultural crops at the separate water basin levels.

The significant share of irrigated agriculture in the overall national water budget is reflected in Table 2. It indicates the historical development and expected future predictions of water demand by the different socioeconomic sectors of the country. Water deficits have been experienced since the mid 1980's and are increasing exponentially unabated. This situation urged the national authorities to search for effective measures to bridge this widening gab through the development of new water resources to augment the presently available water supplies in addition to the selection and implementation of specific technical and institutional arrangements related to water demand management.

The first approach is reflected in the huge water transfer and redistribution system usually known as the Great Man-made River Project (GMR) that has been planned and designed to be implemented through five consecutive phases (Alghariani,1997). After its completion, the Project will transfer and redistribute a total of more than 2000 million m^3 per year of water through probably the largest and most complicated man-made water distribution network of its kind in the dry areas of North Africa and the Middle East.

Although this huge project will provide significant augmentation of the national water budget; it is considered only a partial solution to the water deficit problems of the country as clearly indicated in Table 3 below. Other large scale non-conventional water resources development such as seawater desalination and wastewater treatment and reuse are contemplated at the present time.

Table 3. Past, Present and Expected Future Water Balance at the National Level with the Great Man-Made River Project (MCM/Y)

Year	Water Demand	Water Supply		Balance
		Without GMR	With GMR	
1995	3589	2279.5	1524.5-	2360.5
2000	4493	2279.5	581.0-	3912.5
2010	5794	2279.5	1288.0-	4506.0
2020	7236	2279.5	2730.0-	4506.0
2025	8022	2279.5	3516-	4506.0

Source: General Water Authority (2000).

The second approach of implementing measures of demand water management seems to be immediately needed at the present time. One of the most apparent aspects of water management related to this approach is reducing agricultural water demand and producing more crops with less water through improving water use efficiency and increasing crop water productivity that are discussed in the following sections of this report.

3. Water Use Efficiency and Water Productivity

The term "Water Use Efficiency" as a widely used concept in irrigation management is highly controvertial and can be clarified only according to one's perspective and purpose within the context of several interrelated factors. When generally defined as the total benefits (material goods, services, crop yields or financial returns) produced by each unit volume of water diverted or consumed, it can be directly linked to water productivity, demand water management, opportunity cost of water uses, comparative production advantages of agricultural crops and other macro-economic manipulations.

Water Use Efficiency (WUE) is used and defined in this report as the ratio of volumetric crop transpiration (m^3) to the volume of total water supply diverted to irrigate the crop (m^3). Since it is impossible to separate crop transpiration and measure it directly under field conditions; the numerator of the ratio is replaced by volumetric crop evapo-transpiration (ET) which can be easily measured by several available methods.

Water Productivity (WP), however, is defined as the ratio of economic yield of a crop in kilograms (kg) to total water supply diverted to irrigate the crop (m^3).

These two concepts as defined here are selected because they are easier to calculate under field conditions and reflect the total water losses for water use from both the engineering and agronomic perspectives. Thus, they provide a wider spectrum for manipulations and interventions towards real savings in irrigation water supplies.

4. Country Review of Water Use Efficiency and Water Productivity

During the preparation of this report, extensive available data related to crop water uses and crop yields throughout the country had been reviewed and assessed. Twelve major crops were selected on the basis of data accuracy, coherence and reliability. They represent several horticultural and field crops grown under two hydroclimatic zones in the country. The first zone is along the coastal strip of the Southern Mediterranean, characterized by its relatively milder climate; while the second one is deeper into the Sahara desert in the Fezzan region, known for its extreme hydroclimatic aridity.

Both WUE and Water Productivity (WP) are calculated for these crops on the same basis as defined in the previous section of this report. The final results are presented in Table 4. It is important to mention that all irrigation water supplies to the selected crops are derived from pumped groundwater wells and diverted to closed pressurized conduit distribution networks to be applied by sprinkler irrigation systems. Only in the limited cases of olive trees and grapes, localized irrigated systems are used. The volumes of water diverted for irrigation and used to calculate the values of both WUE and WP that are presented in Table 4. The figures are based on measured and estimated crop evapotranspiration according to the prevailing hydrometeorological conditions in both locations. Water is supplied to the crop with an overall irrigation efficiencies of 75% along the coastal strip and 70% deep in the Sahara desert. A leaching fraction of 5-15% of irrigation water has been included to control soil salinity and ensure sustainability of irrigated areas under the harsh climate of severe aridity and the relatively high salt content of the groundwater resources used for irrigation.

Effective rainfall is considered a significant part of the total water supply to the winter crops grown in the coastal strip zone. It is interesting to note the relatively high values of WUE for most crops in both locations especially where localized irrigation systems are used. This is mainly due to the fact that in the absence of any significant surface water supplies, all irrigated agriculture depends on groundwater resources. The relatively low discharge rates from irrigation wells and high infiltration rates of the agricultural soils that are mostly sandy eliminated all surface irrigation systems and replaced them by pressurized conveyance networks and highly efficient sprinkler and localized irrigation systems.

When considering the WP values in Table 4, it is interesting to note the large variation between the two hydroclimatic locations among the different crops in the same location. This fact offers the opportunity for significant improvements at the crop level and at the local and national levels of water management as discussed in the following sections of this report.

5. Prospects for Improvement of Water Use Efficiency

As mentioned in the previous section the calculated values of WUE in Table 4 are relatively reasonable compared with corresponding values reported elsewhere in WANA Region and other parts of the world.

Table 4. Values of Water Use Efficiency (WUE) and Water Productivity (WP) in kg/m^{3}for Selected Major Crops Grown at Different Agroclimatic Zones

Major Crops	Along the Coastal Strip		Deep Sahara Desert W	
	WUE	**WP(kg/m^3)**	**WUE**	**WP (kg/m^3)**
Wheat	0.72	0.66	0.66	0.29
Barley	0.74	0.96	0.67	0.42
Alfalfa	0.67	1.03	0.63	0.53
Oats	0.75	1.45	0.69	0.67
Sorghum	0.61	0.97	0.61	0.38
Citrus	0.64	1.56	0.61	0.74
Grapes "Sprinkler"	0.63	1.73	0.61	0.72
Grapes "Localized"	0.87	3.02	0.86	1.28
Potato	0.67	4.73	0.62	2.10
Onions "Winter"	0.67	7.10	0.58	2.53
Onions" Summer"	0.59	4.03	0.58	1.68
Tomato "Spring"	0.65	3.54	0.63	2.16
Tomato "Summer"	0.64	3.11	0.64	2.08
Watermelon	0.64	2.87	0.63	1.28
Olives "Sprinkler"	0.68	0.49	0.63	0.16
Olives "Localized"	0.87	0.80	0.86	0.28

Source: Calculated by the author.

Increasing the WUE within any uniform hydroclimatic zone can be achieved only through increasing irrigation efficiency which is already close to 75%. The only potentially available option to realize any further increases above this value is to shift from sprinkler to localized irrigation systems (drip, bubbler, etc.).

It is important, however, to realize that any significant increases is WUE through further improvements of irrigation efficiency will depend on the hydrological conditions of the water basins in which these improvements are sought after.

If the presently practiced irrigation efficiency reflects significant water losses that are considered water outflows of acceptable quality out of any given water basin, then any local improvement of irrigation efficiency within that basin will tend to increase WUE at the basin level. But if the wasted outflows are recaptured and reused for irrigation or any other beneficial water use within the same basin as it is most likely to happen in Libya, then any local improvements in irrigation efficiency and WUE are only apparent gains while the overall basin WUE remains the same. In this case improvements at the agricultural field level can only be achieved at the expense of water shortage in other locations within the same water basin.

Irrigation efficiency and WUE as defined in this report should be optimized within the constraints of achieving the maximum potential yields of crop plants and maintaining the minimum water basin outflows that are required by the environmentally acceptable salt balance for sustainable irrigated agriculture. Precautionary measures should be taken against deficit irrigation and the urgent calls recently made for the introduction and expansion of supplementary irrigation with its correlates of crop water deficiencies and soil salinization.

6. Improving Water Productivity

Because evapotranspiration (ET) represents a more or less fixed proportion of the total water supply diverted for irrigation under similar irrigation efficiencies and leaching requirements; WUE is not significantly influenced by changes in the hydroclimatic conditions of different locations as indicated in Table 4 . But unlike WUE, water productivity (WP) of the same crops grown in different geographical locations varies widely depending on the prevailing hydroclimatic conditions in each location. As presented in Table 4, the WP of most crops grown in the deep Sahara desert of the southern regions of the country is much less than 50% of the WP of the same crops grown in the northern regions along the coastal strip. This is due to the fact that while evapotranspiration is highly sensitive to changes in the weather elements associated with the given hydroclimatic zones, the economic yields of the same crops are almost the same under similar agricultural and agronomic practices in both locations. This fact alone proves that the concept of WP as defined here offers a wider scope than WUE for manipulations and interventions leading towards improved water management.

Large water savings could be achieved by moving crop production from the southern regions that are characterized by high ET rates to the coastal strip regions of much lower ET values. Also in regions of water scarcity, like most water basins in Libya, large water savings can be achieved by substituting crops grown in the hot seasons by crops grown in the cooler seasons, or growing the same crop in the cooler season of the year instead of the hot season as in the case of onions and tomato in Table 4 . The concept of WP can be used as a planning tool for water allocation among competing crops under the limited water supplies of the country. When WP is expressed in terms of economic returns per unit volume of water consumed, it can be used for crop selection according to the principles of comparative economic advantages and the opportunity cost of water in addition to helping water managers in setting the most appropriate and effective irrigation water pricing policies. Table 5 presents the economic returns on irrigation water use for some selected crops grown in the Libyan hydroclimatic zones discussed in this report.

Table 6 Principles, strategies, options and practices for enhancing crop water productivity at different scales. After: Kijne et al (2002)

Strategies	Options and Practices		
	Plant level	*Field level*	*Agro-ecological level*
Principle 1: Enhancing marketable yield of the crops for each unit of crop transpiration			
Increasing yield or value of the product	• Increasing harvest index (short stature: Sd1, Rht) • Increasing photosynthesis (e.g., C photosynthesis; PEPC, PPDK, ME) • Increasing sink strength (cell wall invertase)	• Crop and resources management for enhancing yield • Synchronizing water application with crop water demand • Changing to higher value crops	• Improving water management to synchronize system water supply and field-level water demand • Reallocating water from lower-value to higher-value uses • Spatial analyses for maximum production and minimum transpiration
Reducing transpiration	• Reducing non-stomatal transpiration, e.g., waxy cuticle • Reducing stomatal transpiration • Shortening crop duration	• Crop scheduling to match season with low evaporative demand • Deficit irrigation	
Principle 2: Reducing non-beneficial atmospheric depletions and the outflows from the domain of interest			
Reducing evaporation from soil and water	• Early shading • Seedling vigor	• Crop scheduling to reduce evaporation during fallow period • Plant spacing and row orientation • Tillage and soil management (e.g., minimum tillage, mulching) to reduce evaporation • Irrigation techniques (e.g., drip, subsurface irrigation) • Saturated culture with rice on bed	• Land use planning over the whole domain of interest to reduce evaporation from fallow land, decrease free water surfacing...
Reducing transpiration from weeds	• Increasing weed competitiveness • Seedling vigor	• Weed management	• Land use planning to reduce weeds and other non-beneficial vegetations
Reducing percolation	• Deep roots • Aerobic rice	• Leveling and precision irrigation • Water-saving irrigation in rice	• Reducing percolation and runoff into sinks • Water reuse
Reducing runoff		• Water harvesting • Tillage to increase infiltration	
Principle 3: Enhancing the effective-use of rainfall, water with marginal quality and water stored in the domain of interest			
Effective use of rainfall	• Drought escape • Drought tolerance • Submergence tolerance	• Risk management in rain-fed agriculture • Synchronizing crop demand and rainfall • Nutrient management to reduce drought effects • Drainage	• Irrigation scheduling to account for rainfall variability • Utilization of medium and long-term weather forecasts for reducing risk • Water table control, flood control
Effective use of water storage	• Deep rooting for drought avoidance	• Water harvesting and supplementary irrigation	• Conjunctive use of surface water and groundwater • Increasing water storage within the domain to capture runoff
Effective use of water with marginal water quality	• Salinity stress tolerance	• Mixing marginal water with water of good quality • Crop management to reduce salinity effects	• Land management to reduce salinization hazard

Table 5. Economic Returns on Water Use for some Selected Crops Grown at Different Hydroclimatic Zones in Libya

Crop	Along the Coastal Strip		Deep Sahara Desert	
	WP kg/m^3	Economic return US Dollars/m^3	WP kg/m^3	Economic Return US Dollars/m^3
Wheat	0.66	0.11	0.29	0.06
Barley	0.96	0.08	0.48	0.04
Oats	1.45	0.15	0.67	0.09
Alfalfa	1.03	0.09	0.54	0.06
Citrus	1.56	0.64	0.70	0.30
Potato	4.73	1.04	2.10	0.46
Watermelon	2.87	0.98	1.28	0.74
Winter onion	7.10	1.38	2.53	0.65
Spring tomato	3.54	1.92	2.16	1.17

Source : Calculated by the author.

7. Policies Related to Improving Water Use Efficiency and Water Productivity

The expected future national water balance as presented in Table 3 necessitates the formulation and implementation of drastic water management policies and strategies that reduce the unbridgeable increasing water deficits. The present concerns of water management are mostly related to allocation problems of the limited available water supplies among the different sectors of water use. The economic and sociopolitical challenges are enormous but not insurmountable. The opportunity cost of water in the competing sectors for water use should be one of the guiding criteria for water allocation. Irrigation water subsidies must be limited to the minimum equity requirements for the poor and unprivileged farmers. Water pricing and water rights systems should change the present conception of water resources from water as a free common pool resource to water as an economic commodity in the market place.

Irrigated agriculture will certainly be a loser under these institutional arrangements. But irrigation does not have to be necessarily expanded or even maintained at its present level as long as the water supplies, reallocated from the agricultural sector to the other sectors, produce economic activities for the population and sufficient financial returns for food importation from the international markets. Agriculture may be restricted to crops of relatively high and competitive comparative production advantages at the national, regional and global levels. If this approach is adopted, then the selected crops with the highest economic comparative advantages should achieve their maximum genetically determined potential yields with the least amount of water used. To realize these objectives, several agronomic and water management interventions as presented in Table 6 should be implemented (Kijne (2002).

Implementation of the above policies and strategies requires the establishment of an effective and efficient institutional arrangements which are presently lacking at both the public and private levels. There is an urgent need to establish these institutions as soon as possible.

8. Conclusions and Recommendations

Based on the available information about the potentially available water resources and the calculated WUE and WP presented in this report it is recommended that:

i. In view of the relatively reasonable values of WUE, the only available option for improvement of this water management parameter is through increasing irrigation efficiency by replacing sprinkler irrigation with localized irrigation systems.
ii. In contrast to WUE, the depressingly low values of WP offer a wider range for improvement such as concentrating most irrigated areas in the northern regions' This calls for substituting crops grown in the hot season by crops grown in the cooler season and introducing agronomic and water management policies and strategies that maximize crop yields and minimize water supplies diverted for irrigation through an efficient agricultural extension service and effective irrigation water pricing system, respectively.
iii. The concepts of WUE, WP and economic returns per unit volume of water consumed by irrigated crops should be used as a guiding criteria to reduce, or prevent altogether, the production of crops with lower values of WP and economic returns such as cereal and forage crops and reallocating their irrigation water requirements either to irrigate more water efficient crops or to other beneficial uses.
iv. The widening gap of water deficits in national water resources budget must be bridged either through the reduction of irrigated areas and more dependence on virtual water in the form of imported agricultural products or by transboundary water importation and large scale water desalination and reuse schemes.
v. There is an urgent need to establish both public and private institutional arrangements that enable decision makers and water users to implement the above suggestions and recommendations through a realistic and relevant action programmes that involve all stakeholders including planners, water specialists and direct beneficiaries.

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WATER USE EFFICIENCY IN MOROCCO

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Summary

Water is a necessity for human existence, therefore, the lack of access to water resources is a sign of poverty. Today, with growing population and high living standards, water demands are increasing continuously.

Like most of developing countries, Morocco uses most of its developed water resources in agricultural production. Because irrigation water contributes to many productive and livelihood activities, Morocco has promoted irrigation to achieve rural and agricultural development, food security and drought mitigation. The benefits of irrigation are realized through raising production yields and lowering the risk of crop failure.

During the last two decades, however, Morocco has been hit by several years of drought and consequently it suffered from severe water scarcity. Many research and development projects dealing with water use efficiency in agriculture were implemented in Large Scale Irrigation (LSI) and Small and Medium Scale Irrigation (SMSI) perimeters. New techniques were developed aiming at utilizing efficiently the limited water resources available.

Regulations and laws are continuously reviewed to better serve a sustainable use of water. In addition, water allocation to different sectors is continuously revised and new reforms and mechanisms are developed. However, the role of the state is still in the governing issues such as water mobilization, distribution, pricing and water allocation.

This paper begins by briefly presenting water resources in Morocco, then describes water management techniques and gives examples of water use efficiency of major crops, and later presents the institutional and policy framework, and finally proposes some suggestions for a better use of irrigation water.

1. Introduction

The total area of Morocco is 71 million ha; out of which only around 12% (8.7 million ha) is considered as arable land. The rest consists of bare and non productive land (44%), pasture (30%), forest (8%) and native alfalfa (5%). About 83% of this land is rainfed and 17% is irrigated (Benyassine and Laklalech, 2006).

The agriculture sector plays an important role in Moroccan economy. In fact, there is a high positive correlation between the gross domestic product (GDP) and the agricultural gross domestic product (AGDP). During the last decade, the added value represented 15 to

20% of the GDP. Moreover, agricultural products exports represent, in average, 18% of the total exports of the country.

Irrigated agriculture contributes 45% to the added agricultural value, ensures more than one-third of employment in the rural areas and accounts for 75% of agricultural exports. The contribution to the added value can reach 70% during dry years.

2. Physical Environment

The climate in Morocco is a Mediterranean type that is subjected to the oceanic, mountainous and Saharan influences. It is characterized by two distinct seasons; summer which is hot and dry and winter that is relatively wet and cold but short and variable from region to region. Morocco's climate is also marked by high annual and inter-annual fluctuations.

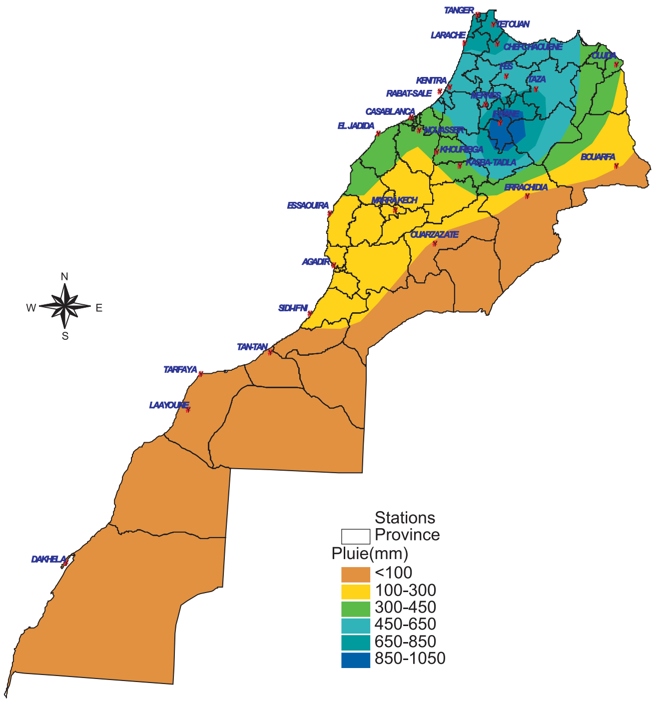
Precipitation, in Morocco, is an erratic and extremely discontinuous phenomenon. During last two decades, rainfall deficit has become more frequent. The frequency of drought was, in average, 1 in 5 years before 1990 and increased to 1 in 2 years during the last decade. These climatic constraints have affected crop production and water resources availability. Although water deficit can occur at any time during the growing season of crops, two types of droughts are generally observed. The early drought that occurs usually in November and December and affects stand establishment of fall grown crops; while the late drought occurring during spring and early summer is more frequent and has a negative effect on grain set and filling of annual crops (Karrou, et.al. 2006).

In general, precipitation decreases from north to south and from west to east (figure 1). In the northern part of the country, it can reach more than 1000 mm per year. However, in the Saharan regions they are lower than 100 mm. Temporal variations of these precipitations are described by Figure 2.

3. Water Resources Availability and Allocation

Water demand of the agricultural activities in Morocco is very important. It was estimated to be about 90% of the global water demand. Drinking water and industrial activities demand represent only 10%. However, the percentage of water that is allocated to agriculture will drop in the future and that of the domestic use and industry will increase as a result of growing population.

Water resources availability depends on the amount of rainfall and its distribution. The spatial variation of rainfall is so high that 50% of precipitation falls on only 15% of the arable land of the country, and the wet season is generally from November through April.



Mean Annual Rainfall in Morocco
Source: H.Benaouda, Agroclimatology and GIS Laboratory, INRA Settat

Figure 1. Spatial Variation in the Average Annual Rainfall in Morocco

Graph. 1 Average monthly rainfall since 1959/60

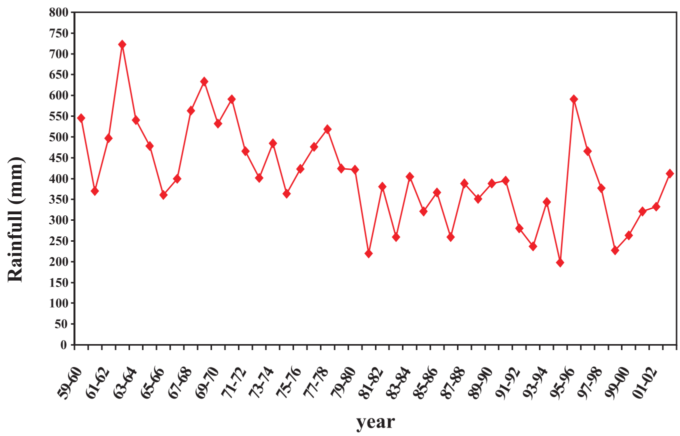


Figure 1. Spatial Variation in the Average Annual Rainfall in Morocco

4. Water Resources

The average annual water precipitation in the country is estimated at about 150 billions m^3 (BCM). Around 80% (120 BCM) of this water goes back to the atmosphere through evaporation and transpiration processes. Only 30 BCM are stored in dams or infiltrated underground, and consequently are considered as potential water resource. However, the potential useful surface water resources represent 16 BCM, of which more than half is already used. Potential groundwater resources sums to 5 BCM, of which 3.7 BCM are already used, as shown in Figure 3 (Jellali , 2002).

4.1. Irrigation Water

- Public
  - Potential: 1 364 000 ha
    - **Large scale irrigation (LSI): 880 000 ha**
    - Small and Medium Scale Irrigation (SMSI): 484 000 ha
  - · Effective: 1 016 700 ha
    - **LSI: 682 600 ha**
    - **SMSI: 334 100 ha**
- Private, effective: 441 430 ha
- Seasonal (swellings): 300 000 ha

Total effective: 1 700 000 ~ (18 % ~ of total agricultural area)

4.2. Infrastructure

The introduction of modern infrastructure started in 1920 by the construction of the early large dams. The objective was mainly directed towards supplying drinking water, developing irrigation water and generating electricity. Until 1966, the policy of water mobilization remained rather timid since only 16 dams of a total capacity of 2.2 BCM were built in 38 years (Ben Abderrazik, 2002).

In 1967, when His Majesty King Hassan II laid down the objective of irrigation for a million ha, a new decisive impulse was given to the policy of construction of dams. A particular interest was granted to the mobilization of water resources in the arid regions south of the Atlas Mountains in order to ensure their socioeconomic development (Jellali, 2002).

4.3. Dams

As a result of the policy of dam construction, today, Morocco has more than 100 dams with a storage capacity exceeding 16 BCM. These facilities allow the use of an average volume of surface water of about 6.5 BCM. Principal dams are presented in Table 1.

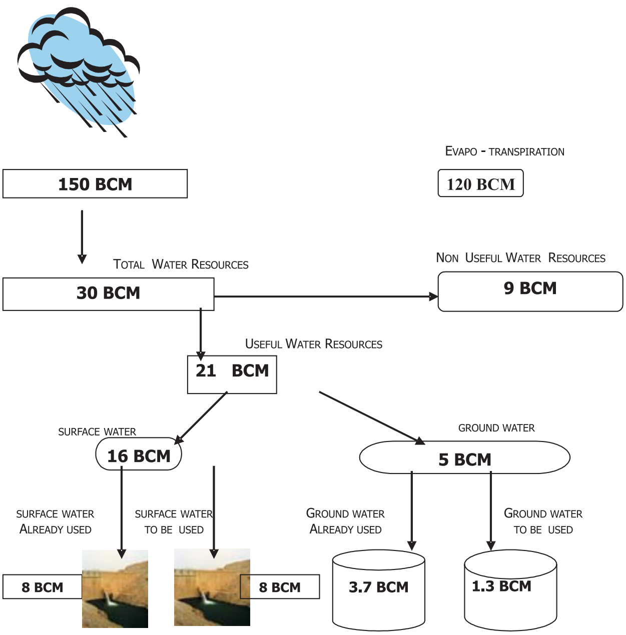


Figure 3. Water Resources in Morocco (Source: Jellali, 2002)

Table 1. Principal Dams in Morocco

Dam	Basins	Nearest city	Date of operation	Capacity (Mm^3)
El Kansera	Sebou	Sidi slimane	1935	266,0
Bine El Ouidane	Oum Er Rbia	Azilal	1953	1384,0
Mohamed V	Moulouya	Berkane	1967	410,0
Moulay Youssef	Oum Er Rbia	Demnate	1969	175,0
Hassan Addakhil	Atlas south	Errachidia	1971	347,0
Youssef Ben Tachfine	Souss-massa	Tiznit	1972	303,5
Mansour Eddahbi	Atlas south	Ouarzazate	1972	529,0
Idriss 1st.	Sebou	Fes	1973	1186,0
Sidi Mohamed Ben Abdallah	Bou regreg	Rabat	1974	486,0
Wadi el Makhazine	Northern morocco	Ksar kebir	1979	773,0
Al Massira	Oum Er Rbia	Settat	1979	2760,0
Abdelmoumen	Souss-massa	Agadir	1981	216,0
Hassan 1st.	Oum Er Rbia	Azilal	1986	262,5
Aoulouz	Souss-massa	Aoulouz	1991	110,0
09-avr-47	Northern Morocco	Tangier	1995	300,0
Saquia El Hamra	Atlas south	Laayoune	1995	110,0
Al Wahda	Sebou	Ouazzane	1997	3800,0
Sidi Chahed	Sebou	Meknes	1997	170,0
Asfalou	Sebou	Taounate	2000	317,0
Ahmed El Hansali	Oum Er Rbia	Zaouiyat Echeikh	2001	740,0
Moulay Abdallah	Souss-massa	Agadir	2002	110,0

4.4. Ground Water

Underground water resources are relatively known in Morocco due to their contribution to irrigation and drinking water. A lot of effort was made to explore and exploit subsoil water. As a result, about 45 000 m are realized per year in well drillings. These realizations allows the country to have a volume of almost 2.7 BCM annually. Figure 4 shows the geographical repartition of underground water.

Basin Transfer
Water transfer has been considered to develop irrigation projects in arid and semi arid zones and to supply drinking water for urban towns. Significant efforts were made to balance the distribution of water between the basins having a surplus of water resources and those which are in need of water to satisfy their demand [4]. Thus, water transfer projects are a continuous activity in Morocco. Currently, these projects allow the transfer of a total flow of about 175 m^3 / s and using a total canal of 875 km length. An annual volume of about 2.185 million m^3 of water is transferred and is used primarily for irrigation (Table 2).

Table 2. Principal Water Transfer Projects

Project	Basin	Volume Mm^3	Débitance m^3/s	Length (km)
High Sebou-Inaouene towards				
- Casablanca	High Sebou	550	38	15
- Fouarat	Sebou	20	1	140
- S. Said Maachou	Oum Errbia	50	2	80
- Daourat	Oum Errbia	70	3	84
- Bou Regreg	Bou Regreg	240	6	82*2
El Abid towards Tessaout downstream	Oum Errbia	235	11	90
Oum er Rbia towards Doukkala	Oum Errbia	550	42	120
Lakhdar towards				
- Central Haouz	Oum Errbia	300	20	120
- Ziz	Rheris	15	15	17
			20	10
Moulouya towards the area of Nador	Moulouya	155	17	45
Total		**2185**	**75**	**875**

3.5. Water Application Techniques

Surface irrigation is the main irrigation technique covering 83% of the irrigated area, sprinkler systems cover 10% and drip irrigation systems used mainly in tree orchards cover only 7% of the irrigated area. In surface irrigation schemes, basin irrigation is the prevailing technique and is used mainly to irrigate annual crops. Irrigation field efficiency associated with basin irrigation is reported to be around 50%.

3.5.1 Principal problems associated with irrigation management

i. Alarming reduction of surface and groundwater resources due to drought and overexploitation of groundwater;
ii. Salinization of soils and groundwater;
iii. Loss of agricultural land due to encroachment of urban and rural settlements;
iv. Dominance of traditional techniques of irrigation with low field efficiency. Small basin irrigation is practiced on most LSI schemes;
v. Water supply shortage led to strict water quotas which are conditioned by growing a prescribed area of some strategic crops (example of sugar beet).

3.5.2 Irrigation techniques that improve water use

(Figure 5) introduced within the framework of projects are not. There was a lack of adoption by farmers of the new improivement techniques and that was due to the following reasons, analyzed in Table 3 below:
• Land Structure dominated by small farms affected by the joint possession;
• Difficult access to financial credit;
• Introduced techniques considered to be expensive;
• Lack of training and information about the introduced new techniques.

Table 3. New Irrigation Techniques to Improve Water Use

Traditional Robta	**Graded Border System**
Duration of watering: 12 to 15 h/ha: 4 to 7 h/ha more than what is granted within the framework of water quota with a flow of 30 l/s	Duration of a watering: 9 h/ha with a flow of 30 l/s
Dimensions: 40 m^2; 250 squares/ha, multitude of banked-up bed, soil loss and difficulty of mechanization	Dimensions: 80 to 120 m length and variable width - Uniform Slope of 1 ‰, application of water by tubular siphons
Improved Graded Border System	**Level Basin System**
Reduction of infiltration losses by 15 % and better control of injected flow	Time of watering: 8 h/ha for a flow of 30 l/s; null slope achieved by laser leveling
Devices tested: concrete pavement, plastic film, géomembrane films associated with the tubular siphons	The Level basin system allows uniform applications of water by immersion, and a homogeneous plant emergence and growth
Sprinkler Systems: pivot and lateral move	**Trickle Systems**
Sprinkler systems are practiced in the dryland zones and near the irrigated perimeter	Trickle systems allow: - To save up to 50% of water, - To control fertilizer applications - To improve crop yields and quality

4. Agricultural Production

Moroccan experience in irrigated agriculture development is the result of increasing water shortage due to drought and high demand on water resources. However, technological progress made during the last decades allowed a good contribution of the national agricultural production to meet the basic food products need. In fact, this contribution is about 72% for cereals, 52% for sugar, 25% for oil, 87% for milk and 100% for meat, vegetables and fruits. In terms of trade exchange, agricultural products exports represent, on an average, 18% of the total exports of the country. Yields and agronomic efficiency of the principal crops are presented in Tables 4 and 5.

Table 4. Average Yield of the Principal Crops in the LSI Perimeters

Crop	Avg. Yield (1993-1997)	Avg. Yield (1997-2001)
Cereals	3.4 (2.5 to 4.4)	3.4 (1.7 to 4.6)
Sugar Beet	50 (36 to 63)	51.5 (35 to 59)
Sugarcane	67 (50 to 70)	78 (72 to 98)
Alfalfa	60 (40 to 66)	50.3 (30 to 69)
Legumes:		
Early harvest	52 (48 to 62)	54.3 (45 to 56)
Season	20 (12 to 21)	22 (14 to 32)
Citrus fruits	19 (14 to 21)	20.6 (18 to 24)
Olives	2.3 (1.5 to 3)	2.1 (0.7 to 4.6)
Dates	3.2 (2.3 to 3.6)	2.3 (1.6 to 2.9)

Table 5. Agronomic Efficiency of the Principal Crops

Crop	Efficiency
Cereal	1.31 kg/m^3 (grain)
Sugar Beet	9.36 kg/m^3 (root)
	1.65 kg/m^3 (sugar)
	9.05 kg/m^3 (stem)
Alfalfa	10.4 kg/m^3 (green matter)
Truck farming:	
Early product	7.24 kg/m^3 (green matter)
Season	2.93 kg/m^3 (green matter)
Rice	0.75 kg/m^3 (grain)
Sunflower	0.82 kg/m^3 (grain)
Citrus fruits	3.6 kg/m^3 (fruits)

5. Agricultural Research

There is a long history of irrigation research in Morocco involving national institutes (Hassan II Institute for Agriculture and Vetinerary, IAV,; National Institute of Agricultural Research,INRA and National School of Agriculture,ENA) and international organizations. Research on irrigation includes:

• Border irrigation and improved traditional small basins;
• Field irrigation efficiency and salinization;
• Sprinkler system evaluation; and,
• Drip irrigation research trials on fruit trees and legumes.

6. The Institutional and Political Framework of Water Use

6.1. Institutional Frame before the 1990's

Since 1960, the Office National de l'Irrigation (ONI) was in charge of all matters pertaining to irrigation. In 1965, the Office de Mise en Valeur Agricole (OMVA) was created and was in charge of irrigation and land developpement. In 1966, OMVA split into 5 ORMVAs (Office Regional de Mise en Valeur Agricole), which will become 7 and then 9. The ORMVAs are in charge of LSI, while DPAs (Direction Provinciale d'Agriculture) are in charge of SMSI and private irrigation. However, the most important feature of the era is the Agricultural Investments Code (CIA).

6.2. The Agricultural Investments Code (CIA)

The CIA states the responsibilities of the State and farmers, respectively:

- The State is responsible for fully equipping the perimeters of LSI, down to farmers' parcels, and for bearing most of the cost;
- Farmers have to contribute up to 40 % of the cost of land improvement, to pay a water fee and, most important, to farm and use water in prescribed ways. The State helps them through cropping contracts, guaranteed prices and a variety of subsidies to intensify farming and to organize in cooperatives.

The CIA also introduces an agrarian reform and a land reform: part of previous colonial land is redistributed to small farmers, and collective land falling within LSI perimeters is privatized. A minimum holding size is imposed (5 ha).
Although the CIA system allowed an impressive progress in terms of agricultural productivity, it was doomed to fall down because of:

- Internal reasons, such as:
    - Lack of discipline of farmers both in large and small farms
    - Heavy cost of the system (ORMVAs: 10 000 employees; prohibitive cost of operation and maintenance; etc.)
- External reasons, like :
    - Disengagement of the State
    - Pressing calls for liberalization
    - Recurrent drought waves

As a result, by the early 1990's, mandatory cropping systems were abandoned, farmers were free to farm and use water more scarce than ever, in the way they wanted and a new arrangement for the management of the irrigation system between the State and farmers was sought.

6.3. The New Arrangements

6.3.1 The Law 10-95 (the law started in 1995)

This law now governs the use of all water all over the country. It reiterates that all water in Morocco is a public domain, except for certain sources of water on which certain traditional communities have long-established rights of use. Even for those communities, the Law stipulates certain limitations, such as the obligation to use water for agricultural purposes only.

The Law also establishes structures in charge of the concerted management of water. At the national level, the head of these structures is the High Council for Water and Climate (HCWC), which ratifies the National Water Plan (NWP)—a synthesis of sub national Integrated Water Resources Management Plans (IWRMP)—and which is composed of half of national government officers and of representatives of Watershed Agencies (WA) and the other agencies involved with drinking water, energy production and irrigation, and for half of representatives of water users, of local elected assemblies, of agricultural training institutions, of professional associations and of scientists and experts (Herzeni, 2006).

The most important feature of the Law, however, is the establishment of the Watershed Agencies (WA), at the sub national level. These are meant to be legally and financially autonomous public institutions. They elaborate and implement IWRMP, as part of the NWP. The latter runs for 20 years, but they have the latitude to correct and adjust it as imposed, mainly, by the availability of water.

The essential task of WA is to attend to the equitable and efficient distribution of water amongst the users—irrigation farmers, energy production and drinking water. To this end, they have to regularly consult with the users and their representatives. The Law has provided for this continuing consultation process by instituting Provincial (or Prefectoral) Committees for the Integrated Management of Water Resources (PCIMWR). Moreover, the administrative boards of WA are composed for two thirds of representatives of the users, governmental and non governmental.

Other tasks of WA include: release of authorizations to use water; maintenance of a registry of holders of water use rights; financial and technical assistance for the use, the management or the protection of water; police of water; and technical tasks related to the measurement of the quantities and qualities of water over time and place.

6.3.2. The Actors

Although the Law insists on concession, consultation and participation, in fact the main actors remain the same. As far as agriculture is concerned, they are: the WA and even more heavily still the Regional Office for Agricultural Management (ORMVA). Water Users' Associations (WUA) in particular hardly start having some bearing on important decisions. Since 1995, ORMVA was supposed to progressively transfer its water management prerogatives to WUA, for the sake of its own conversion into a modern, efficient and profitable business. However, the process proved arduous and complex. Until now, ORMVA has not been able to deliver a precise evaluation of the costs to be transferred to WUA. There is no agreement yet about the pricing of water in particular. On the other side, WUA are still short of the competency necessary for accurate evaluation of costs. They are all less-motivated to cooperate since many promises that were made to them were not held to so far such as: discounts on water bills, access to credit, rebates on the Value Added Tax and on energy costs, etc. The result is that although their number has grown, their effective participation is lacking and limited, in the best cases, to contributing to the maintenance of irrigation infrastructure (Herzeni' 2006).

7. Challenges

In a report published by the High Council for Water and Climate (HCWC), the estimation of water balance showed that Morocco would experience a severe water shortage in the coming years. The balance between water supply and demand presented in Table 6 below was generally positive during the last decade (1990's). Nevertheless, basins such as Moulouya, Souss and Tensift have already shown some deficits. Prediction studies demonstrate that by the year 2020 this balance will be mostly negative and the country-wide deficit will be 0.5 Mm^3. Consequently, the amounts of water that is allocated to domestic and agriculture uses will be reduced.

Table 6. The Balance (Blce) between Water Resources (Res) and Demand (Dm) in Morocco in TCM (Berdi et. al. 2005)

Hydraulic Basin	1992			2020		
	Res	Dm	Blce	Res	Dm	Blce
Rif-North	464	403	61	1545	1052	493
Moulouya	1122	1205	-83	1670	1816	-146
Sebou	2329	1704	625	4768	3916	852
Bouragrag	339	327	12	852	902	-50
Oumrabia	3977	2846	1131	4067	4869	-802
Tensift	644	1067	-423	1221	1630	-409
Souss	675	734	-59	777	1175	-398
Massa	143	118	25	144	185	-41
Total						
	9693	8404	1289	15044	15545	-501

There are many facts indicating that water resources will become more and more limited. Among these indicators, one can cite:

- The total amount of water per capita that could be potentially mobilized in 2000 was 1000 m^3. This amount will be only 750 m^3 in 2020 and 500 m^3 in 2025;
- The potential irrigated area per capita is in clear regression under the demographic pressure. It was 0.2 ha in 1956 and became only 0.055 ha;
- The over-exploitation of groundwaters is resulting in a continuous draw down of the water table level (about 2 to 4 m /year).

7.1. What are the Development Options?

Morocco like other semi-arid countries is already facing problems associated to water scarcity. To alleviate these problems, the country should:

- Invest more in improving efficiency of current uses rather than continue to increase supply to meet increasing demands;
- Orient public investments towards the rehabilitation/modernization of the irrigation networks;
- Improve water productivity by developing water saving techniques;
- Develop more incentive tools to encourage more water saving; and,

Develop new approaches of integrated management of natural resources, especially water, to make the community more involved in irrigation water management in order to improve water productivity.

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AGRICULTURAL WATER USE EFFICIENCY IN SULTANATE OF OMAN

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1. Location and Climate

Sultanate of Oman is situated in the extreme southeastern corner of the Arabian Peninsula. It occupies an area of some 309,500 Km^2 and it is the second largest country in the Arabian Peninsula. The land area encompasses plains (3 % of total) which is mainly used for agriculture; the mountains (15%) and the sand and desesrt areas (82%).

Oman is located in the arid zone, which is characterized by high temperatures and low and erratic rainfall. It is hot and humid during the summer in the coastal areas and hot and dry in the interior, while the winter is fairly cool. In the northern mountains and Southern Region, the climate is moderate in both summer and winter. The rainfall is generally low and irregular. Mean annual rainfall is between 50 mm in the interior and about 100 mm in the coastal areas, with the exception of Dhofar on the south, where regular rains (200 to 260 mm) fall between June and October because of the monsoons. About 80 % of the total rainfall is evaported due to high evapotranspiration (figure 1) which reaches 3000 mm per year. Only 15 % go for groundwater recharge and 5 % lost to the sea.

2. Water Resources in Oman

Water is the primary limiting factor for agriculture in Oman as in most Near East countries. Because Oman is devoid of reliable surface water supplies, it depends entirely on the groundwater to meet its water requirements. Water resources can be divided into traditional water from Tube Wells and Aflajs- (which are underground water channels); and non traditonal water (from desalination of sea water and treated waste water). Wells and Aflajs are the main water sources for most sectors. Aflaj (single falaj) are traditional horizontal channels, which tap groundwater and have a rate descent lower than that of the surface and it used to transfer the water from its source to the agriculture land.

Desalination of sea water is restricted for potable use due to its high capital cost (0.500 OR/m^3 = US$ 1.29). There are about 22 Desalination Plants scattered throughout the country (Al-Ajmi and Abdel-Rahman, 2001). Current desalinated water amounts to 52 million m^3 per year with 48 million m^3 in the capital area alone (Zaibet and Omezzine, 1997). Treated wastewater is used to irrigate ornamental trees due to health and environmental aspects. The current Wastewater Treatment Pants produced about 28.6 million CM/year.

3. Agricultural Water Use

All the water available for agriculture comes from two main sources: (i) tube wells which are more than 127,000, irrigating 46.8 % of the total farms; and (ii) the Aflajs which are about 4112 falajs, irrigating 38 % (Al-Mamari, 2001). About 33 % of the water comes from Aflaj, 29 % from traditional wells, 20 % from new wells and 18 % from mixed wells (Figure 2). Agriculture is the main user of water; it consumes more than 90 % of the total usage, domestic use 2% and industrial and comercial 2 % as shown in figure 3.

4. Water Scarcity Problem

In Oman, the combination of aridity, extensive urban expansion and expansion of irrigated farming during the last decades due to improving living standards and increasing industrial and commercial development have brought about substantial water demand increases. This further intensified the imbalance between rising water demand and the limited existing water supply. Expansion in perennial cropping patterns such as permanent trees (date palm and fruit trees) and perennial forage crops (Alfalfa and Rhodes grass), was causing significant overdraft of water resources beyond its natural renewal capacity. Irrigated area exceeded more than 63,632 ha according to the Census of Agriculture (shown in Table 1). Perennial crops occupied more than 50,834 ha, whereas annual vegetables posing great importance as an alternative to the perennial crops, occupied only an area of 5,154 ha (Ministry of Agriculture and Fisheries-MAF, 2004). Irrigation of these crops was based largely on traditional surface irrigation methods (flooding, border, basin and furrow irrigation) which is estimated to be over 80 % of the total irrigated area (MAF, 2004). These methods of water distribution and application fail to measure and optimize the water supply needed to satisfy the time variable demands of different crops.

Excessive water pumping resulted in water deficit and seawater intrusion that progressively increased both irrigation water and soil salinity and thus limited crop productivity in the coastal areas, especially Batinah coastal area which sustained more than 60% of the cropped area in the Sultanate. Most recent studies reported that the water deficit (Difference between available water and water requirements) reached 369 million cubic meters (figure 4).

5. Water Use Efficiency

The term efficiency is generally understood to be a measure of the output obtainable from a given input. Irrigation efficiency can be defined in different terms, economically, technically and physiologically. Economic criterion of efficiency is the financial return in relation to the investment in water supply. The problem is that costs and prices vary from year to year and from place to place, and the benefits cannot be easily quantified, especially in places where a market economy is not yet fully developed. Physiologically efficiency is the plant – water use efficiency, i.e., the amount of dry matter produced per unit volume of water taken up. As 99% of the water taken up by plants in the field is transpired, water use efficiency in effect is the reciprocal of the transpiration ratio. Technical efficiency is the ratio of the net amount of water added to the root zone to that taken from the source, the difference represents the evaporation, losses incurred in conveyance and the losses due to seepage, deep percolation and runoff from the field.

There are many reasons behind low irrigation water use efficiency in Oman as other parts of Arabian Peninsula. Some of them related to natural effects such as location and climate of the country and the soil characteristics, which encourage water loss through evaporation and deep percolation. Some of them are related to water application methods and management followed by farmers. Although efforts from the government to replace the traditional irrigation methods (flood irrigation) with modern ones; still 80 % of the cultivated land is irrigated by flood irrigation, which have an efficiency ranging from 40 to 60 % depending on the soil and management practices. These figures are related to some extent to aflaj system because all the agriculture land under aflaj system is irrigated by flood methods. Water in the aflaj is based on time-share not on the amount share and it is distributed according to the ownership and not on the need. When the farmers get this amount of water they lead it all to the land by flooding. Table (3) shows that 96 % of the date palm area is still irrigated by flooding, whereas in fodder crops only 58 % of the crops are under flooding because most of the new Rhodes grass farms are irrigated by sprinkler systems. In vegetables the percent decreased to 48% under flood methods.

Previous studies indicated that the actual water applied is significantly more than crop water requirements and this is related to the wrong idea by the farmers: increasing the yield can be through increased water application, particularly in the absence of water pricing. The cost of water to the user can have a significant effect on how efficiently the water is used. A study in Oman indicated that less irrigation water per unit area is used when water costs are high and supplies are limited. In contrast, farms that depend on pumped groundwater, can be very inefficient because the water is cheap. The cost to the owner is only the energy needed to operate the pump which is found to be 0.022 OR. As a result, large areas are devoted to producing crops with high water requirements.

Table (2) shows Water Productivity in different terms based on the input in Table (1). These tables indicated that water productivity in terms of fresh produce in Kg/m^3 of the date palm and fruit crops are very low. Whereas vegetables which occupied only 8 % of the total irrigated area have higher water productivity in terms of fresh produce in Kg/m^3 than others crops and that is due to low water requirements of vegetables. In terms of OR/m^3 , vegetables also have the higher net return than other crops.

6. Water Conservation in Agriculture

To combat water shortage problems, the Sultanate has adopted an integrated system of water conservation and augmentation. Water conservation including the introduction of new techniques to improve irrigation efficiency and water augmentation alternatives, such as recharge dams, desalination, utilization of brackish water and treated wastewater reuse have been adopted.

Water conservation is an important and essential part of the sustainable management of this resource to meet current and future demand by all users; agricultural, domestic and industrial. Because most of the cultivated areas were irrigated by traditional surface system, the adoption of modern irrigation methods and management for efficient water use can and will make a significant contribution to the sustainability of one of the most essential natural resources. There is still significant potential to improve the efficiency with which water is used in both modern and traditional irrigation methods. The studies indicated that water application exceeded irrigation water requirements, so that significant savings in water consumption could be achieved through improved irrigation methods and the system management.

The Ministry of Agriculture and Fisheries followed conservation policies to curb demands for potable water and improve the efficiency of agriculture without increasing water demand. It restricted future agriculture development to be in accordance with the available resources and changing agricultural cropping patterns and irrigation practices where resources are presently overdrawn.

In order to rationalize agriculture consumption, the Ministry has provided financial subsidies and policies to encourage farmers to use modern irrigation systems (Drip for vegetable, bubbler for trees and sprinkler for fodders) as means of water conservation practice through reducing water loss and icreasing yield. The Ministry grants a subsidy of 100 % of the material cost to replace traditional surface irrigation systems (MAF, 1993). As agriculture is the main user of water, so conserving water at this sector will result in saving huge quantity of water. Conservation of existing water resources is one of the important objectives that the Ministry of Agriculture and Fisheries try to reach. It announced some priorities to achieve these objectives. The following research activities are of top priority for the Directorate General of Agricultural and Animal Research.

7. Regional Assessment of Crop Water Requirements for Enhancing Water Use Efficiency

Crop water requirement is important and necessary in irrigation scheduling and management as well as to improve water use efficiency. There is a lack of information dealing with crop water requirements and crop coefficient for most crops grown in Oman. Under arid conditions with limited water resources, studies related to crop water requirements and irrigation scheduling for improving water use efficiency and crop production are recommended. Crop water requirements are essential pre-requisites in all planning and developments of water resources. It can be calculated from climatic and crop data. The main challenge in estimating crop water requirements is extrapolation of climatic and crop coefficient data, obtained by measurement at specific sites, to areas without data. In addition, apart from literature data on crop coefficients, relatively little work has been done on the reassessment of crop coefficients for local crop cultivars under the specific climatic conditions. As a result, assessment of crop water requirements is usually very site-specific and difficult to generalize to agroecological zones. Although some research has been conducted on crop water requirements, considerable gap in knowledge still exists. In Oman crop water requirements were mainly based on estimates. So there is urgent need for valid experimental work to determine irrigation water requirements in terms of quantity and intervals for the priority crops under different climates. i.e., irrigation scheduling for different regions.

8. Application of Controlled Deficit Irrigation

There is a tendency nowadays to increase food production at minimum water usage. The deficit irrigation is a method of irrigation where the amount of water used is kept below the maximum level and minor stress that develops has minimal effect on the yield. Deficit irrigation can achieve significant water preservation with only a minor effect on the crop yield. This method of irrigation is applied when the cost of water is very high or at limited water resources. It is believed that controlled deficit irrigation can improve water use efficiency by reducing irrigation adequacy. It can be expected that along with the dwindling water resources, deficit irrigation will become the main method of irrigation, particularly in arid areas of the world. Some crops have already been subjected to deficit irrigation practices while others will soon be exposed to this type of irrigation. Further investigations of deficit irrigation are required since different plants and trees react in distinct ways to water reduction.

9. Application of Hydroponic Agriculture

Hydroponics or soil-less culture is a technology for growing plants in nutrient solutions that supply all nutrient elements needed for optimum plant growth with or without the use of an inert medium such as gravel, vermiculite, peat moss, etc. to provide mechanical support. This technique helps in water conservation as there is no water loss due to direct evaporation or deep percolation. The plant takes only the water needed and the water recycled. More research is needed to transfer this technology to the farmer in a simple and economic way. Adoption of this technology for various crops needs to be tested and the nutrient solution concentration for different crops also needs more research.

10. Using Marginal Water for Agricultural Purposes

Due to limited water resources and in order to save fresh water;efficient and effective use of all water available is, therefore, a priority for arid countries. Saline water and treated wastewater are the important marginal water that can be used in agriculture.

10.1. Saline Water

Due to excessive water pumping and prolonged drought with reduced recharge resulted in sea water intrusion that progressively increased salinity in irrigation water and soil. Using saline water for agriculture in marginal lands becomes one of the top priorities in such arid countries. Saline agriculture is adopted to utilize saline water. Production of crops is one option that could be especially promising for direct use of saline water in water scare environment. However, high salinity levels restrict crop production. Large number of plants species can grow and produce in the presence of salts particularly animal feed and forages species. Depending on the level of salinity, many plants species can be grown using saline land and water. The economics of production depends greatly on the specific conditions where they are found. However, there are indications that a range of plants can make profitable use of saline resources that would otherwise be unused. More research should concentrate on the following:

- Evolution of management practices for utilization of saline water.
- Nutritional aspects of crops when grown in saline environment.
- Leaching requirements of saline water.
- Salt tolerance studies.
- Identification, screening and domestication of natural and exotic salt tolerant genetic material.
- Breeding of plants for salt tolerance.

10.2. Wastewater Utilization on Irrigated Land

The use of treated wastewater has become necessary as the waste water increased due to increase in population. Wastewater becomes a burden on the environment but it is one of the water sources for agriculture which can be used to mitigate water scarcity in the arid countries. But using treated wastewater has some constraints which need more research to solve them. Biological and toxic chemicals are the major concerns that should be addressed. There is a need to develop economical irrigation technologies that utilize biological and chemical wastes to prevent environmental degradation and wasted natural resources

11. Institutions in Control of Water Use

There are many instituions or ministries other than Ministry of Agriculture and Fisheries that deal with water use in the country and they are:

- Ministry of Regional Muncipalities, Environment and Water Resources. It deals with water resources assesment and management and construction of water harvesting structures (Recharge Dams). The Ministy constructed 17 major dams that augment natural recharge and reduce the waste of floodwater to the sea or to the desert , as well as to combat seawater intrusion in coastal areas. These dams trap around 60 million m^3 annually (Al-Ajmi and Abdel-Rahman, 2001).

- Sultan Qaboos Unversiy, Department of Soil and Water Management. It conducts research in irrigation management, water resources management and pollution control.
- Ministry of Housing, Electrisity and Water. It deals with water for domestic uses only.
- Diwan of the Royal Court, with its overall concerns on irrigation.

12. Recommendations and Suggusstions for Improving WUE

Water conservation by improving water use efficieny cost much less than augmentation or producing water by desalination and wastewater treatment. So it is important to find effective and applicable methods of water conservation. The government should move fast in replacing traditional irrigation with modern systems by increasing the budget for this purpose. It is also important to change cropping patterns, giving priorities to high economical crops which have low water requirements.

Table 1. Cultivated Area and Prodcution of the Main Crops Grown in Oman.

Crop	Cultivated area (ha)	Total Production (ton)	Water Req. (mm/y)	Water Req. (m^3/ha)	Total water Req. MCM
Date palms	31365	247331	1413	14130	443.2
Coconut	463	4807	1160	11600	5.4
Lemon	1243	6159	1240	12400	15.4
Mango	1071	7743	1589	15890	17.0
Banana	2226	26720	1589	15890	35.4
Papaya	71	1371	_	_	_
Others	487	9059	_	_	_
Total Fruit crops	5561	55859	_	_	_
Alfalfa	5447	222393	1589	15890	86.6
Rhodes grass	7294	289666	1677	16770	122.3
Others	1167	27780	_	_	_
Total Fodder crops	13908	539839	_	_	
Wheat	271	865	550	5500	1.5
Barley	1129	3327	_	_	_
Sorgum	2048	9541	_	_	_
Sugarcane	24	626	_	_	_
Others	4171	12202	_	_	_
Total Field crops	7644	26561	_	_	_
Tomatoes	864	39359	592	5918	5.1
Cucumbers	57	1360	300	2995	0.2
Potatoes	209	5940	274	2740	0.6
Peper	295	5527	731	7310	2.2
Eggplant	234	4585	686	6863	1.6
Onion	266	5389	486	4855	1.3
Cabbage	188	5064	325	3252	0.6
Cauliflower	142	3134	368	3683	0.5

Water mellon	518	16487	401	4013	2.1
Cantaloupe	497	12040	_	_	_
Okra	241	3984	640	6402	1.5
Raddish	84	1200	_	_	_
Garlic	73	774	_	_	_
Carrots	62	733	309	3090	0.2
Squash	155	1471	278	2782	0.4
Others	1269	12091	_	_	_
Total Vegetables	**5,154**	**119,138**	**_**	**_**	**_**

Table 2. Land Productivity and Water Productivity of the Main Crops Grown in Oman

Crop	Land Productivity ton/ha	Water Productivity Kg/m^3	Price OR /Kg	Total Return OR	Return in OR $/m^3$
Date palms	7.89	0.56	0.388	95964428	0.217
Coconut	10.37	0.89	0.100	480700	0.089
Lemon	4.96	0.40	0.291	1792269	0.116
Mango	7.23	0.45	0.550	4258650	0.250
Banana	12.01	0.76	0.163	4355360	0.123
Papaya	19.31	_	0.202	276942	_
Others	18.60	_	_	_	_
Average Fruit crops	11.48	0.61	0.28		0.16
Alfalfa	40.83	2.57	0.050	11119650	0.128
Rhodes grass	39.71	2.37	0.016	4634656	0.038
Others	23.80	_	_	_	_
Average Fodder crops	34.78	2.47	0.03		0.08
Wheat	3.19	0.58	_	_	_
Barley	2.95	_	_	_	_
Sorgum	4.66	_	_	_	_
Sugarcane	26.14	_	_	_	_
Others	2.93	_	_	_	_
Average Field crops	7.97	0.58	_	_	_
Tomatoes	45.54	7.70	0.115	4526285	0.885
Cucumbers	23.98	8.01	0.200	272000	1.601
Potatoes	28.45	10.38	0.140	831600	1.453
Peper	18.76	2.57	0.221	1221467	0.567
Eggplant	19.63	2.86	0.098	449330	0.280
Onion	20.26	4.17	0.070	377230	0.292
Cabbage	26.96	8.29	0.075	379800	0.622
Cauliflower	22.00	5.97	0.150	470100	0.896
Water mellon	31.80	7.92	0.113	1863031	0.895
Cantaloupe	24.24	_	0.158	1902320	_
Okra	16.55	2.58	0.195	776880	0.504
Raddish	14.21	_	0.218	261600	_
Garlic	10.59	_	0.162	125388	_
Carrots	11.79	3.81	0.126	92358	0.481
Squash	9.46	3.40	0.150	220650	0.510
Others	9.53	_	_	_	_
Average Vegetables	20.86	5.64	0.15		0.75

Table 3. Percentage of Cultivated Area and Water Use for Different Crops Grown in Oman

Crops	Cultivated Area (ha)	Cultivated Area (%)	Water use %	Area irrigated by Modern Systems %	Area Irrigated by Flood Methods %
Date palms	31,365	49	53	4	96
Fruit crops	5,561	9	10	18	82
Fodder crops	13,908	22	32	42	58
Field crops	7,644	12	3	9	91
Vegetables	5,154	8	2	52	48
Total	**63,632**				

Table 4. Total Cultivated Area and Average WUE for Different Crops

Crops	Area (ha)	Water Productivity Kg/m³	Land Productivity ton/ha	Price OR /Kg	Revenue in OR /m³
Date palms	31365	0.56	7.89	0.39	0.22
Fruit crops	5561	0.61	11.48	0.28	0.16
Fodder crops	13908	2.47	34.78	0.03	0.08
Field crops	7644	0.58	7.97	_	_
Vegetables	5154	5.64	20.86	0.15	0.75

(1 Omani Rial (OR) = US$ 2.6).

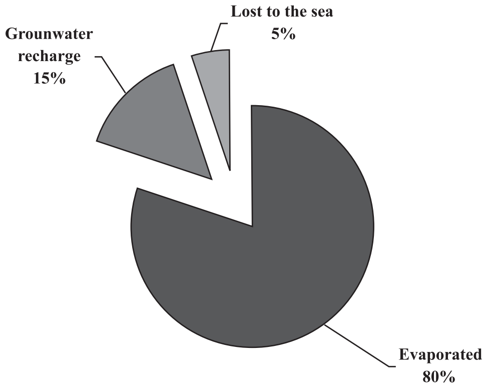

Figure 1. Benefit from Rainfall (MWR, 2004)

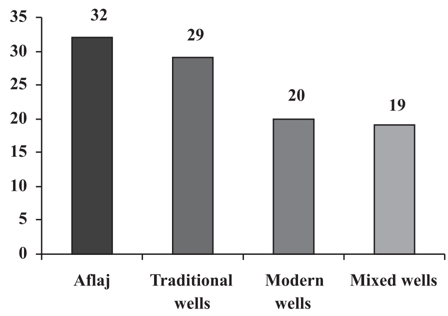

Figure 2. Water Resources Consumption Shares (MWR, 2004)

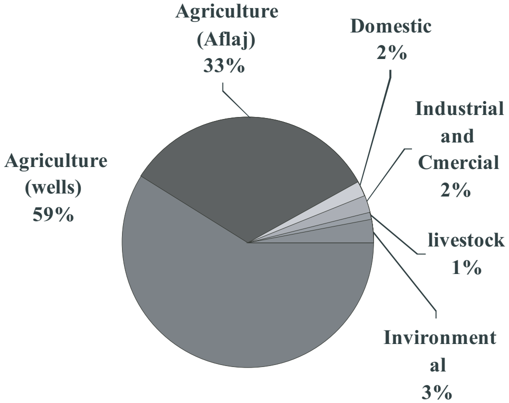

Figure 3. Water Demand (%) by Different Sectors (MWR, 2004)

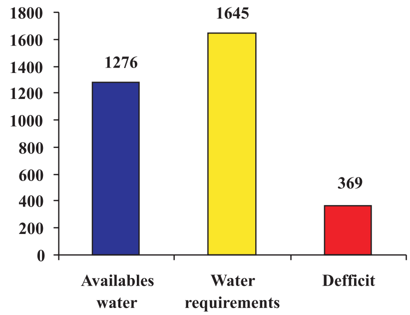

Figure 4. Water Balance and Deficit in Oman (MWR, 2004)

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WATER USE EFFICIENCY AND RESEARCH WORK IN THE SUDAN

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Sudan is one of the largest countries in Africa with a total area of about 2.5 million km^2. The country has borders with 9 countries and shares surface and ground water with 12 counters. Climate extends from desert in the north to super humid in the south.

1. Water resources: (Abdalla, 2005)

The Nile basin is shared by 10 countries, namely : Burundi, D.R. of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda. The hydrology of the Nile and its tributaries in billion cubic meters (BCM) is shown in table (1).

Table 1. Supplies from the Nile and its tributaries, (BCM)

Tributary	Total Annual Supply (BCM)
Blue Nile	5.7
Rahad	1.09
Dinder	3.0
White Nile	27.8 at malkal
Bahr El Gazal	14
Bahr El Jabal	26 at Mangala
Sobat	13.3 reaches Malakal
Atbara	12
Main Nile	84 at Aswan

The extreme annual flow fluctuations recorded at Aswan necessitated construction of storage dams namely, Sennar and Roseires dams on the Blue Nile and Girba dam on Atbara and Gebel Aulia'a dam on the White Nile. The average annual flow at Aswan is estimated as 84 BCM. According to the 1959 Nile Water Agreement between Sudan and Egypt, Sudan share is (18.5 BCM) and Egypt's share is (55.5 BCM). Ten billions were estimated as evaporation per annum. Table (2) summarizes current amount of available water to Sudan.

Table 2. Available Water to Sudan in BCM

Water Resources	Quantity	Constraints
Present share from the Nile Water agreement	20.5	Seasonal pattern and low storage facilities
Wadis water	5 to 7	Highly variable, short flow duration
Ground water	4	Deep water need high cost for pumping
Present total	30	
Expected from swamp reclamation	6	Capital investment
Total	35.5 to 37	

2. Legal Framework:

There is no existing single legal document that governs the development, management and utilization of water resources in the Sudan. The main regulations in Sudan are based on the 1951 regulations, which included provisions for the following:

- Solving disputes through arbitration.
- Obliging the licensee to maintain canals to avoid seepage.
- Organization of the rotation of the crops.
- Obliging the licensee to cultivate crops making optimal of water pumped under the license.
- Annual fees to be paid for each license.

According to the National Comprehensive Strategy (NCS) 1992, the policy objectives and strategies of the water resources are as below:

- Full and efficient utilization and development of surface and ground water recourses.
- Building of dams on the Nile and Wadis.
- Addressing the problem of silt in the reservoirs.
- Eliminating thirst and develop water supply networks all over the country.
- Development of water equipment manufacturing industry.
- Development of economic criteria for the utilization of water in such a manner as to maintain balance between the cost on one hand and the economic and social return on the other.

3. Research on Water Management and Water Use Efficiency

Research on crop water requirements started in late 1960's to mid 1970's. Farbrother (1996) conducted a series of experiments under Gezira farm conditions. During this period, crop water requirements of the main crops in the Gezira scheme were estimated as the product of a crop factor and potential evapotranspiration. Water requirements for cotton, wheat, sorghum, groundnut and sesame are shown in Table (3).

Table (3): Total Crop Water Requirements, cubic meters per fedan*

Cotton (Barakat)	5110-5320
Cotton (Acala)	3470-3680
Wheat (Giza)	2560-2760
Dura (Long term)	2620-2660
Dura (Short term)	2270-2310
G/N Short term	2430-2600
G/N Long term	333-342
Sesame	246-257

* Fedan is 4200 m^2, or equivalent to an acre.

Till the mid 1980's, research on water management mainly focused on testing the response of different crops to different irrigation intervals.

Farah (1986) studied the response of the wheat variety *condor* to variations of irrigation intervals at three growth stages, (see Table 4). The results indicated that the yield is highest when irrigation intervals were shortened.

In a second trial, Farah (1987) following the same approach, tested the response of wheat to different irrigation intervals imposed at different growth stages but this time water use efficiency was recorded. Grain yield for the different treatments ranged between 1078 and 1789 Kg/ha. Water use efficiency (WUE) values were in the range of 0.38 to 0.68 kg/m^3/ha, Table (5).

The effect of three watering regimes on grain yield of three wheat released genotypes was studied, Farah (1993). The highest (WUE) values were reported under the wet i.e., more frequent irrigation treatment.

Consumptive water use and WUE values in response to four watering regimes, namely watering every 10 or 20 days during vegetative and reproductive stages of three wheat genotypes were reported by Ahmed (1993). Results indicated that the reproductive stage is more sensitive to water stress compared to the vegetative stage, (Table 7).The highest WUE value of 0.72 kg/m^3/ha was recorded by the wet treatment i.e., watering every 10 days throughout the season. It is worth noting that the above-mentioned results for wheat were conducted under the Nile Valley Program, sponsored by ICARDA (wheat WUE network). For more details, see Ageeb, (1995).

Due to the high cost of pumping irrigation water from River Nile, farmers in the area north of Khartoum generally apply lower number of irrigations than recommended. Following the objective of saving irrigation water with minimal losses in seed yield, a series of experiments were conducted at Hudeiba Research Farm. The program mainly focused on testing the response of different faba bean, chickpea and lentil genotypes to different irrigation intervals. Salih, et al (1993) tested the performance of 10 faba bean genotypes to water stress. Response of the different genotypes to water stress was assessed using the methods of Fisher and Maurer (1978). This was accomplished by regressing mean yields of the different genotypes against an environmental index consisting of the mean of all tested genotypes at each water level. No attempt to measure consumptive water use or water use efficiency was made.

Results in Table (8) showed that genotypes BB7 and Bulk 1/3 attained the best yields under stressed conditions and thus were rated as the most tolerant to water stress. The two genotypes were released to farmers in December 1993. For more details, see a chapter on water relations of faba beans, chickpea and lentil, Salih et al (1996).

Table 4. Effect of Irrigating Wheat at Different Intervals during the Three Growth Stages on Grain Yield of Wheat

Irrigation Interval				
Planting to booting	**Booting to milky**	**Milky to maturity**	**Yield (kg/ha)**	**Grain yield (kg/m^3/ha)**
10 - 14	10	14	1272	0.38
10 - 14	10	21	1090	0.41
10 - 14	14	14	1113	0.49
14	14	21	1257	0.53
14	10	14	1213	0.48
14	10	21	1174	0.54
14	14	14	1055	0.68
21	14	21	930	0.66
21	10	14	965	0.46
21	10	21	797	0.51
21	14	14	761	0.44
SE (±)	14	21	118.9	0.44

Source : Farah (1986).

Table 5. Effect of Irrigating Wheat at Different Intervals in the Three Growth Stages on Yield and Water Use Efficiency (WUE) of Wheat

Irrigation Interval				
Planting to PI*	**PI + to heading**	**Heading to maturity**	**No. of irrigations**	**Grain yield (kg/ha)**
14	10	10	9	0.38
14	10	14	8	0.41
14	10	21	6	0.49
14	14	10	8	0.53
14	14	14	7	0.48
14	14	21	6	0.54
21	10	10	7	0.68
21	10	14	6	0.66
21	10	21	5	0.46
21	14	10	5	0.50
21	14	14	5	0.44
21	14	21	5	0.44

* PI = Panicle Initiation
Source : Farah (1987).

Table 6. Effect of Three Irrigation Regimes on Grain Yield and Water-use Efficiency (WUE) of Three Wheat Genotypes

Irrigation interval	Grain yield (kg/ha)	WUE + (kg/ m^3 / ha)
10 days		
Debeira	2246	0.42
El Neilain	2511	0.45
Wadi El Neil	2672	0.47
Mean	2477 a+	0.44
14 days		
Debeira	1645	0.31
El Neilain	1247	0.26
Wadi El Neil	2333	0.48
Mean	1742 ab	0.33
21 / 14 days		
Debeira	797	0.21
El Neilain	1113	0.26
Wadi El Neil	1495	0.35
Mean	1135 b	0.28

+ values within a column followed by the same leter(s) are not significantly different at the 5 % level according to DMRT.
Source : Farah et. al. (1993).

Table 7. Grain Yield, Consumptive Water Use (CWU), Water Use Efficiency (WUE) and Relative Turgidity of Three Wheat Cultivars as Affected by Irrigation Regime

	Irrigation Regime *				Mean
	WW+	DW	DW	DD	
Grain yield (kg/ha)					
El Neilain	3153	2890	2066	2136	2561
Debeira	2688	2416	2045	2074	2306
Wadi El Neil	2186	2111	2753	1867	1979
Mean	2676	2472	1955	2026	
CWU (m^3 / ha)	4390	4260	3700	3430	
WUE (kg/ m^3 / ha):					
El Neilain	0.72	0.68	0.56	0.62	0.64
Debeira	0.61	0.57	0.55	0.6	0.58
Wadi El Neil	0.5	0.5	0.47	0.54	0.5
Mean	0.61	0.58	0.53	0.59	
Relative turgidity (%):					
El Neilain	42			40	41
Debeira	34			32	33
Wadi El Neil	32			31	31
Mean (SE = ± 0.061)	3632			34	

Source : Ahmed (1993)

+ WW = 10 days irrigation intervals throughout the season;
DW = 20days until heading and 10 days thereafter;
WD = 10 days until heading and 20 days thereafter;
DD = 20 days throughout the season.

Table 8. Regression Parameters of Grain Yield of 10 Faba Bean Genotypes against an Environmental Index for the Means of all Genotypes at each Water Level

Genotype	Intercept	Slope	R *	SE (±)	Yp‡ (kg/ha)	Ys§ (kg/ha)	S
Bulk 1/3	396	0.868	0.95	0.099	4302	700	0.922
BB 7	395	0.940	0.98	0.075	4625	724	0.929
SML 85/1/1	173	0.997	0.98	0.075	4660	522	0.978
BF 2/2/8/1	-107	1.000	0.87	0.201	4393	243	1.040
ZBF 1/1	-308	1.101	0.97	0.094	4607	37	1.092
Bulk 1/1	113	0.962	0.99	0.047	4442	450	0.990
F402	132	1.059	0.99	0.062	4898	503	0.988
Hudeiba 72	-17	1.023	0.99	0.059	4587	341	1.019
ZBF 9/4	213	1.010	0.98	0.080	4758	567	0.970
ZBF 3/3	-259	1.040	0.98	0.083	4421	105	1.075

* R = Co-efficient of correlation.
‡ Yp = Seed yield under wet conditions.
§ Ys = Seed yield under water stress conditions.
¶ S = Fisher drought susceptibility index.

WATER USE EFFICIENCY FOR AGRICULTURAL PURPOSES IN THE SYRIAN ARAB REPUBLIC

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1. Introduction

Water resources (WRs) in Syria in general have an exceptional importance, strategic dimension and crucial effect on the whole national socioeconomic development. In spite of this importance and increased stress due to the rising water demand, the agricultural WUE (which consumes 88% of water) is estimated around 40 – 45%. Improvement irrigation system efficiency (through using modern and water-saving techniques) associated with water awareness and extension would clearly rationalize water applied in agriculture. This can be conducive to retrieval of the equilibrium between the available renewable WRs and their demand on a sustainable basis.

The Syrian Government's strategy for WRs sustainability and protection from pollution and depletion is based on the integrated water demand management principle; giving the environmental dimension a special importance for maintaining water quality suitable for domestic, agricultural and other uses.

2. Water Resources Uses in Syria

Table (1) shows the annual surface and ground flow at different supply probabilities according to the seventh hydrological basins. Available renewable traditional WRs are estimated for an optimistic year at P = 50%, considering that the regulation degree at basin level reflects WRs control and distribution potential as follows:

Total traditional regulated WRs in Syria: 15094 million m^3/year, of which:

- 5254 million m^3/year ground water, and
- 9840 million m^3/year surface water

Surface water of the Euphrates according to the Provisional Protocol with the Turkish Government in 1987 and the Syrian-Iraqi Convention of 1989 pertaining to the Euphrates water allocation in Jarablus are estimated to 6,623 million m^3/year (representing about 67.3% of total annual surface water supplies).

National water balance according to the season 2005–06 was calculated in terms of population number, irrigated areas and WRs corresponding to P = 50% in an optimistic year close to the medium according to the following parameters:

i. Water requirements per ha at country level: 13,000 m^3/ha/year surface sources and 10,000 m^3/ha/year ground water.
ii. Drainage effluents were calculated on average 15% of total uses for agricultural purposes at country level.
iii. Industrial and wastewater effluents were calculated at 70% of actually used water in both sectors added to systems' losses.
iv. Evaporation losses from water bodies were calculated based on the report of "Agriculture and Irrigation Status" prepared by State Planning Commission.

Table 1. Annual Water Flow in Syria by Hydrological Basin at Different Supply Probabilities (P)

Basin	Area	Water	Average		P = 50%		P = 75%		P = 95	
	km^2	source	Mm	million m^3	mm	million m^3	mm	million m^3	mm	million m^3
Barada & Awaj	8630	Surface	98	20	92	19	66	13	39	8
		Ground		830		774		557		328
Yarmouk	6724	Surface	66	180	62	168	45	121	26	71
		Ground		267		249		179		105
Orontes	21630	Surface	126	1110	117	1036	84	745	50	438
		Ground		1607		1499		1078		635
Coastal	5049	Surface	462	1557	431	1453	310	1045	183	615
		Ground		778		725		522		307
Tigris & Khabour	21129	Surface	113	788	105	735	76	529	45	311
		Ground		1600		1493		1074		632
Euphrates	51238	Surface	17	7105	15	7075	11	6948	7	6816
		Ground		371		346		249		147
Steppe	70786	Surface	5	163	5	152	3	109	2	64
		Ground		180		168		121		71
Average			54		50		36		21	
Total	185,180			16,556		15,891		13,289		10,549

Table 2. Water Balance for Surface and Ground Water Resources

Hydrological data	Unit	% of the above item	Syria
Area	km^2	100	185180
Regulation degree	**%**		**94.8**
Regulated surface	million m^3	65.19	9840
Euphrates	million m^3	67.31	6623
Groundwater	million m^3	34.81	5254
Total	million m^3	79.98	15094

Drainage effluents	million m^3	13.49	2546
Wastewater effluents	million m^3	6.53	1232
Evaporation losses from surface bodies	million m^3		1949
Total renewable WRs	million m^3	**100.00**	**16923**
Groundwater irrigated area	ha	54.00	805795
Surface water irrigated area	ha	46.00	686441
Total irrigated area	ha	100.00	1492236
Groundwater	million m^3	47.48	8058
Surface water	million m^3	52.58	8924
Total Agricultural	million m^3	**90.61**	**16972**
Domestic uses	million m^3	6.29	1179
Industrial uses and others	million m^3	3.10	581
Total uses	million m^3	**100.00**	**18732**
Water balance	million m^3		**-1809**

The imbalanced exploitation of water resources by different users, specially in the agriculture sector has led to a severe depletion of groundwater, where the deficiency exceeded 2.8 billion m^3/year. There is an agreement among both technicians and decision-makers that such situation could not possibly continue in handling water resources due to the expected negative impact on the national economy.

2. Water Use Efficiency Development for Agriculture

The change of weighted annual water requirement per ha at national level from 13,400 m^3/ha in 1992 to less than 11,300 m^3/ha following 2000 was developed for rationalizing water abstraction due to the prevailing drought. Water Scarcity also resulted in varied crop rotations as well as application of the most advanced water-saving techniques. However, present studies indicate the fluctuations of actual water requirements as a result of the slow adoption of modern irrigation methods and techniques , as well as the persistence of reasons leading to various losses of irrigation water.

Table 3. Average Percent Efficiency of Irrigation Systems by Crop

Crop	Types of Irrigation System			
	Traditional	**Improved surface**	**Sprinkler**	**Localized**
Wheat	49		79	
Maize	60		89	
Sugar beet	44		80	
Cotton	51	63	78	88
Olives	50			94
Grapes	60			91

Table 4. Water Uase Efficiency (WUE) for Variuos Irrigation Systems by Crop (expressed as kg/ m^3)

Crop	Types of Irrigation System			
	Traditional	**Improved surface**	**Sprinkler**	**Localized**
Wheat	0.56		1.08	
Maize	0.48		1.10	
Sugar beet	7.13		14.26	
Cotton	0.23	0.37	0.49	0.74
Olives	0.74			1.90
Grapes	2.97			5.77

Overall efficiency of irrigation systems at country level is estimated at 42–45%, distributed as follows:

~60–65%	for improved surface irrigation techniques following land leveling.
~ 70–81%	for spray and sprinkler techniques.
~ 80–94%	for drip and pressurized irrigation systems
~ 35–40%	for traditional flooding irrigation methods

3. Policy of Water Resources Application Efficiency in Syria

Development and improvement of the irrigation system efficiency would contribute to achieving the strategic goals of national economic planning. All factors involved ought to be considered such as: climatic, environmental and socioeconomic conditions, crop and soil type, hydro-geological conditions, landholding size, keeping in focus the beneficiaries's interests.

This situation calls for developing mechanisms, policies and procedures in conformity with a realistic and feasible plan , perhaps with the Government bearing a major part of costs incurred for the conversion process of upgrading of the irrigation system efficiency.This ought to be adopted under careful procedures for proper monitoring and follow-up towards accomplishing the planned objectives. To accomplish this, the Government strategy under the framework of Water Resources rationalization and their use efficiency improvement is represented by:

- Plan to reach total irrigation system efficiency by 75% at national level.
- Obligatory planning of irrigated areas on the basis of renewable water supply at supply probability P = 75%.
- Protection of surface and groundwater resources from pollution, and putting an end to catchment degradation.

***The Government has taken a range of procedures including*:**

a. Issuance of the Syrian Water Act Nú 31 of the year 2005, focusing in its article 36 on:

- Irrigation system violators (excess abstraction over the permissible abstraction from state systems) are liable to a fine of 5.0 SP/ m^3 added to the annual legal fee stipulated in the Legislative decree N° 8 of the year 1996.
- Agricultural plan violators in the domain of wells are liable to a fine of 5.0 SP/ m^3 doubled in case of repetition and the pumping unit is removed and the license is cancelled at the third time.
- The removal of pumping unit at the expense of the violators if they don't abide by the law and the equipment is confiscated until the costs of equipment removal are paid in double.
- In case of non-installation of a meter on the exploited well, the violators are liable to a fine equal to licensing fees, and the license is cancelled if the violation is not settled during three months.

b. Issuance of Environment Protection Law N° 50 of 2002 which makes the environmental juridicial police in place. The Water Act and its clauses related to pollution depends upon the above law.

c. Creation of the Irrigation Development Fund as per Decree N° 91 of 2005 to which an amount of 52 billion Syrian Pounds (1US$= 50 Syr. Pounds) were allocated for adopting rational usage of irrigation water (improved surface, sprinkler, localized) according to suitable conditions.

d. Creation of a Special Administration for Irrigation Development Fund as per the Resolution N° 2817 of 2005 including Fund's Higher Committee, and Provincial Committees for administering the Fund and setting up the criteria and conditions of crediting, monitoring, following-up, and checking and testing irrigation equipment, and penalties.

e. Issuance of the instructions of Government contribution to irrigation development process by providing grants for water sources, where the targeted converted area is located.

Other Governmental Efforts includesd:

(i) Governmental loans are granted for converting the irrigated areas in the domain of groundwater sources, including:

- Exempting loans from bank interest
- Offering 20% of the loan as a grant
- Allocating 2.0% fees for the Agricultural Cooperative Bank for collecting loans as a grant
- Allowing 10 years as a recovery period of which two slack years (government contribution).
- Allowing 8 years as a recovery period without interests.

(ii) Government contribution for irrigated areas in the domain of state
- irrigation projects and others:
- Exempting loans from bank interest
- Offering 10% of the loan as a grant
- Allocating 2.0% fees for the Agricultural Cooperative Bank for collecting loans as a grant
- Allowing 10 years as a recovery period of which two slack years (government contribution).
- Allowing 8 years as a recovery period without interests.

4. Institutions Involved in Water Resources Management for Agriculture

The currently effective provisions of the Syrian Law include the entities involved in water use management for irrigated agriculture as follows:

At country level
- Water policy: Higher Water Committee representing all decision-makers, agencies and beneficiaries (government and NGOs).
- Water Planning: Ministries of Irrigation and Agriculture
- National System of Performance Evaluation and Obligatory Periodic Monitoring.

At basin and provincial level
Water policy: Water Basin Management Committee representing all Decision-makers, Agencies and Beneficiaries (government and NGOs).
Water Planning: Directorate of Water Resources and the Branch of Agricultural Council.
- Police: Water and Environmental Police.

At region and sub-basin level
Branch of Water Awareness Directorate
• Water Planning: Services of Agriculture & Extension, Regional Agricultural Committees.
Water Users Associations and Farmer Associations
Water Monitoring Patrols

5. Recommendations for Water Resources Use Efficiency in Syrian Agriculture

The main objective of irrigation efficiency improvement and water use rationalization is not only to expand irrigated areas but also to achieve the equilibrium between supply and use and the adoption of demand management principle. In order to achieve the highest use efficiency and economic revenue per applied natural resource (water, energy, and manufactured materials etc.); the Water Act N° 31 of 2005 and the Syrian National Environmental Strategy and Work-plan of Ministry of State for Environmental Affairs was

issued in 2003 in cooperation with UNDP and the World Bank.The water exhaustion problem was considered at top priority that requires prompt handling and taking basic measures to reduce the resource losses and degradation.
Towards this goal, it was inevitable to take the following range of procedures:

a. Related to water legislation

- Issuing the Executive Regulations as an application mechanism of the contents of the legislation governing the users' duties and rights as well as the penal rules in case of water source encroachment and irrational use
- Forming the Water Basin Committees that include water applying/benefiting agencies, and it was deemed indispensable to involve NGOs in the field of environment protection.
- Adopting a specialized approach for decision-makers' and beneficiaries' awareness through workshops in which the Water Act is explained (items, justified reasons and objectives) especially for farmers.

b. Related to administrative issues

Selecting the administrative and technical staff of the project from well-qualified/experienced technicians; providing them with specialized training course to reach to a precise understanding of the project by studying and implementing the project document in detail to be acquainted with the project components; and concluding the implementation mechanisms and how to reach the beneficiaries.

Finding out a social conceptual background supporting the economic orientation toward the rationalization of natural resource use (water, soil, and human resources).

c. Related to the training component and staff strengthening

Setting up advanced and specialized programs for qualifying water extensionists, specially with a focus on small farmers' awareness.

d. Related to coordination among different institutional entities

Activating the work of Higher Water Committee and Water Basin Committees.
Setting up a mechanism for cooperation and coordination at center and site levels, aiming at cooperation and integration and to avoid duplication. This integration should address the objectives of the National Project for Converting to Modern Irrigation.

e. Related to supporting activities for resources conservation:

The application of water harvesting and spreading.
The application of renewable non-traditional energies (solar energy, wind, biogas etc.).

f. Reviewing the agricultural policy, cropping patterns and crop rotation at water-deficit areas level quantitatively and qualitatively by adopting the key principle of demand management. This entails the equilibrium between the available water resources and the demand, as a basis for addressing water deficiency.

g. Reviewing the mechanism of irrigation fees and adopting the calculation applied water amount per unit area**.**

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WATER USE EFFICIENCY IN TUNISIA

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1. Introduction

Tunisia is an arid country where agriculture is practiced on 5.2 million ha (30% of the total area), out of which 4.2 million cultivated, 0.6 million fallow and 0.4 million ha are pasture lands. Rainfall is erratic and decreases by going south. Rainfall ranges from 1500 mm at the Kroumirie mountains near the Algerian border to less than 150 mm in the outskirts of the Sahara. The country could be subdivided into three major ecological zones: The Northern, Central and Southern regions.

- The northern region, representing 17% of the country receives the most rain (400 to 1500 mm). It has the major dams and the only permanently flowing river of the country, *the Medjerdah*. This region produces cereals, pulses, vegetables, fruits, forages, meat and milk. Rainfall meets the water requirement of most winter crops and water resources development is based on the collection and storage of surface water. Human pressure and social issues related to unequal distribution of fertile lands are the underlying social problems to the best use of agriculture and natural resources of the region.

- The central area, representing 22% of the country, lies between the isohyetes 400 mm and 200 mm. Most of the cultivated surfaces are located in this part of Tunisia. Because crops need additional water supply to produce normally in this region, various water harvesting techniques have been developed under traditional farming systems. Micro-catchment techniques are widely used in the coastal area on sloping lands; whereas water diversion and spreading are used for producing cereals in the central plains. Farming systems based on olive, fruit trees, and cereals cultivation along with sheep raising prevail in this region. Small scale irrigation on shallow wells and from few major dams are also well developed. However, decreasing profitability of rainfed systems is the most challenging issue for agriculture sustainability in this part of Tunisia.

- The arid and pre-desert region, in the south, represents 61% of the country but receives no more than 30% of the rainfall waters. Agriculture relies mostly on oases systems and extensive grazing. Major threats to the regions are linked to desertification because of over grazing and excessive salinization in the oases.

Cropping systems tend to be highly diversified as a strategy or an adaptation to frequent droughts which characterize the climate in North Africa. Droughts are mostly feared for their devastating impact on cereals, pasture and livestock production. When drought occurs over two or three successive years the irrigated sector can be also largely affected by dangerous increase in soil salinity.

2. Water Resources

Total precipitation produces an average water amount of 36 Km^3, but its inter-annual variation is extremely high. Succession of drier-than-normal years are quite frequent and may cause total crop failure even in the northern region.

Being aware of the irregular feature of its precipitation regime, Tunisia has given priority to the mobilization and exploration of all its water resources. By implementing major action plans, the country has succeeded to mobilize most of the technically accessible surface water. This has been accomplished after construction of major dams, small dams and small hill reservoirs. Table (1) shows the amount of water potentially available, accessible and total mobilized water.

Table 1. Water Resources in Tunisia (km^3)

	Potential	Accessible	Mobilized (2004)
Surface waters	2.7	2.5	2.0
Deep groundwater	1.4	1.4	1.1
Shallow groundwater	0.7	0.7	0.8
Annual renewable resources	4.8	4.6	3.9

Source BPEH, 2005.

Soft water resources are quite limited, since 50% of the total resources have a salinity higher than 1.5 g/l and as much as 23% more than 3 g/l. Water quality of the Medjerdah river, fluctuates considerably from one season to another and from one location to another. Total Dissolved Solids (TDS) keeps increasing when going downstream from the western border with Algeria to the coastal plain, near Tunis city. Some hydraulic constructions have been used to cut off the main saline effluents and keep salinity within a range of 0.5 to 2 g/l. Water quality of other rivers in the northern part of the country are comparable to the Medjerdah. In central and southern Tunisia there is little surface water, and underground water is the main resource for irrigation. Because of over-exploitation, salinity keeps increasing in many regions reaching quite often 4 g/l in the southern region, threatening seriously the sustainability of many oases.

Since the mobilization of surface and ground water resources is approaching its potential, adoption of water saving practices have become the logical solution to meet the increasing demand for water (Table2). To reach this goal, many measures have been taken by the government to reduce water losses. For instance, subsidies covering 40 to 60 % of the total cost of any water-conservative-irrigation-system are proposed to farmers. Other measures were in favor of involving water users in the management processes of their resource. Subsidies have had an immediate success and its effectiveness has been very significant in reducing losses and improving production. However, it does not seem to help in curbing down the demand for more irrigation water and withdrawals for irrigation keep increasing as Table 2 below indicates.

Table 2. Overall Water Withdrawals (km^3)

	1990	2000	2004	share (%)
Agriculture	1.57	2.12	2.13	82
Domestic	0.18	0.27	0.29	12
Industry	0.09	0.12	0.12	5
Tourism	0.02	0.02	0.02	1

Source: BPEH 2005.

3. Agricultural Water Use

Rainfed farming systems are based primarily on cereal and olive cultivation. Livestock, mainly sheep, is also a major component. Vegetables are produced in small areas under irrigation; however, their social role is very important since they absorb a large labor force and represent a source of revenue for many rural communities. The most cultivated species are: tomato which is used either for direct consumption or for the canning industry, potato and pepper. Table (3) gives the overall distribution of major crops in Tunisia where both the rainfed and the irrigated sectors are considered together.

Table 3. Distribution of the Major Crops in Cultivated Areas

Crops	Area (%)
Trees (mostly olive)	9
Cereals	37
Forage	9
Vegetables	4
Legumes	2
Other Crops	1
	4

Source: DGEDA 2006.

Small-scale irrigation based on water from wells, rivers, water diversion systems and flood water spreading have been practised in Tunisia for centuries. Large scale irrigation works based primarily on dam construction and large water conveyance structures witnessed an important development during the second half of the last century and resulted in an important expansion of the irrigated lands.

According to the latest survey conducted by the Government (DGEDA, 2006), the total area effectively irrigated is 330 000 ha and in terms of irrigated crops, the statistics give a value of 405 000 ha , since there are more than one crop on the same parcel per year for vegetables. Surface water stored in dams is used in relatively well equipped irrigation districts. In central Tunisia, most irrigated lands use water from shallow wells; whereas in the south, deep aquifers are the main source for irrigation (Table 4). Shallow wells are privately owned, which is an advantage for the implementation of best irrigation scheduling practices. They are however exposed to the risk of salinization because of over exploitation.

Table 4. Water Origins and Shares (%) in Northern, Central and Southern Tunisia

Source	Country	North	Centre	South
Shallow wells	48	32	71	35
Dams	21	42	6	0
Deep aquifer	25	16	19	64
Others	6	10	4	1

Source: DGEDA 2006.

The private sector owns more than 60 % of the total irrigated surfaces nation-wide. However, its share varies tremendously from one region to another and represents 50 %, 75 % and 90 % of the irrigated areas respectively in the northern, central and southern regions. The participatory approach introduced during the 1990's allowed the establishment of many Water Users Associations (WUA) with the task of contributing to agricultural development. Presently there are about 3000 WUA's.

4. The Irrigated Crops

The earliest strategies on irrigation was favoring cash crops. These included vegetables produced off season and fruits aimed for exports and some industrial species such as sugar beet aimed at reducing the burden of importing commodities for local consumption. During the last twenty years profound institutional changes have occurred in order to enhance productivity of the agricultural sector. The practice of supplemental irrigation has been adopted on a large scale. Olive and wheat cultivation from strictly rainfed jumped to take respectively the first and second rank in irrigated crops, and the cultivation of the highly water consuming crops such as sugar beet has been totally abandoned.

Table 5. Major Crops in the Irrigated Areas (%)

	North	Center	South
Fruit trees	33	36	61
Vegetables	37	33	18
Cereals	14	19	2
Forage	13	11	17
Legumes	1	1	1
Others	2	0	1

Source: DGEDA 2006.

Fruit trees cover 160 000 ha and represent about 50 % of the total irrigated lands. Intercropping is practiced in central Tunisia and represents the main cropping system in the oases where date palms are grown in association with many fruit species and vegetables. Table (6) gives major tree species cultivated under irrigation and shows the relative importance of olive, citrus and palm trees. On the other hand, vegetables occupy about 87 000 ha of land, but with intensification they actually represent about 130 000 ha (in these respective percentages: 25%, 23% and 19% of, tomato, potato and pepper. For cereals the figures are respectively 48 000 ha and 58000 ha for land occupation areas and cropped areas, with durum wheat as a major species.

Table 6. Percentage of Major Irrigated Tree Species

Crops	Percent of Area (%)
Olive trees	31
Olive in association	5
Citrus	10
Apples	7
Pear	4
Peach	4
Grapes	4
Grenades	3
Palm in association	18
other	14

Source: DGEDA 2006.

5. Research on Water Use Efficiency (WUE)

Many projects have been implemented in order to address the issue of water productivity in agriculture. It is possible to list here projects that have had a direct impact on the decision-making process and contributed to the increase of awareness at various levels. To this respect, the National Programme on Supplemental Irrigation is probably a land mark to a series of measures aimed at improving water productivity in the agricultural sector. It was launched in the late 1980's following active research efforts on the irrigation of wheat that started 15 years earlier. The objective was to adopt *supplemental irrigation* in a sector that was totally rainfed. Backstopping of this ambitious work was provided at the beginning by "Projet d'appui au programme national d'irrigation d'appoint des céréales, UNDP/FAO/TUN /86/014".

The regional project UNDP-RAB-90-005 on "Supplemental irrigation and improvement of water management in the irrigated areas" was launched on the basis of experiences gained in Tunisia and Egypt. Its aim was to promote collaboration between Arab countries which have the potential to improve irrigation performances at the field level particularly for wheat production.

The regional project UNDP-RAB-89-003 on "Current technologies in water resources management in the Mashrek and Maghreb" was an extension of previous projects implemented in the Maghreb region concerned with the development of water supply. As it was structured, this project helped the transfer of appropriate technologies between North African and Middle Eastern countries having similar environments. It promoted practices about monitoring and water resources development at the watershed level. It also enhanced knowledge about groundwater recharge and protection.

The IAM-Bari irrigation network established in 1993 was intended to develop synergies among teams working on water use efficiency, management of irrigation systems and the use of saline waters in agriculture.

The ICARDA initiative (1995) concerning the "On farm water husbandry" addressed the issue of water harvesting techniques and showed its potential for improving agricultural production in the dry areas of West Asia and North Africa.

The EU WASIA project came to consolidate the available knowledge and to promote capacity building in the subject matter of water management. WASIA was carried out within the framework of the national federative project "Besoin en eau et systèmes de culture" with funding from the Government of Tunisia, the World Bank and the Belgian Cooperation Agency. The productivity of water in agriculture and possibilities of its improvement has been investigated under this program. Moreover, an important effort has been deployed in terms of capacity building at the national level.

Research on water saving is presently continuing within the ICARDA regional project Water Benchmarks and the European-funded project DIMAS. The objective is to assess the impact of supplemental and deficit irrigation on yield for major Mediterranean Agricultural Systems.

VI. WUE-Estimates

WUE is defined as the ratio of marketable yield to the water used (Kg/m^3). The WUE figures presented in this document are obtained from work concerned primarily by development. Estimates correspond to three categories: i) regional figures which are obtained from production statistics and rainfall data, and are considered to represent the actual average values; ii) data from surveys and monitoring of private farms, in order to have current values at the field level; and iii) research data obtained from field experiments either in research station or in well managed private fields, on large plots under the full intensity of local environments. In our judgment the three categories represent respectively the regional, the current, and the attainable yields. Table 9 presents average values of WUE obtained for major crops.

Under rainfed conditions crop evapotranspiration is considered as the effective rainfall during the growing season including the pre-planting period. Estimation of effective rainfall for a given crop uses the USDA methodology which is based on average evapotranspiration, soil holding capacity and root depth.

For irrigated crops, reliable data on irrigation water and yields in large scale irrigation districts is rare, so no regional estimates are produced. Only results from local surveys and research work are presented here.

In the case of olive, sets of even successive years have been used for average values calculation because of error risks associated with alternate bearing.

Table 9. WUE of major crops obtained under rainfed and irrigated conditions. Figures are given in terms of marketable yields per total water supply (Kg/m^3).

Crop	Supply(mm)	WUE(kg/m^3)	Comments
Wheat	200-700	0.1-0.6	rainfed, estimated from district statistics and
	400-800	0.5-1.0	rainfall data.
	350-600	0.9-1.7	irrigated, farms under current management practices.
			irrigated, fields under optimum management and/or research investigation. Potential is estimated = 2.0 kg/m^3).
Olive	200-500	0.3-0.5	rainfed, commercial farms in the arid
	500-800	0.8-1.2	and semi arid areas.
			irrigated, commercial farms with productive
	500-800	0.3-0.5	local varieties, experimental plots. Potential is estimated = 1.6 kg/m^3.
			irrigated (orchards with actively growing young trees and/or with less productive table varieties).
Potato	440-570	2.5-3.5	Irrigated, private fields under furrow irrigation with saline waters.
	400-550	2.5-7.5	irrigated, private fields under drip irrigation
	250-400	8.3-9.5	with saline waters.
			irrigated, private/research fields under optimum management and drip irrigation with saline waters. With good quality waters WUE = 11.4 kg/m^3.
Tomato	450-550	4.0-6.5	private fields, furrow irrigation, local vari-
eties,			
	550-850	6.5-12.5	low inputs
			private fields, drip irrigated, intensive production systems.
Barley	200-350	0.1-0.6	rainfed, estimated from districts statistics
	250-450	0.9-1.2	and rainfall data
			550-850 irrigated, saline water but good management.
Citrus	800-1000	3.0-5.0	irrigated, furrow system, good management
Peach	1000-1200	3.3-4.1	irrigated, good quality water, good management
Apple	800-1000	4.0-6.0	irrigated, intensive, good quality water, good management

Sources: INAT MS theses: Oueslati, Jenouane, Rezgui, Mekki, Ghrab, Ben Mrad, Ben Issa, PhD Nagaz and unpublished data

Table 9 shows that there is a gap between local performances and results obtained under research conditions. Observed highest values, although do not represent necessarily many common situations in the country, give an estimate of the attainable levels. Regardless of the data precision, there is definitely high potential of improving water productivity by adopting appropriate practices and good irrigation strategies exists.

VII. Summary and Conclusions

Water Use efficiency (WUE) refers here to the ratio of commercial yields per unit of water used. Water consumption is assumed to be the total supply from effective rainfall and/or irrigation in most cases; but for research figures, changes in the soil water store is included in the calculation. Using regional production statistics and surveys, WUE values are estimated under a range of conditions for the two major crops: olive and cereals which cover together about 70% of the cropped area. For cereals values of 0.5, 1.0, 1.5 and 2.0 Kg/m^3 could be used respectively as current, attainable, optimum and potential values. For olive production, ratios seem to follow the same trend but probably with lower absolute values i.e., within the range 0.4-1.6 Kg/m^3. For horticultural crops there are dependable figures for potatoes, tomatoes, citrus, peach and apple grown under irrigated conditions. WUE varies basically within a range of 3 to 12 Kg/m^3 for vegetables and 3 to 6 kg/m^3 for fruit trees.

Beyond the precision associated with the presented values, the potential for improvement, as estimated by the gap between the current figures and the attainable yields is high. The water factor in the case of olive and cereals has an overriding impact. This suggests that fine tuning of the practice of supplemental and deficit irrigation, are key solutions to the improvement of WUE, in the irrigated areas, whereas, in strictly rainfed areas, progress could be achieved by improving the buffering role of the soil in order to reduce the impact of drought. For horticultural crops, irrigation is important, but the used cultivars and cultural practices have major impacts on productivity. For instance in the case of tomatoes large differences are observed between hybrid and fixed varieties, whereas for apple any inappropriate choice of the training systems of trees could have a disastrous result. For irrigated horticulture, WUE improvements could be envisaged by considering two major systems: i) intensive systems with highly productive cv, sophisticated management and high investments or ii) semi intensive systems with a reasonable combination of low inputs and management practices. The second option has the advantage to suit farmers with low risk bearing capacity and probably responds better to some environmental concerns. However it requires the development of many variants of cropping patterns to suit the different local conditions.

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WATER USE EFFICIENCY OF MAJOR CROPS IN TURKEY

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Summary

Water scarcity, poverty, under- and malnourishment and environmental stress co-exist in many parts of the world. In both rainfed and irrigated food production systems, the potential to improve water productivity, i.e., to produce more food per unit of water, is substantial. Measures required include: Improved management of water in irrigated and rainfed agriculture, based on secure water use rights and land tenure. Improvement of biological, chemical and physical properties of the soil through appropriate tillage practices; dryspell mitigation though rainwater harvesting and supplementary irrigation; effective arrangements and support services for marketing, affordable credit, technological improvements and extension services, with particular focus on rainfed agriculture. Investment in new irrigation and storage infrastructure and improved management of existing irrigation committed and additional withdrawals are impossible. Sinking groundwater tables are a serious problem in developed as well as developing countries. A real challenge is inter-sector competition, including growth in urban and environmental demand, which moves water from irrigation into higher value urban and industrial uses, and increasing water pollution (Howell, 2006; Kassam et al., 2006; Molden et al., 2001).

After several decades of publicly funded surface irrigation, and more recently of privately developed groundwater irrigation, remaining opportunities to harness new resources for agriculture are fewer and more expensive. Investment is increasingly focused on rehabilitating and improving the existing systems. However, water productivity remains generally low especially in large-scale irrigation. New solutions are needed, based on new management options and widely available technologies. The role of government is changing; responsibility is being decentralized, farmers are playing an increasingly important role in decisions and investment. How to meet the ever rising demand for food while at the same time increasing farmer incomes, reducing poverty, and protecting the environment, all from an increasingly constrained water resource base; is the main challenge facing agricultural water management (AWM) according to the World Bank, (2006).

A comparatively liberal supply of heavily subsidised water encourages inefficiency and lack of reliability. With growing urban centers, the context is changing. Farmers in many irrigation systems are seeing “their” water being reallocated to cities or, increasingly, released back to rivers and streams to improve environmental flows.

This paper reviews results of the research carried out by Universities and various research

institutes on water use efficiency for the major crops (wheat, cotton, corn, soybean and sunflower) in the arid and semiarid areas of Turkey. The great challenge of the agricultural sector is to produce more food from less water, which can be achieved by increasing water use efficiency (WUE) or Crop Water Productivity (CWP). Based on a review of 90 literature sources with results of experiments, it was found that the ranges of WUE of wheat, cotton, maize, soybean and sunflower exceed in all cases those reported by FAO earlier. Experimentally determined WUE values ranged from 0.42 to 1.50 kg/m^3 for wheat; 0.16 to 1.54 kg/m^3 for cotton; 0.75 to 2.86 kg/m^3 for corn; 0.26 to 1.07 for soybean; and 0.17 to 0.82 kg/m^3 for sunflower.

Efficiency in the use of water for irrigation consists of various components and takes into account losses during storage, conveyance and application to irrigation plots. Identifying the various components and knowing what improvements can be made is essential to making the most effective use of this vital but scarce resource in Turkey's cultivated areas. Enhancements in water use efficiency (WUE) depend on productivity gains, depicted by consistent increases in outputs per unit inputs and the irrigation techniques.

1. Introduction

Turkey occupies a total area of about 78 million ha, of which about 1.1 million is inland lakes. Turkey forms a bridge between Europe and Asia, with about 3 percent of its land in Europe and the rest is in Asia.

The growing world population will result in considerable additional demand of food. Simultaneously, water demand from non-agricultural sectors will keep growing in both developed and developing countries. A recent FAO analysis of 93 developing countries expects agricultural production to increase over the period 1998–2030 by 49% in rainfed systems and by 81% in irrigated systems (Anonymous, 2003). Therefore, much of the additional food production is expected to come from irrigated land, three quarters of which is located in developing countries. The irrigated area in developing countries in 1998 nearly doubled that of 1962. There are many reasons to believe that such rapid rate of expansion will not continue in the next decades. FAO estimates that the irrigated area in the selected 93 developing countries will only grow by 23% over the 1998–2030 period. However, the effective harvested irrigated area (considering the increase in cropping intensity) is expected to increase by 34% (Playan and Mateos, 2006).

Population increase and the improvement of living standards brought about by development will result in a sharp increase in food demand during the next decades. Most of this increase will be met by the products of irrigated agriculture. At the same time, the water input per unit irrigated area will have to be reduced in response to water scarcity and environmental concerns. Water productivity is projected to increase through gains in crop yield and reductions in irrigation water.

FAO expects that the withdrawal of irrigation water in the 93 countries of its study will grow during the period 1998–2030 by only about 14%, a small increase compared to the projected increase in the irrigated area. Crop water consumption per unit area is expected to decrease by 3%, and gross crop water use by 16%. FAO explains most of this difference by an expected improvement in irrigation efficiency, that should result in a reduction in the water withdrawals per unit of irrigated area. Another part of this reduction will be due to changes in cropping patterns for some countries, such as China, where a substantial shift from rice (high-water demanding crop) to wheat (low-water demanding crop) is expected (Playan and Mateos, 2006).

The International Food Policy Research Institute (IFPRI) recently performed a study focusing on water productivity based on assumptions slightly different to those of FAO (Cai and Rosegrant, 2003). This study concluded that the average water productivity of cereals other than rice will increase in the period 1995–2025 from 0.56 to 0.94 kg.M^{-3} in developing countries and from 1.00 to 1.32 kg.M^{-3} in developed countries. The major expected contribution will come from the increase of crop yield. Therefore, the goal to meet the projected water productivity needed to feed the growing population will be challenging breeders, agronomists and irrigation specialists in the upcoming years.

Scarce water resources and growing competition for water will reduce its availability for irrigation. Achieving greater efficiency of water use will be a primary challenge for the near future and will include the employment of techniques and practices that deliver a more accurate supply of water to crops. In this context, deficit irrigation can play an important role in increasing water use efficiency (WUE).

Increasing water scarcity and competition for the same water from non-agricultural sectors drive the need to improve crop water productivity to ensure adequate food for future generations with the same water presently available to agriculture. Quantifying crop water productivity reveals gaps in knowledge regarding the best ways to increase crop water productivity. However, one cannot deny the possibility of breakthroughs in molecular breeding and advances in the identification of interventions that will lead to improved crop water productivity at various scale levels.

2. Climate of Turkey

Turkey is under effect of both maritime and continental weather patterns, which cause extreme geo-climatic diversity when combined with a highly varied topography. The Mediterranean region (southern coastal region) is regarded as sub-tropical, characterized by hot, dry summers and mild, rainy winters. The Black Sea region receives rain throughout the year and lives both mild summers and winters. The Aegean Region (Western Anatolia) has mountains which run roughly east to wes. Central Anatolia is a vast high plateau with an average altitude of 1,000 meters above sea level and a semi-arid continental climate, i.e., hot and dry summers.

The average annual temperature varies between 18-20°C on the south coast, falls to 14-15°C on the west coas. The annual average precipitation is 643 mm, but it varies from 250 mm in the central part to 3000 mm in the Eastern Black Sea region. About 75 percent of annual rainfall is received in the winter season. Except for the coastal areas, Thrace and Eastern Anatolia, annual rainfall is less than 500 mm; therefore irrigation is of paramount importance (Fig.1)

Generally, agricultural production is adversely affected by the shortage and inconsistency of the rainfall during the growing season. Moreover, it is possible to have 2-3 crops from irrigated areas by allowing 270-day crop growing seasons. However, some crops may be harvested before maturation, particularly in Eastern Anatolia with its 60-90 growing days. The southeast region records very low humidity levels. The coastal regions have quite high levels being in line with precipitation rates. Inevitably, the topographical features are main factors shaping the distribution. The long-term annual evaporation rates indicate a high rate particularly in the southeast region, which receives almost no rainfall during the summer and reaches more than 2000 mm per year (Map 1 and Map2).

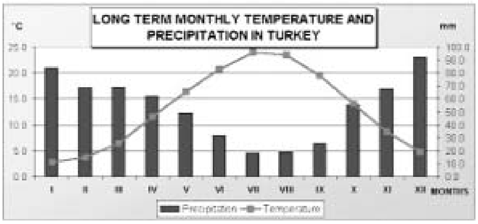
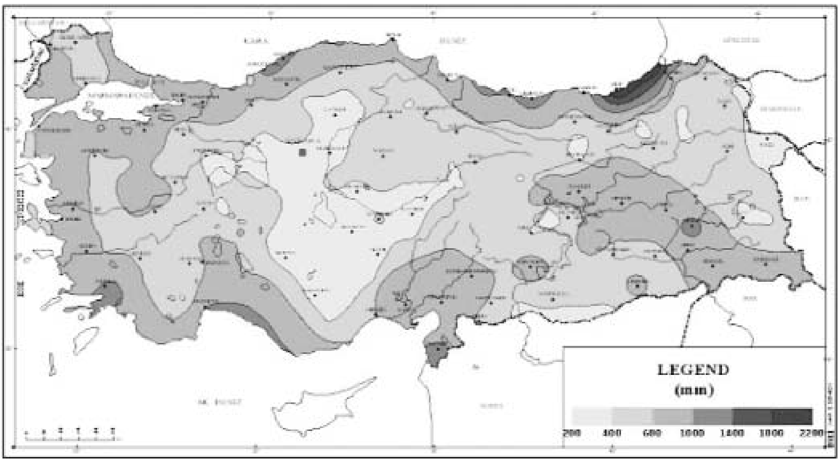
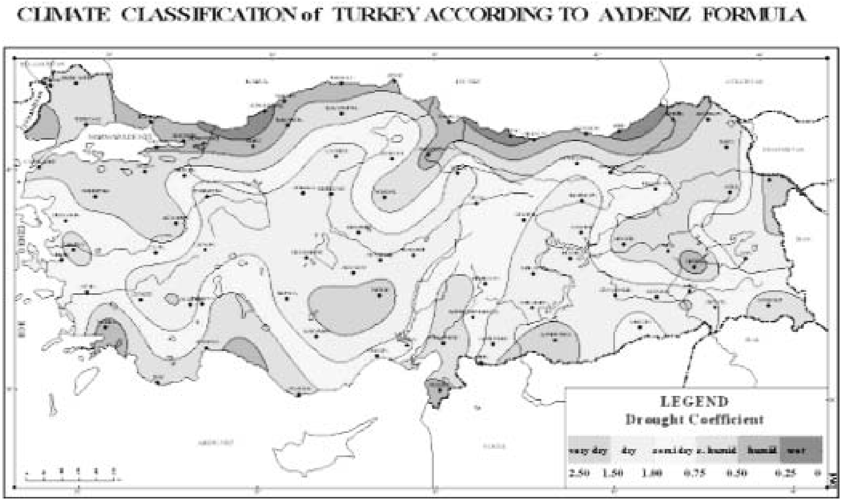


Figure 1. Long-term Monthly Mean Temperatures and Precipitation in Turkey. (www.meteor.gov.tr)



Map 1. Average Annual Precipitation Distribution in Turkey (www.meteor.gov.tr)



Map 2. Climate Classification of Turkey- (www.meteor.gov.tr)

3. Land Potential in Turkey

The total area of Turkey is 78 million ha, separated into 28.05 million ha of arable lands, 21.51 million ha of pastures, and common grazing lands, 1.17 million ha of water surfaces areas, 23 million ha of shrubs, and forests, 3.95 milion ha of residential areas (Table 1). Of the arable land, 25.85 million ha is irrigable and 2.21 million ha is non-irrigable land. Table 2 Shows the arable, non-arable and irrigable and rainfed areas in the country.

Table 1. Land Cover in Turkey (Million ha)-(GDRS*, 2003)

Land Cover	Total	% Cover
Agricultural	28.05	36
Rangeland	21.51	27.6
Forests	23.23	29.8
Residential	3.95	5.0
Water bodies	1.16	1.5
Total	77.90	99.9

*GDRS: General Directorate of Rural Services.

Table 2. The Distribution of Arable Land in Turkey- (GDRS, 2003)

Land	Area (10^6 ha)
Arable Area	28.05
Non-irrigable Area	2.20
Irrigable Area	25.85
Sloped Area	9.34
Plain Area	16.51
Arable Area (today)	
Special Farming	1.40
Irrigated Farming	4.90
Dryland Farming	22.35
Fallow Dry Farming	16.52
Non-Fallow Dry Farming	5.83

It should be noted that important changes have taken place with respect to land use. The area, which can be made available for irrigation, is estimated by DSI (State Hydraulics Works) at 8.5 million ha gross area (6.4 million ha for major irrigation projects), of which about 4.9 million ha has already been under irrigation.

4. Water Potential in Turkey

The average annual precipitation of the country is 642.6 mm, which corresponds to a water potential of 501 Km^3 per year. Runoff amounts to 238 mm, an average rate of 37 %, and the remaining 63% is lost to evapotranspiration. A certain amount of the runoff is allocated to meet the water rights and requirements of the neighboring countries. The amount of surface water, which is utilized for consumptive purposes, is in the range of 95 Km^3 per year. According to the studies based on groundwater resources, the total safe yield of groundwater resources is estimated to be 14 Km^3. The potential of total available water resources from surface flow and groundwater plus water coming from neighboring countries (3 Km^3) would amount to 112 Km^3 per year (Table 3).

Table 3. Water Potential of Turkey- (DSI 2006)

Average Annual Precipitation: 643 mm Water Potential from Precipitation: 501 km^3	
Surface Water Potential, km3	Km^3
Annual Flow	186.05
Runoff Coefficient	0.37
Utilizable potential	95.00
From neighboring countries	3.0
Annual Reserve of Groundwater	14
Total	112

5. Irrigation Development in Turkey

Irrigation plays a key role in the efforts to diversify and improve the productivity of Turkey's agriculture. But out of 8.5 million ha considered suitable for irrigation development, only 4.5 million ha have been developed to-date. In the Southeast of the country, approximately 1.7 million ha will be developed within the framework of GAP (Southeast Anatolia Project), involving some 13 major schemes/projects and with a time frame likely to be in 20 years.

Out of the cultivable area of 28 million ha, almost 26 million ha are classified as suitable for irrigation. Considering the water resources, this area is reduced to 12.5 million ha. When economic considerations are brought in, the official estimated irrigation potential of Turkey is 8.5 million ha, of which 93% would be from surface water resources and 7% from groundwater.

As of 2003, the total water managed area was estimated at almost 4.2 million ha, or 49 % of the irrigation potential of 8.5 million ha. Over 3.1 million ha have so far been developed by the public sector, compared with less than 0.5 million ha in 1965. Irrigation development in the country is shown in the Table 4 below.

Table 4. Irrigation Development in Turkey- (Tekinel, 2003)

Agency Responsible for Development	Irrigation Development Area (ha)
State Hydraulic Works (DSI)	2 340 200
GDRS	1 002 250
Private and others*	1 000 000
Total Irrigation Equipped Area	4 342 450

* Other agencies: irrigation cooperatives, heads of villages, municipalities, some state organizations.

On public schemes, the national average of the irrigation ratio (the part of the equipped area actually irrigated) varies between 64 and 72% with wide regional and annual fluctuations. Overall irrigation efficiency in DSI operated irrigation schemes is about 45%.

Almost 94% of the total area is irrigated using surface irrigation methods (furrow, basin, border, wild flooding). The remaining part is under sprinkler irrigation (mainly hand-move) and some micro-irrigation. The conventional (hand-move) sprinkler irrigation is common all over Turkey and estimated 200 000 ha are irrigated using this method. On DSI schemes, 63 849 ha are irrigated by sprinklers, mainly for sugar beet, cereals, beans, alfalfa, cotton, sunflower, water melons and vegetables. Micro-irrigation is practiced on 386 ha of DSI schemes, mainly for citrus, vineyards, vegetables, strawberries and watermelons. However, in recent years, drip irrigation systems has been also used for irrigating row crops such as cotton and corn (Yazar et. al., 2002).

During the last three decades the GDRS has carried out a lot of on-farm water development works, for example the reclamation of saline and alkaline soils on 803 000 ha and open drains on 3 143 000 ha. In 1992, about 223 000 ha were estimated to be power drained. The flood protected area amounted to almost 800 000 ha in 1994. It was estimated in 1992, that of the total area operated by DSI, about 41 000 ha was salinized by irrigation.

In several areas, problems are emerging as urban activities encroach into agricultural lands. There is an increasing interest in using the land as a vehicle for the treatment and disposal of the wastewater from agri-business and urban activities. In particular there is current concern about the use of polluted water resources to irrigate agricultural lands, especially in western Turkey, which has been experiencing water shortages on a regular basis in recent years.

A regional agricultural development project, the South East Anatolian Project (GAP), is planned for the lower Euphrates river and the Tigris river basin within the boundaries of Turkey. The project involves the integrated development of irrigated agriculture and agroindustry, and supporting services, including communications, health and education. It includes 13 major projects of which 7 are in the Euphrates basin and 6 in the Tigris basin. After full development it will include 22 darns, 19 hydroelectric power plants and the irrigation of almost 1.7 million has.

6. Water Withdrawals

In 1992, total annual water withdrawal was 31.6 Km^3, of which agricultural use accounted for 72.5% (16.4% is withdrawn for domestic use and 11.1% for industrial use). About 24% of total water withdrawal, or 7.6 Km^3, was estimated to be groundwater, of which 3.7 Km^3 for agricultural purposes. Almost 98% of the urban and 85% of the rural populations have access to safe drinking water. The treatment of domestic wastewater is estimated at 0.1 Km^3/year. The total annual water withdrawal is 42.0 billion m^3 for whole country by 2000. Estimated sectoral annual water requirements and water consumption in Turkey is given Table 5 and Table 6. The total development of water resources by public institutions in several sectors reached 32 billion m^3 in 1994. Almost 75 % of these developed water resources are being used for agricultural purposes. In 2003, 40.1 billion m^3 volume of water was consumed in various sectors in Turkey; 29.6 billion m^3 in the irrigation sector, 6.2 billion m^3 in the water supply sector, 4.3 billion m^3 in the industrial sector.

Table 5. Water Requirements for Turkey (DSI)

Year	Total (10^6 m^3)	Sectoral Use		
		Domestic (10^6 m^3)	Irrigation (10^6 m^3)	Industrial (10^6 m^3)
1990	43.300	5.900	32.300	5.100
1995	50.600	7.400	37.000	6.200
2000	58.100	9.000	41.800	7.300

Table 6. Water Consumption for Turkey (DSI)

Year	Total Consumption Million (m^3)	Development (%)	Sectoral Consumption		
			Domestic Million (m^3)	Irrigation Million (m^3)	Industrial Million (m^3)
1990	30.600	28	5.141	22.016	3.443
1992	31.600	29	5.195	22.939	3.466
1995	33.500	30	5.300	24.700	3.500
2000	42.000	38	6.400	31.500	4.100

7. Institutional Environment

There are two governmental organizations involved in major irrigation and drainage development: The State Hydraulic Works (DSI) was established in 1954 as a legal entity and brought under the aegis of the Ministry of Public Works and Settlement .The DSI is responsible for the planning, design, construction and operation of water resources development for various purposes like irrigation, flood control, swamp reclamation, hydropower development, navigation and water supply to cities with over 100 000 inhabitants.

The General Directorate of Rural Services (GDRS) was established in 1984 by incorporating several organizations like soil conservation, irrigation, rural settlements and roads, water and electricity into one organization. It is responsible for the development of small-scale irrigation schemes and small reservoirs, rural roads and water supply to rural areas. It is also responsible for land consolidation and the on-farm development of all irrigation projects, including the projects developed by DSI. It was formerly under the Ministry of Agriculture and Rural Affairs, but now falls under the Prime Minister's Office.

8. Trends in Water Resources Management

Turkey began an accelerated program of transferring management responsibility for large irrigation systems to locally-controlled organizations in 1993. As of 2006, the national irrigation agency, DSI, had succeeded in transferring nearly two million ha, or 75% of the publicly-managed irrigation in the country, to local government units or to special-purpose Irrigation Associations (IAs) created at the local level. Important motives driving this fast-paced implementation were: (a) rapidly escalating labor costs; (b) a hiring freeze on government agencies; and (c) consequent concern over the agency’s ability to operate and maintain systems serving the expanding irrigated area for which it was responsible.

From the point of view of water use, some large-scale irrigation projects operate in an inherently in-efficient way. Where water is delivered to the users on a fixed schedule and charges are imposed on a flat rate regardless of the actual amount used, users tend to take as much water as they can. This often results in over irrigation, which not only wastes water but also causes project-wide problems connected with the disposal of return flow, water logging of soils, leaching of nutrients, and elevation of the water table requiring expensive drainage. Although it is difficult to arrive at reliable statistics, it has been estimated that the average irrigation efficiency in such schemes is probably well below 50% (and may be as low as 30%). Since it is a proven fact that, with proper management, it is possible to achieve irrigation efficiencies as high as 85% or even 90%, there is an obviously much room for improvement (Tekinel et al., 1990).

8.1 Participatory Irrigation Management in Turkey

The international literature on irrigation management has long used the terms "Water Users' Association" and "Irrigators' Group" in discussing irrigation management institutions. The term Water Users' Association (WUA) usually refers to a local-level organization based on the active involvement of water users who come together for the purpose of organizing and practicing irrigation system operation and maintenance. The term "Irrigators' Group" suggests a less formal grassroots collective effort aimed at operating and maintaining lower level facilities in an irrigation scheme. In order to avoid misunderstandings regarding the social and institutional characteristics of the organizations involved, we will therefore use the term Irrigation Association (IA) to refer to the organizations which have been formed for the purposes of managing irrigation units covering more than one village or municipality. The term Irrigation Group (IG), correlates literally with the corresponding Turkish term.

In general, user organizations are responsible for operation and maintenance (O&M) of irrigation schemes transferred to them according to the agreement signed by the involved parties. The users organizations are:

- Irrigation Group
- Irrigation Cooperative
- Water User Association
- Village Legal Entity
- Municipality

8.2 Water Users' Associations (WUA) and Irrigation Associations (IA)

Irrigation Associations are formed under the Municipality Law, No 1580, which allows for associations made up of local government entities to be established. Municipal legislation and implementing regulations were obviously not written with Irrigation Associations in mind, however, and questions related to the appropriateness of municipal law as applied to IAs have arisen.

8.3 The Irrigation Group Program

Since the early 1960s, DSI had a program to transfer O&M responsibility for secondary and tertiary distribution networks to Irrigation Groups (IGs). Under this program village headmen (muhtars) or mayors of municipalities, designated as heads of Irrigation Groups, take administrative responsibility for tasks such as collecting and submitting farmer water demand application forms, managing water distribution below the secondary canal, and cleaning and minor repair of canals, siphons, and kanalets.

- The daily water allocation for each tertiary canal is based on the crops and crop areas shown on farmers' request forms. Flow rates and total water use are measured and recorded at each major canal branch.

Maintenance
DSI maintenance and repair activities are guided by a "Maintenance and Repair Manual" adapted from a United States Bureau of Reclamation Manual. Maintenance requirements are assessed annually by DSI inspection teams. These teams inspect irrigation and drainage facilities and prepare a costed list of maintenance and repair requirements for each scheme. This work consists mainly of maintenance and repair of canals, kanalets, sediment removal and weed control along waterways, and grading of roads. Only large and complicated work is awarded to private contractors.

The farmers are not charged any fees based on the resource value of the water they use for irrigation. They pay an annual area-based fee to recover the costs of operation, maintenance expenses, and the capital cost of the project.

Institutional Issues
There are problems of lack of coordination, overlapping duties in the same area by several organizations, hence wasting time and money. Lack of coordination and synchronization of activities among the concerned institutions has resulted in a significant number of unfinished irrigation and drainage schemes. This has also caused inefficiency and frequently decreased the potentials of irrigation practices by the farmers, while further eroding potentials for sustainability.

Water User Associations have many problems associated with finance, administration and machinery. Some irrigation schemes are still operated by DSI.

Irrigation development in Turkey has been hampered by inappropriate investment management, which is manifested at the start-up of many new irrigation projects, excessively long completion periods, low economic rates of return (ERRs) to irrigation investment.
There is no owner or responsible organization of on-farm works (subsurface drainage , quarter canals, farms access roads, land levelling, some civil works etc.) done by GDRS and left as it is after installation. As a result of the irrigation management deficiencies, subsurface drainage and several other on-farm works need to be repeated at some 15-20.

All rural infrastructural services are provided by GDRS. Here, there are two main problems: there is almost no involvement of the beneficiaries and there is no environmental concern at the stage of project preparing and implementation.

Technical and Training Issues
Extension on irrigated agriculture is not effectively delivered by the Ministry of Agriculture. Land and water management advice is not clearly included in the extension programs for the improved management of land and water.

The coverage of piped and pressurized irrigation system has very small percentage (less than 5%) of overall irrigated area. The prevailing irrigation system in Turkey is the conventional surface methods.

Because of the lack of training all the concerned parties are not aware enough of the situation and the measures to be taken.

DSI and GDRS are technical (engineering) organizations and do not have specialists to address the socioeconomic and environmental aspects of land and water management, including costs benefits analysis, collective choice arrangements, monitoring, conflict resolution mechanisms etc.

9. Water-related Constraints to Sustainable Agriculture

In Turkey, 90% of irrigation canals are concrete lined. These increases the conveyance efficiency in the system. But overall water use efficiency is about 40% ranging from 10% to 70%. Those indicators show a deficiency in irrigation water management. Runoff, drainage and deep percolated water from irrigated lands contain high level of agricultural chemicals, as a result of over fertilizer and chemical usage.

Rapid irrigation development and poor water management have put pressure on natural resources. In some irrigation schemes, the drainage water is reused or flow to marches threatening endangered wild life. Some drainage discharges and city sewage seriously threaten some lakes, estuaries and marine life as well.

Sediment accumulation in dead storage of dams and reduction of available water for irrigation and domestic use is threatening irrigated agriculture in many locations because of sever soil erosion from upper watersheds.

Water is conductive medium for the spread of diseases carrying bacterial and viral pathogens. The risk that one or more of those diseases are introduced or have impact is significant in irrigation schemes where land drainage is poor or badly maintained and where there are new settlements of immigrants at the suburbs of big cities.

10. Overview of Agricultural Sector Development

Total agricultural area of 39 million ha consists of arable land (24 million ha), permanent crops (2.5 million ha) and permanent meadows and pastures (12.7 million ha). Fallow land makes up more than 20 % of total arable land. Family owned farms form the basis of agricultural production, and family members provide most of the farm labour. There are 3 million agricultural holdings, mostly fewer than 5 ha. The national average farm size is 6.1 ha, with an average number of 6 plots.

Cereals, especially wheat and barley, are Turkey's most important crops. With production of 21 million tons in 1998, the country ranked 7th in the world in wheat production, 8th. in barley. Except for certain processed products, wheat is not an export crop.

Turkey's most important agricultural exports are tobacco, cotton, dried fruit (hazelnuts, seedless raisins, figs, apricots), pulses (chickpea and lentil), live sheep, goats, fresh fruits (apples and citrus fruits) and fresh tomato.

WATER USE EFFICIENCY CONCEPT

Water use efficiency (WUE) represents a given level of biomass or grain yield per unit of water used by the crop. With increasing concern about the availability of water resources in both irrigated and rainfed agriculture, there is renewed interest in trying to develop an understanding of how WUE can be improved and how farming systems can be modified to be more efficient in water use.

Large amounts of water evaporate through crop plants, normally several hundred kg of water per kg of biomass produced. In some rainfed systems, only 5% of the rainfall or less is consumed as transpiration (T). In irrigated systems, some 30% of the water input is considered normal as transpirational losses. There are, therefore, substantial opportunities to increase the proportion of rainfall and irrigation water that is used consumptively in agricultural systems, thus improving the efficiency of water use.

Sinclair et al. (1984) described WUE on various scales from the leaf to the field. In its simplest terms, it is characterized as crop yield per unit water use. At a more biological level, it is the carbohydrate formed from CO_2, sunlight, and water through photosynthesis per unit transpiration.

Tanner and Sinclair (1983) summarized the different forms of relationships that have been used to characterize WUE. Most researchers describe WUE as:

WUE = Crop yield (usually the economic yield)/ Water used to produce the yield

$$WUE = Y/ET \quad (1)$$

where *Y* is the yield of the crop, either in total harvest source biomass or marketed yield, and *ET* is the evapo- transpiration of water from the soil surface, plant leaves, and through the stomates (transpiration).

The water use in Equation (1) is difficult to determine precisely. So, in some situations, a "benchmark" WUE (WUEb) is used by many irrigation practitioners. It can be defined as

WUEb = Yield (usually the economic yield)/(Pe+ I+ SW) (2)

where Pe is "effective" rainfall, I is irrigation applied, and SW is soil water depletion from the root zone during the growing season. The denominator of Equation (2) is a surrogate estimate for the water used to produce the crop neglecting percolation, ground water use, and surface runoff.

The concept of water productivity (WP) is offered by Kijne *et al.* (2003) as a robust measure of the ability of agricultural systems to convert water into food. While it was used primarily to evaluate the function of irrigation systems – as 'crop per drop'.

For agricultural systems, WP is a measure of output of a given system in relation to the water it consumes. Assessment may be required for the whole system or parts of it, defined in time and space (Cook et al., 2006).

WP = Agricultural Benefit / Water use

Scientists and engineers will continue to discover and disseminate new information regarding the technology of water management. However, the effective demand for that information at the farm level will be limited in areas where water prices and allocations do not reflect scarcity conditions. The rate at which improvements in water management are implemented by irrigators around the world might be enhanced substantially by replacing inappropriate policies with those that motivate farmers and others to use scarce resources efficiently.

Irrigated agriculture is often seen as a water source for alternative uses, given the large proportion of the diverted water that is used for irrigation. Irrigated agriculture can play an important role in mitigating water scarcity if integrative, coordinated approaches to water management are pursued at the basin and regional levels. However, in water-limited environments, improvements in agricultural water use efficiency must be sought in both irrigated and rainfed agriculture (Oweis and Hachum, 2006). Effective water management in rainfed and irrigated agriculture has very similar goals: maximizing the productive use of stored water and minimizing losses to runoff and percolation. There is no reason to isolate rainfed from irrigated agriculture, since in many agricultural systems a continuum exists from rainfed, with or without water harvesting, to supplemental or deficit irrigation to full irrigation. Water also plays a critical role in supporting environmental services and, therefore, environmental water use should not be considered in isolation from other uses, including agriculture. There is insufficient information on environmental needs and on the functioning of many aquatic ecosystems, in particular those that have been altered by intensive water development. This is one reason why environmental demands have been a source of conflict among water users, in particular with agriculture because of the large amounts of water used in this sector (Kassam et al, 2006).

Management of these competing demands is also constrained by the absence of governance systems that allow for equitable sharing of the benefits of water use, whether this is for agriculture or maintenance of ecosystem benefits. Such governance systems need to be developed and provided with accurate information on the nature and distribution of the benefits of different forms of water use. Here, a number of new approaches in water and watershed management are directly relevant to the effective and efficient management of water resources for agriculture, environment, domestic consumption and industrial uses.

The improvement of water productivity (WP) by increasing yield and/or reducing ET, always results in a reduction of agricultural water requirements. *This is the reason why it is important to focus on improving WP as a fundamental research goal in water-limited regions.* Indeed, international research has made an important contribution to the regional and global increase in agricultural WP over the last few decades. In contrast, little if any reduction in ET has been achieved, the denominator in the WP ratio. This is because the ET rates are dictated by the evaporative demand of the environment until the plants are subjected to significant water deficits. In this regard, the evaporative demand in the drier sub-tropical regions is very high, and that imposes inherently lower WP values than those observed in more humid regions of milder climate (Kassam et al., 2006).

Hatfield et al., (2001) provided a review and synthesis of the literature directed toward understanding the role of soil management practices for WUE. Soil management practices affect the processes of evapotranspiration by modifying the available energy, the available water in the soil profile, or the exchange rate between the soil and the atmosphere. Plant management practices, e.g., the addition of N and P, have an indirect effect on water use through the physiological efficiency of the plant. A survey of the literature reveals a large variation in measured WUE across a range of climates, crops, and soil management practices. It is possible to increase WUE by 25 to 40% through soil management practices that involve tillage. Overall, precipitation use efficiency can be enhanced through adoption of more intensive cropping systems in semiarid environments and increased plant populations in more temperate and humid environments. Modifying nutrient management practices can increase WUE by 15 to 25%. Water use efficiency can be increased through proper management, and field-scale experiences show that these changes positively affect crop yield.

The increase in water productivity in recent years has been spectacular: over the period 1961–2003 the water needed to produce food for one person was reduced from 6 m^3 a day to less than 3 m^3 a day. Over the same period, the production of rice and wheat went up by 100 percent and 160 percent, respectively, but with no increase in water use. However, in many basins, water productivity remains startlingly low and take up of modern technology is slow: drip technology has been adopted on less than 1 per cent of irrigated lands worldwide (World Bank, 2006).

Measures to Improve WUE

Agricultural WUE is broader in scope than simply the use of agronomic and biological solutions and must be considered on a watershed, basin, irrigation district, or catchment scale. The main pathways for enhancing WUE with limited irrigation are to increase the output per unit of water (engineering and agronomic management aspects) (Zhang et al., 1998), reduce losses of water to unusable sinks, reduce water degradation (environmental aspects), and reallocate water to higher priority uses (societal aspects) (Howell, 2001). At present engineering technologies for water-saving agriculture, such as prevention of channel leakage, water delivery with low-pressure pipe, sprinkler and drip irrigation systems have been advocated and adopted. However, some solutions such as advanced surface irrigation techniques, water-saving irrigation scheduling and optimized water allocation in irrigation areas, and irrigation forecasting technology have not been widely advocated or adopted. Further study on new technologies for water-saving agriculture, such as combining biological water-saving measures with engineering solutions is also necessary (Deng et al., 2003b). Promoting water-saving agriculture is not only able to increase water use efficiency, but can also facilitate the structural adjustment needed by agriculture (Shan, 2003).

Howell (2006) provides some examples of options available for improving irrigation efficiency at a field level adapted from Wallace and Batchelor (1997).

Improvement Category	Options
Agronomic	crop management to enhance precipitation capture or that reduces water evaporation (crop residues, conservation till, plant spacing, etc.); improved varieties; advanced cropping strategies that maximize cropped area during periods of lower demands and/or periods when rainfall may have greater likelihood of occurrence
Engineering	irrigation systems that reduce application losses and/or improve distribution uniformity; cropping systems that can enhance rainfall capture (crop residues, deep chiseling or paratilling, furrow diking, dammer-diker pitting, etc.)
Management	demand-based irrigation scheduling; slight to moderate deficit irrigation to promote deeper soil water extraction; avoiding root zone salinity yield thresholds; preventive equipment maintenance to reduce unexpected equipment failures.
Institutional	user participation in an irrigation district (or scheme) operation and maintenance; water pricing and legal incentives to reduce water use and penalties for inefficient use; training and educational opportunities for learning newer, advanced techniques.

Techniques and inputs that improve WUE have been extensively researched and tested on research stations and at farm or field levels. The dry areas comprise a region of heterogeneous land and variable weather. It is expected that variability of experimental results caused by uncontrolled factors such as physical and biotic environment, will greatly exceed the variability due to controlled factors. Therefore, localized research results alone cannot produce an optimal strategy for maximizing WUE. Dealing with water issues on a basin-wide level will present many problems and constraints that are not so apparent on the farm or research station level. This holistic approach has not yet been given enough attention. When developing water-harvesting projects runoff is often intercepted at the upstream reaches of the catchments, thus depriving potential downstream users. The lack of balance in these systems for equitable water allocation among upstream and downstream users often causes social, economical and environmental problems. Moreover, in many areas socio-political considerations override any optimization of the management of these resources (El- Beltagy, 1997).

The global debate on water resources management and food security is sharpening the agenda for Agriculture Water Management (AWM). Water resources and food production are increasingly global issues, and now debate is beginning to focus attention on key AWM questions, such as the potential conflicts between water for food and water for nature; the environmental impacts of irrigation intensification; and the trade-offs between low food prices and producer incentives and incomes. Pioneering work by the International Food Policy Research Institute (IFPRI), the International Water Management Institute (IWMI), and the Food and Agriculture Organization (FAO) have started to bring the issues to the fore, with major recent publications by these agencies exploring the water-for- food challenge. International research is now starting to reflect the growing emphasis on water productivity (World Bank, 2006).

The challenges and opportunities for future research in improving WP can be discussed around three system components: the biological (crop), the environmental, and the management component. However, it is through synergies among such components that progress in increasing WP has been and will be made (Kassam et al., 2006).

In the biological area, genetic improvement of WP has already been achieved as part of the yield gains effort, particularly in the irrigated systems, and more will be possible as effective demand for biological products continue to improve, allowing farmers to increase yields. Specific breeding programmes aimed at improving WP, in rainfed systems, have not been nearly as successful except in the relatively favourable rainfed production systems. Primary reasons in the unfavourable rainfed systems have been the multiplicity of crop responses to drought and the large spatial and temporal variability of drought-prone environments. Notwithstanding such difficulties that make short-term progress in drought adaptation a very uncertain proposition, the new possibilities that biotechnology offers, if combined with the scientific expertise in crop adaptation and performance in adverse environments, should open an important avenue in research in the medium term on the improvement of drought and salinity tolerance by concentrating “abiotic tolerance genes" in agronomically adapted plant types. As an example, one important goal would be to aim at yield stability in low rainfall years in marginal and less favourable environments in an attempt to produce cultivars that would avoid the catastrophic impact of severe droughts but continue to provide high or bumper yields in average and good rainfall years. Another important longterm research objective could be the development of cultivars much more tolerant to low temperatures through metabolic engineering which, if achieved, would allow production during winter and thus increase significantly the WP of the major rainfed and irrigated crops (Kassam et al., 2006).

The major reason why it has been so difficult to reduce evapotranspiration (ET) is that it is primarily dependent on the evaporative demand of the environment. That characteristic cannot be changed easily, but there are opportunities for WP improvement in the cooler temperate zones and mid and higher altitude tropics and subtropics, and in the lowlands if crops could be raised when the evaporative demand is lowest; i.e., in winter. However, the primary way to reduce total ET is by growing a crop that has lower total water requirements because of its shorter growth cycle. Here, crop choice, environment and management (by selecting optimal planting dates) interact and new research could produce excellent results if modelling is combined with experiments to offer the best strategies that maximize WP and income. As it is the T portion of ET, which determines biological performance, increasing through rapid or continuous ground cover can lead to higher WP. WP in the summer is several times lower than in the winter of mild climates and inside unheated greenhouses and plastic tunnels which point to the need for need for involvement in market gardening and horticultural research where appropriate (Kassam et al., 2006).

In the short term, the major opportunities that exists in improving WP and that demand priority research efforts reside within the management component. Inadequate management is the primary cause of the low WP in rainfed and irrigated systems. There are also challenges in the biophysical area related to maximizing WP under limited or deficit irrigation. It is likely that many irrigated areas in the region will not have full supplies in the future and will be forced to use limited supplies in an optimal fashion. Research at optimizing a limited amount of water has been carried out in the past, but the new tools of spatial analysis and simulation modelling have much to add to the development of effective tools for advising irrigators in optimal scheduling methods. One other major challenge in rainfed but also, irrigated systems, is the need to maximize the potential for stored soil water in the crop root zone. Water conservation measures including minimum tillage practices that increase the fraction of rainfall that ends up in transpiration need to be developed and tailored to each major system. The major advances in the improvement of WP until now have been achieved by yield increases through improved crop husbandry. A primary issue in this regard is the study of the interactions between soil fertility, plant nutrition and water management, from the plant, plot and system levels up to the basin level (Kassam et al., 2006).

Improving water availability and productivity in rainfed agriculture and watersheds is essential for household food security and poverty reduction, yet solutions are much less evident than for irrigated areas. There is a significant research agenda, particularly on land and water management and agronomic practices, but priorities are the transfer of existing technology, the development of market outlets, and physical investment in rural infrastructure and in water control structures. Market-driven integrated approaches that reduce risk, and that involve community participation throughout are most likely to succeed (World Bank, 2006).

Annex I

WATER USE EFFICIENCY OF MAJOR CROPS IN TURKEY

WHEAT

Cereal production occupies 75% of Turkey's cropland. With a wheat production (21 million tons) and barley production (9 million tons) in 1999, Turkey is one of the world's biggest wheat and barley producers. Even though Turkey produces large quantities of cereals, productivity per unit area needs improvement. In 1998, average wheat yield in Turkey was 2234 kg/ha, one-third of that in advanced countries (world average 2624 kg/ha).

To obtain a greater yield per unit rainfall is one of the most important challenges in dryland wheat production. Highly efficient use of limited water may be one means of achieving this goal. In this paper we reviewed the results irrigated wheat experiments in Turkey with water deficit and variable conditions. The results of the wheat experiments concerning irrigation water efficiency are summarized in Table 8. WUE of wheat varied from 0.08 to 2.39 kg/m^3 . Thus, the range of WUE values of wheat is quite large as compared to those given by Zwart and Bastiaanssen (2004) for wheat 0.6–1.7 kg/m^3. However, the values of WUE given in table 8 corresponds to the highest yiled obtained treatments and ranged from 0.42 to 1.77 kg/m^3. The variability of CWP can be ascribed to: (i) climate; (ii) irrigation water management and (iii) soil (nutrient) management, among others.

This review reveals the compensatory effect of limited irrigation and fertilizer supplement on wheat water-use efficiency (WUE) and highlights the breeding of new varieties for high WUE that could improve wheat productivity under water-limited environments in the semiarid area. Considerable potential for further improvement in wheat productivity in semiarid area seems to depend on effective conservation of moisture and efficient use of this limited water. Different crops, soil and water management strategies should be adjusted according to the conditions that prevail in the various semiarid areas. By combining soil and water conservation approaches with regulating the cropping system by cultivating drought-tolerant and water-saving cultivars, the increase in wheat productivity could be achieved.

Yields of dryland (rainfed) wheat in Turkey have increased steadily over the past century despite rainfall being unchanged, indicating that the rainfall-use efficiency has increased. Analyses suggest that at least half of the increase in rainfall-use efficiency can be attributed to improved agronomic management. The adoption of agronomic procedures such as minimum tillage, appropriate fertilizer use, improved weed/disease/insect control, timely planting, and a range of rotation options, in conjunction with new cultivars, has the potential to increase the yields and rainfall-use efficiency of dryland crops.

Table 8. Review of Wheat Experiment Results and Evolution of Water use efficieny in Turkey

Reference	Region	Year	Wheat Variety	Grain Yields kgha^{-1}	Water Use (mm)	Irrigation Water (mm)	WUE kgm^{3}
Madanoğlu, (1977)	Ankara	69-75	Yektay-406	4157	690	391	0.60
Sevim, (1988)	Erzurum	84-86	Bezostia	5960	398	238	1.50
Yakan and Kanburoğlu (1992)	Kırklareli	86-90	Bezostia	5110	557	131	0.92
Uzunoğlu, S., 1992	Ankara	87-89	Gerek-79	4180	731	394	0.57
Üstün and Ayla (1993)	Ankara	85-90	Çakmak-79	5405	777	433	0.70
Çetin (1993)	Harran	89-91	Balcalı-85	4460	950	512	0.47
Sezen and Yazar (1996)	Çukurova	91-92	Panda	7530	519	184	1.25
Çelik and Balçin, (1996)	Tokat	92-94	Bezostia	4010	639	357	0.63
Işik et al. (1996)	Sarayköy	92-93	Gerek-312	2215	309		0.71
			Kunudura -1149	2024	312		0.65
Işik et al. (1996)	Lodumlu, Ankara	92-93	Gerek-312	2601	352		0.74
			Kunudura-1149	1847	366		0.50
Işik et al. (1996)	Eşkisehir	92-93	Gerek-312	2533	444		0.57
			Kunudura-1149	1600	385		0.42
Işik et al. (1996)	Konya	92-93	Gerek-312	2105	331		0.63
			Kunudura-1149	1624	330		0.49
Sezgin et al. (1997)	Aydın	94-	Seri-82	5459	731	248	0.75
		95		6475	813	337	0.80
		96		5967	772	393	0.77
Sezen (2000)	Çukurova	95-97	Seri-82	4930	495	42	1.00
				6870	457	60	1.50
Yazar et al. (2001)	Çukurova	2000		6176 FW	480	180	1.29
				6427 12dS/m	445	198	1.44
Yazar et al. (2002)	Tarsus	92	Seri-82	7510		193	
		94		3693		85	
		97		4427	611	138	0.72
Sezen et al. (2006)	Harran	93-96	Balcalı 85	8340	602	392	1.39
Ilbeyi et al. (2006)	Ankara	98-02	Bezostia	5425 SISf			1.13
				5220 SI2/3			1.16
				4650 SI1/3			1.77
Baruçular et al. (2006)	Harran	98/99	Ege-88	5340 I1		528	1.01
		99/00		6700 I2		444	1.51
				6230 I1		744	0.84
				6310 I2		689	0.92 IWUE

COTTON

Cotton maintains its place and importance as a major textile raw material despite the steady increase in the production of synthetic fibres. Presently, cotton constitutes 60% of all textile raw materials. As an industrial crop, cotton has significant place in the national economy with its fibre used in textiles and with its cake as a feed used by stock breeders. In Turkey, cotton farming is practiced mainly in three regions; the Aegean Region, Çukurova and Southeastern Anatollia. Cotton cultivated area varied from 630 000 to 721 000 ha, total production varied from 1 160 000 to 1 457 000 tons in the last five years. Recently, Southeast Anatolia Region is the most important region of cotton farming of Turkey with about 300 000 ha of land is under irrigation and over 400 000 ton of the production of raw materials. About of 50% production of cotton received from this region. Especially, with the implementation of GAP, area allocated to cotton farming is expected to expand rapidly (Figure 3).

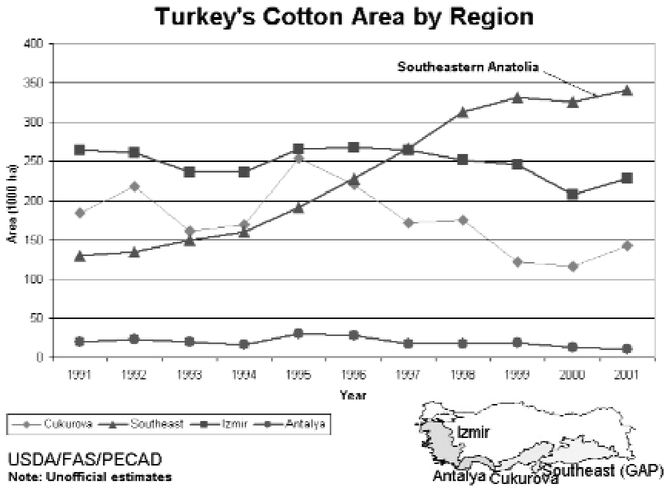


Figure 3. Cotton Production Areas in Cotton Grown Regions in Turkey

In Turkey, early irrigation experiments on cotton were conducted in 1940s in Çukurova Region (Alap, 1958). Deficit irrigation of cotton was first proposed by Tekinel and Kanber (1979) who investigated crop water requirement and yield production functions of cotton. In general, cotton is irrigated by surface methods in Turkey although sprinkler and drip irrigation have been suggested as a means of supplying most types of crops with frequent and uniform applications of water, adaptable over a wide range of topographic and soil conditions. Recently, pressurized irrigation systems have been introduced for cotton as a result of increased pressure to develop new irrigation technology suited to limited water supply as well as to specific topographic and soil conditions. The results of the cotton experiments concerning irrigation water efficiency carried out by various universities and research institutes in Turkey are summarized in Table 9.

Table 9. Review of Cotton Experiment Results and Evolution of Water Use Efficiency in Turkey

Reference	Region	Years	Cotton Variety	Yields $kgha^{-1}$	Water Use (mm)	Irrigation Water (mm)	WUE kgm^3
Kanber (1977)	Tarsus	74-76	Deltapine 15/21	5860	785	523	0.75
Kanber & Derviş (1978)	Tarsus	73-77	Deltapine 15/21	4620	888	670	0.52
Tekinel & Kanber (1979)	Tarsus	76-78	Deltapine 15/21	3900	618	380	0.63
Baştuğ (1987)	Adana	85-86	Deltapine 15/21	3075	1059	821	0.29
Karaata (1985)	Harran	80-82	Caroline Queen	3320	1325	1125	0.25
Kanber et. al., (1986)	K.Maraş	78-81	Deltapine 15/21	3400	847	667	0.51
Kanber and Tekinel (1991)	Harran	89-90	-	4150	1418	1100	0.29
Kanber et. al., (1992)	Harran	83-86	Deltapine 15/21	3790	1670	1555	0.24
Özkara and Şahin (1993)	Nazilli		Nazilli-84	3504	390	233	0.90
			Nazilli-87	4043	472	339	0.86
Ul et al. (1993)	Menemen	90/91		2840	444		0.64
Yavuz (1993)	Çukurova	90-91	Çukurova-1518	3260 F	929	928	0.35
				3160 D	756	404	0.42
Topçu (1993)	Çukurova	89-90	Çukurova-1518	2806 S		797	0.35
				3050 D		414	0.74
Bilgel (1994)			Sayar 314	4600	1190	1130	0.39
Eylen et al. (1994)	Tarsus	91-92	Çukurova-1518	4490	467	181	0.96
Özkara and Şahin (1993)	Menemen		Nazilli-84	3350	470	224	0.71
İstanbulluoğlu (1995)	Iğdır	89-91	Çukurova-1518	2890	658	369	0.44
Çetin (1997)	Harran	91-4		3970 F		1561	0.25
				3500 S		1664	0.21
				4900 D		1408	0.35
Anaç et al. (1999)	Menemen	92-94	Nazilli-84	3228	775	576	0.56
Ertek (1998)	Çukurova	94-95	Çukurova-1518	3180	536	401	0.61
Kara and Gündüz (1998)	Harran	93-95	Sayar-314	4390	1535	1344	0.29
Yılmaz et al. (1998)	Aydın	97	Nazilli-84	4777	528	428	0.90
Çetin and Bilgel (2002)	Harran	91-94		4380 D			0.49
				3630 F			0.39
				3380 S			0.24

Yazar et al. (2002)	Harran	99	Stoneville-453	4750 LEPA	854	814	0.56
				5870 Drip IF6	854	814	0.69
				5040 Drip IF3	868	814	0.58
Şener and Çetin (2002)	Harran	94	Sayar-314	3079 F		986	0.31
				3714 S		717	0.52
				3413 D		1033	0.50
				3612 MN		732	0.49
				3020 MD		1059	0.28
				3078 LE		1076	0.29
Şener and Çetin (2002)	Menemen	94	Nazilli-84	2863 F		540	0.53 Ir.
				2724 S		324	0.84 Ir.
				2971 D		205	1.45 Ir.
				2829 MN		324	0.87 Ir
				2862 MD		216	1.32 Ir.
Yazar et al. (2002)	Tarsus	91	Çukurova 1518	4380		625	0.70 Ir.
		93		3192		625	0.51 Ir.
		95		4557		435	1.04 Ir.
		96		4427	795	674	0.56
Dağdelen et al. (2005)	Aydın	02-03	Nazilli-84	5592	626	510	0.88
Dağdelen et al. (2005)	Aydın	03-04	Nazilli-84	4806	974	-	0.49

WUE of cotton varied from 0.12 to 1.54 kg/m^3 in the reviewed studies. Thus, the range of WUE values of cotton is quite large as compared to those given by Zwart and Bastiaanssen (2004) for cotton 0.41–0.95 kg/m^3. However, the values of WUE given in table 9 correspond to the highest yield obtained treatments and ranged from 0.24 to 0.96 kg/m^3. In general, WUE values were lower for cotton grown in the semi-arid to arid Southeast Anatolia region (Harran Plain) due to high vapor pressure deficit, and high evaporative demand in that region. However, with drip and LEPA systems, higher WUE efficiency values can be obtained for cotton in the same region. Therefore, switching from surface irrigation methods to pressurized irrigation methods could result in increased WUE in the same region.

CORN

Corn is one of the most important crops in the Mediterranean, Black Sea, Thrace, Southeast and Aegean Regions in Turkey. In Turkey, among the grain, corn has got the widest field for planting after the wheat and the barley. The corn is an important plant both as human nourishment andanimal fodder. Turkey’s corn production for 2001-02 is estimated at 2.1 million tons, equaling last year’s crop and the 5-year average. Common irrigation methods used for corn production in this region are wild flooding, furrow and sprinkler irrigation. In general, the farmers overirrigate, resulting in high water losses and low irrigation efficiencies, thus creating drainage and salinity problems (Yazar et al., 2002)

Table 10. Review of Corn Experiment Results and Evolution of Water Use Efficieny in Turkey

Reference	Region	Years	Corn Variety	Yields $kgha^{-1}$	Water Use (mm)	Irrigation Water (mm)	WUE kg/m^3
Ul (1990)	Menemen	1988-1990	G-4507	6490	540		1.20
Uzunoğlu (1991)	Ankara	1986-1988	XL-72 AA	8590	809	615	1.06
Ayla (1993)	Bolu	1985-1987	NKPX-525	8318	545	313	1.53
Şener et al. (1994)	Menemen	1989-1991		11260 S		541	2.08 Ir.
				10440 MN	474	2.20 Ir.	
				10350 D		541	1.91 Ir.
				8940 MD		541	1.65 Ir.
				9790 F		541	1.81 Ir.
Köksal (1995)	Tarsus	1993-1994	P-3377	7884 S	723	599	1.09
Çetin (1996)	Harran	1990/1992	TTM-81-19	10150	1359	1303	0.75
Beyazgül, (1997)	Menemen	1993-1995		13954	636	515	2.19
Bayrak (1997)	Bafra	1991-1993	Hybrid 3/47	9742	341	164	2.86
Yildirim and Kodal (1998)	Ankara	1991-1993	Micro	10380	912		1.12
Sezgin et al. (1998)	Aydın	1996/1997	Pioneer-3163	12843	931	835	1.38
Gündüz and Beyazgül, (1999)	Balıkesir	1994-1997	Dracma C-4662	8820	761	611	1.16
Değirmenci et al. (1999)	Harran	1995-1997	TT81-19	9260	938	873	0.99
Çakır (1999)	Kırklareli	1995-1997	P 3377	12438	762	531	1.63
Gençoğlan and Yazar (1999)	Çukurova		TTM-815	10035	1052	823	0.95
Avcı and Ersöz (2001)	Bafra	1996-1998	TTM-823	10210	684		
Yazar et al. (2002)	Harran	1999	P-3394	11330 IF3	562	581	2.01
				11920 IF6	565	581	2.05
Boz (2001)	Çukurova	2000	P 3163	8510 S	645	431	1.32
İstanbulluoğlu et al. (2002)	Tekirdağ		Sandoz-PX 74	9920	586	285	1.69

Yazar et al, (2002)	Çukurova	2001	Pioneer 3163	8875 Drip	750	561	1.18
Pamuk (2003)	Bornova/ Izmir	1999/ 2000	Otello	10500	540	385	1.97
Yılmaz et al. (2005)	Aydin	2003/ 2004	Pionner 3394	11630 11050	547 569	488 497	1.94 2.00
Bozkurt et al. (2006)	Çukurova	2003	Pionner 3394	9790 Drip	701	713	1.40

On-farm WUE can be improved by moving to a more efficient irrigation system. There are three main types of irrigation systems available: border or furrow flood irrigation, sprinkler irrigation and drip irrigation , which is the more efficient than sprinkler irrigation, while sprinkler irrigation being more efficient than border/furrow irrigation.

SUNFLOWER

Sunflower (*Helianthus annuus L.*) is an important oilseed crop in Turkey and its production has greatly increased with the introduction of hybrids. Most of the production is in the Thrace region, with an estimated area of 320,000 ha. About 73% of sunflower production and 30% of corn production of comes from Marmara region. Mostly sunflower is grown without irrigation, but irrigation is sometimes used in sub-humid and semi-arid regions where precipitation is limited, as in the Thrace region. It is possible to increase production by well-scheduled irrigation programs. and utilizing irrigation scheduling principles to develop suitable irrigation management. Irrigation scheduling helps farmers to develop their own strategies for their specific regions and conditions.

Sunfower is one of the four most important oil crops in the world. Because of its moderate cultivation requirements and high oil quality, its acreage has increased in both developed and undeveloped countries. Sunflower oil is highly demanded not only for human consumption, but also for chemical and cosmetic industries. The total area of sunfower production is 545,000 ha in Turkey. Of Turkey's sunfower production of 800,000 tons, 13% of this is produced in southern Marmara region (DIE 2003).

Despite its high water use, the crop has an ability to withstand short periods of severe soil water deficit of up to 15 atmospheric tensions. Long periods of severe soil water deficit at any growth period cause leaf-drying with subsequent reduction in seed yield. Severe water deficits during the early vegetative period result in reduced plant growth.

Table 11. Review of Sunflower Experiment Results and Evolution of Water Use Efficiency in *Turkey*

Reference	Region	Years	Sunflower Variety	Yields $kgha^{-1}$	Water Use (mm)	Irrigation Water (mm)	WUE kg/m^3
Oylukan and	Eskişehir	1971	V.1646	3390	586	371	0.58
Kuşaksızoğlu		1972		2960	562	318	0.53
(1974)		1973		2660	654	390	0.41
		1974		3320	616	307	0.64
Tokat RSRI	Tokat	1973/		2736		358	
(1974)		1974		2218		-	
Çevik	Harran	1989	Raymont	2380	1314	1088	0.18
et al. (1992)		1990	Türkay1	1970	1160	999	0.17
		1991	Türkay1	3850	718	643	0.50
Dorsan	Menemen	1990/		2657	432	254	0.61
et al. (1994)		1991					
Gündüz and	Harran	1991/		3090	962	897	0.32
Kara (1996)		1993					
Kadayıfçı	Ankara	1994	EKYZ1	2332	929	902	0.25
and Yıldırım (2000)		1995		2589	698	579	0.37
Erdem and	Tekirdağ	1998		5215	799	544	0.65
Delibaş (2003)		1999		5063	762	560	0.66
Pekcan	Edirne	2002	TR-6149	3268	360	130	0.91
et al., (2005)		2003		3607	523	150	0.69
Erdem	Tekirdağ	1998	Sunbro	4380	809	679	0.54
et al. (2006)							
Demir	Bursa	2000/	Sunbro	3950	652	355	0.61
et al. (2006)		2001					
Kaya (2006)	Ankara	2002/	Sunbro	3860		431	0.89
		2003		3570		769	0.46
			Tarsan-1018	4220		460	0.92
				3430		726	0.47
			Özdemirbey	4340		560	0.76
				3140		726	0.43

On-farm or experimental plots WUE of sunflower varied from 0.12 to 0.94 kg/m^3 in the reviewed studies. However, the values of WUE given in table 11 correspond to the highest yield obtained treatments and ranged from 0.18 to 0.92 kg/m^3. Thus, the range of WUE values of sunflower is quite large. On-farm WUE can be improved by moving to a more efficient irrigation system along with using higher yielding varieties and appropriate agronomic techniques. It is expected that variability of experimental results caused by uncontrolled factors such as physical and biotic environment, will greatly exceed the variability due to controlled factors. Therefore, localized research results alone cannot produce an optimal strategy for maximizing WUE.

SOYBEAN

Soybean [*Glycine max* (L.) Merr.] is the third important oil seed crop following sunflower and cotton in Turkey. It is mostly produced as a second crop in the southern, south–eastern and Central Black Sea regions of Anatolia which have a production capacity about 150–200 thousand tones per year. Soybean was produced as first and second crop in the Mediterranean and Southeast Anatolia region. In the early 1980s, soybean production was highest in Turkey due to subsidies provided for soybean production. However, later on production of soybean declined due to marketing conditions. In 2003, soybean area and production were estimated at 27,000 has and 85,000 tons, representing a reduction in production of approximately fifty percent compared to previous year. Farmers in the Çukurova region, where eighty percent of the local soybeans are grown, had difficulties marketing their crop in recent years and have shifted to corn. There is little interest to plant soybeans in the coming season as well. In recent years, the Goverment of Turkey has issued production bonuses for soybeans and other oilseeds to increase production of oilseeds. However, late payments and the relatively small amount of the payments are not helping to encourage production. Turkey will continue to be a net-importing country for soybeans and products for many years to come.

Table 12. Review of Soybean Experiment Results and Evolution of Water Use Efficiency in Turkey

Reference	Region	Years	Soybean Variety	Yields $kgha^{-1}$	Water Use (mm)	Irrigation Water (mm)	WUE kg/m^3
Tülücü (1986)	Çukurova	1982/1985	Amsoy-71	3150	-	1040	0.30 WUEir
Derviş and Özel (1987)	Tarsus	1981/1983	Amsoy-71	4088	477		0.86
Bayrak (1989)	Bafra	1984/1986		3496	415	726	0.48
Yazar 0.58	Çukurova	1986/	Land O'Lakes		3500 S	604	467
et al. (1990)		1987	4106				
Tarı (1990)	Çukurova	1988	A-2943	2512	542	460	0.46
Yazar et al. (1991)	Harran	1989/1990	A-2943	2850	1088	936	0.26
Şener et al. (1994)	Menemen	1989/1991		2860 F		474	0.51
				3620 S		338	1.07
				3370 MN		474	0.71
				3210 D		541	0.59
				3200 MD		541	0.59 WUEir
Ersöz et al. (1996)	Bafra	1993/1995		3584	-	240	1.49
	Çarşamba			3624		82	4.42 WUEir
Eylen (1995)	Tarsus	1994	SA-88	3003 Cablegation	568	-	0.53
Kara (1998)	Harran	1994/1995	Asgrow-3127	3290	944	930	0.35
				2150	740	650	0.29

On-farm or experimental plots WUE of soybean varied from 0.14 to 1.01 kg/m^3 in the reviewed studies. However, the values of WUE given in table 12 correspond to the highest yield obtained treatments and ranged from 0.26 to 0.86 kg/m^3. Thus, the range of WUE values of sunflower is quite large. Soybean WUE was lower in the sem-arid to arid Southeast Anatolia region than in Mediterranean and Aegean regions due to higher evaporative demand in that region

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AGRICULTURAL WATER USE EFFICIENCY IN YEMEN

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1. Introduction

The total area of of Yemen Republic is 55.5 million ha (555,000 sq. km). The arable land is only 1.4 million ha or 2.5 percent of the land area. The population is 20,701,257 (July 2002 est.) growing at an annual rate of 3.7 percent and about 85 percent of the labour force works in the agriculture sector.

- The country has an arid and semi arid climate with limited water resources.Temperature and rainfall vary considerably due to the wide range of elevations, ranging from sea level to over 3,700 m. Mean annual temperatures range from less than 15°C in the highland region to 30°C in the coastal plains. Summer temperatures rise to 40°C in the coastal areas and more than 40°C on the desert plateau regions.

Yemen is clearly a water-deficient country. Alleviating this situation requires a number of actions to be taken, the most urgent of which is the improvement of on-farm water use efficiency.

The Water resources management in Yemen is one of the main objects of the Yemeni government various institutions.This issue will be described in this report.

2. Water Resources

The Total estimated rainfall is about 67.2 Billion m^3/year, where 100 mm/y rainfall covers 72.8%, 100-300 mm/ Y rainfall covers 16.8% ; while more than 300 mm/Y rainfall is only 10.45% of the total area.

The rainfall, which directly or indirectly reaches the saturated layer, is the main source of groundwater recharge. Direct recharge of groundwater is generally very low due to the dry climate and low level of rainfall. More than 85 percent of the groundwater pumped from wells is used for irrigation, whose estimated number has reached about 50,000 in the country.

The renewable water resources of Yemen are limited. A comprehensive assessment of water resources potential in Yemen is notably constrained by the length and quality of data available. An assessment of the surface water potential is shown in Table 1. This indicates an aggregated mean annual flow in order of 741million m^3 in the western part of the country and 1,259 million m^3 in the east.

Table 1. Annual Runoff by Wadies and Basins

Western wadis	million m^3	Eastern wadis	million m^3
Mawr	162	Rub Al-Khali Basin	171
Sardud	69	Ramlat Sabetyan Basin	315
Siham	89	Arabian Sea	235
Rima	90	Gulf of Aden Basin	535
Zabid	125		
Rasyan	45		
Harad	35		
Mawza	121		
Minor wadis	97		
Total	741		1,259

It must be noted that mean annual flows from these wadis are irregular, the coefficient of variation of annual flows values ranges from 22 percent for wadi Surdud to 149 percent for wadi Thibi.

The total usable storage (reserves) in the aquifers of the western part of the country is estimated to be 300,000 million m^3. The annual combined recharge for these basins is estimated to be approximately 1,525Mm^3. The approximate annual abstraction from the aquifer system of the country is 2,110 million m^3.

Reports on groundwater abstraction, recharge and storage of water in the major aquifers indicate that high exploitation of groundwater resulted in a deficit up to 260 million m^3/year in Tihama aquifer, 75 million m^3/year in Mukalla aquifer and 400 million m^3/year in highlands. Salinity of groundwater varies from one area to another. In Marib (eastern plateau) electrical conductivity (E.C) has a range between 0.75 to 2.25 mS/cm, while in the coastal areas; it could reach up to 5-6 mS/cm.

Total annual renewal water resources are estimated at about 2,500 million m^3, out of which surface and groundwater contribute 1,000 million m^3 1,500 million, respectively. The current water use is estimated at about 3,400 million m^3 (Table 2). This indicates that Yemen is under continuous water deficit of 900 million m^3 per year, capable of increasing. This deficit is covered from groundwater through exploitation, 91 percent of which is utilized by the agriculture sector.

Table 2. Water Balance During 2000

Description	Balance million m^3	%
Renewable Water Resources:	+ 2500	100
Surface Water	+1000	40
Underground Water	+1500	60
Water Use	-3400	100
Agriculture	-3094	91
Municipal	-238	7
Manufacturing & mining	-68	2
Balance	**-900**	

The per capita renewable water resources availability is about 137 m3/capita/annum, which falls well below the limits of water deficiency level. Available renewable water per capita for the different periods are as follows:

1098 m^3/y	in1955
460 m^3/y	in1990
137 m^3/y in	2003
66 m^3/y in	2026

3. Land Resources and Agriculture

From the total land area of 55.5 million ha, only about 3% is cultivatable. However, the actually cultivated are about 1.2 million ha -representing 82% of the cultivatable area (GDASD 2004). Rain-fed agriculture predominates Yemeni farming (54% of cultivated area), with 35% under tube-well irrigation and the remaining (11%) are under spate and water springs irrigation. Rangelands, together with forests and woodlands, account for 40% of the land area. The remaining land area is mostly desert with limited use potential.

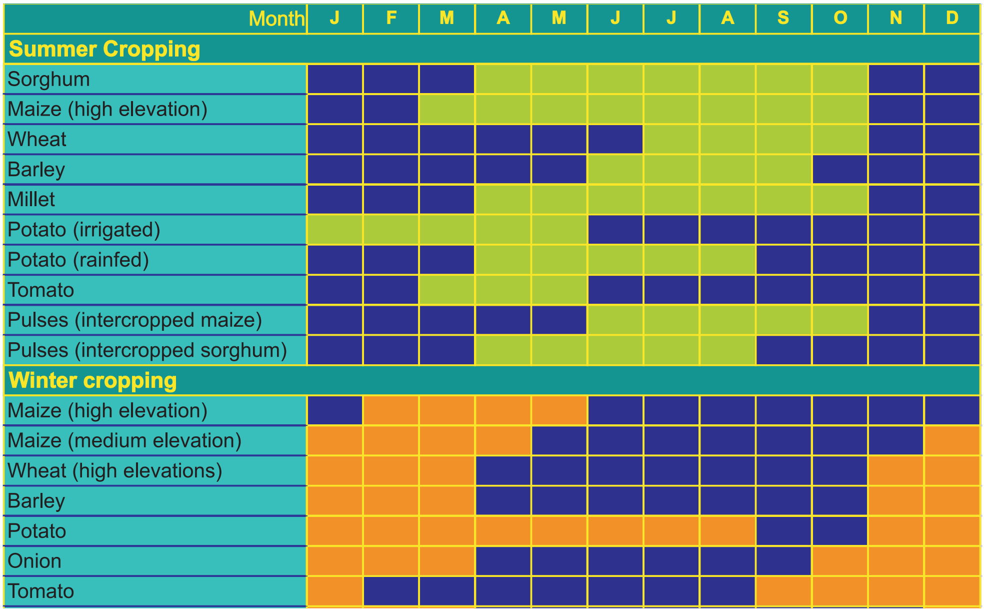
Agriculture (excluding fishing) contributed 14.2% of the country gross domestic product in 2000 (but only 10% if qat production is excluded). This compares to 23.6% of GDP (14.4% without qat) in 1990. The majority of the national workforce is involved in agriculture, but this is declining (56% in 1975, 44% in 1990), largely due to rural to urban migration and the abandonment of traditional terrace agriculture.

The number of recorded agricultural holders exceeds 1.18 million and with 1.2 million ha of cultivated land, this suggests an average holding size of 1 ha (derived from GDASD 2004). However, the Agricultural Research and Extension Authority (AREA) in 1997 gave the following farm size distribution for the Central Highlands:

- 20% of farms are less than 2 ha
- 24% of farms range from 2 – 5 ha
- 56% of farms range from 5 – 20 ha

The cropping pattern and calendar of agricultural activities are determined largely by rainfall pattern and altitude, which dictates temperature. At higher elevations, the vegetative cycle is longer where sowing of most rainfed crops are earlier and harvesting occurs later than at lower elevations. Significant differences in sowing and harvest dates occur between neighboring districts and some crops may be grown in either winter or summer seasons, depending on the availability of supplementary irrigation. Sowing and harvest dates for the principal arable crops grown in the western and central highlands are given in Table 3. Under irrigation, sowing dates are more flexible, although at higher elevations, low temperatures (risk of frost) are a factor for some crops, particularly potato and tomato. Vegetables are grown year round at lower elevations but are not common at higher altitudes.

Table 3. Cropping Patterns



Fertilizer is used only for irrigated crops and not on rain-fed crops as this may cause crop scorching if the rain is not enough. Also, under rain-fed cropping, yields are low and uncertain, and so input costs are kept to a minimum due to the risk of crop loss. Consequently, fertilizer is predominantly used on irrigated land growing high yielding varieties or high value crops, most commonly to qat, coffee, potatoes and some other vegetable, where the return on the investment is more certain.

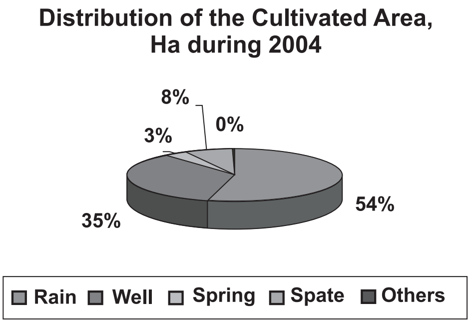
The soils in Yemen are generally sandy to silty or loamy in the coastal plains regions and silty to loamy and clay loamy soils predominate in the highland region. Detailed soil maps are not available in Yemen, although there are pilot studies at the semi-detailed level. Soils are generally alkaline, many above pH 8, and salinity is often high. Organic matter contents are invariably low in all soils, usually less than 1%.

Cation exchange capacities are generally low, depending on the clay content. Knowledge of natural levels of heavy metals in soil is very limited, and only for essential trace elements (Zn, Cu, Mn and Fe). The total nitrogen contents of soils are very low, less than 1%, and available phosphorus is also generally very low, less than 5 mg/kg. Exchangeable potassium concentrations are generally medium to high in the heavier textured soils but low in sandy soils. Overall, the fertility of soils are low and soil erosion caused by run-off is often serious. Wind erosion of soil, and sand encroachment in the coastal regions, are also locally significant.

4. Water Use in Agriculture

Irrigated agriculture can be divided into three fairly defined categories:

Spate irrigation ; Springs irrigation; and Well irrigation
Among the three sub-systems, the well and spate irrigation are by far the most extensive covering 35% and 8% respectively of the total cultivated areas during 2004 (1,188,888 ha). The springs cover about 3% of the total cultivated areas such as shown in the following figure.



Spate irrigation
In the rainfed areas of high altitude, cultivation is done in terraces and Each plot has its own canals and is the private property of the farmer. In areas situated in secondary and small wadis, which are irrigated occasionally by spate, farmers have the right to irrigate their fields according to the sequence of irrigation starting from upstream.
Water distribution is controlled by the Ministry of Agriculture and Irrigation (MAI) through its departments of agriculture offices in the different Governorates or regional development authorities. These departments distribute water according to a seasonal spate irrigation plan which is based on the agricultural production plan. Irrigation starts by diverting spate floods from the most upstream weir through deferent gates and canals to irrigate the lands downstream through the respective weir and canal system according to the plan and in keeping with the “rada’ah” system as much as practicable.

4.1 Spring irrigation

Under spring irrigation system there is no governmental control on the water distribution from this system but it is usual for upstream farmers to take their share of the water before passing on any remainder. For example in Madinat Alsharg (central highlands) the water is diverted from the stream into two main canals, each canal supplies a distinct irrigation catchment. The main canals are permanent stone-lined canals. The diversion structure often does not allow the same quantity of water to flow through both canals simultaneously. An appointee of the sheikh is in charge of collecting payments to cover water costs and upkeep of the main canals and equilibrating the flow in each canal by means of a pump. Water is paid for by the number of days of extraction from the main canal. Payments are made only in the dry season. Individual farmers without any payments take spate and wet season water. As it is feasible for more than one farmer to irrigate in one day the payment for one day is divided by the number of farmers who irrigated during this period. The payment for one day is YR500.

Once water is diverted into the main canal, the group of farmers get together to divert water into their fields. Upper fields have priority. Each farmer irrigates his field within an allotted number of hours.

Maintenance of secondary and tertiary channels is the responsibility of the group of farmers. A special appointee the naib al marad will inform the group if major works are required on the channel. Farmers must provide the labour or pay for someone to participate in this activity.

4.2 Well irrigation

The private sector has complete control the irrigation wells because it provided the capital investment for the drilling and exploitation.

Three methods of well water distribution are used:
- The owner of a well who takes direct benefited from it
- Partnership owners who divide the water into a number of days supply for each partner
- Farmers who buy water from a neighbouring well owner.

Distribution and use of well water for irrigation is varied and based on the ownership right of well water.

Although water resources are scarce and limited, the well water development is supported by Government. Because of this, the well owners just pump as much as they can without any regard for the importance of this resource. With the partnership approach each farmer must take his turn until there is no further need for irrigation (especially if there is rainfall). When farmers have to buy water they try to pump the water for a short time to pay less for the supply.

The cost per hour for pumping water varies from one region to another and it is also based on the crop type. It ranges from YR200-600/h. However, if the cost of water is related to production, there is no consideration for the pumped quantity of water by the farmer. In this situation the cost of water is estimated at 25 percent of the total yield in coastal areas, and 50 percent in the highlands.

5. Irrigation Practices and Efficiency

5.1 Spate irrigation

Basin irrigation is the preferred method of irrigation with spate systems. The plots are usually 0.25–0.3ha.

The traditional practice is a single replanting irrigation of 600–1,000 mm of water, depending on basin embankment height and field leveling. Since the sixties many studies have been carried out to measure the quantities of spate water to be added. The water requirement for sorghum amounts to 350-400 mm in Abyan and 540 mm in Tehama. The requirement for cotton is 600-700 mm (long-Staple) in the Delta Abyan. The medium - Staple consumes 450-600 mm in Abyan and 718 mm in Tehama. It should be noticed that the cotton of medium- Staple is planted under supplementary irrigation in addition to the spate irrigation.

Provisional estimates of surface water irrigation efficiencies were made on the basis of impressions during an agronomic field survey executed in 1993 (Mahmood, 1993). The conveyance efficiency was estimated between 80-85 percent; the distribution efficiency between 70-75 percent and the field application efficiency between 65-70 percent. The overall efficiency for surface water irrigation would then be 36-45 percent.
The factors that affect spate irrigation efficiency can be summarized as follows:

- Weak spate irrigation management
- The traditional of water distribution depends on earth dams and the addition of spate water from one field to another is not effective in improving the efficiency of spate irrigation.

5.2 Spring irrigation

Spring irrigation is managed by the farmer who must rely on his experience for irrigation timing. This depends on the condition of the crop. No studies have been carried out to evaluate the irrigation efficiency of this system.

5.3 Well irrigation

Farmers' practices differ from one farm to another. Surface irrigation is applied in the form of furrow or plot irrigation. Plots are normally small in size. Furrows are short in length. Water from wells is conveyed through earth-channels with low water conveyance efficiency. Data collected in Delta Abyan shows that the average loss of irrigation water through earth-channels is more than 50 percent in irrigating of vegetable crops.

Irrigation is applied at intervals ranging from 7 to 9 days for vegetables in Delta Abyan without considering the available soil water content in the root zone. The interval between irrigations is a farmer's decision. Results also indicate that irrigation is applied when the soil water content reaches 83 percent from field capacity. This percentage is much higher than the recommended water content, which ranges from 75 percent to 65 percent under special conditions of vegetable cultivation and type of soils.

Many studies have been carried out to determine the crop water requirements for well irrigated crops like sorghum, wheat as well as vegetables, like tomato, potato, onions. The water consumption of wheat at Marib and Siyiun is between 398-460 mm. Onion consume 363-504 mm, banana 1970-2200 mm, tomato 459-600 mm and potato 340-384 mm in Alkod, Syiun and Marib regions.

5.4 Water Use Efficiency

There are several studies related to water use efficiency were conducted. The results are shown in the tables 4 and 5. Water use efficiency for sorghum under spate irrigation system ranged from 0.51 – 0.80 kg/m3 and from 0.64 – 1.75 kg/m^3 under well irrigation system, for Wheat, onion, banana, tobacco, potato, tomato, garlic and maize 0.64 – 0.92, 4.7 – 12.4, 2.03-2.73, 0.595, 5.8 – 9.4, 3.5 – 12, 2 and 0.9 – 2.01 kg/m^3, respectively, under well irrigation system. The water use efficiency for millet, sesame, groundnut, watermelon and cotton were 0.31, 0.13 - 0.34, 0.32 – 0.441, 0.28, 0.56 – 0.59 and 9.1 kg/m^3, respectively under spate irrigation system

Table 4. Assessment and Review of Research and Studies on Irrigation by Spate Water

Crop	Station	Water Require-Ments (mm)	Irrigation Water m^3/ha	Total growing period (day)	Years of Research	Water utilization efficiency kg/m^3	Remarks
Sorghum	Al-Kod	350- 400	5000-5714	95	2	0.51	
	Tihama	561	669	98	1	0.447	
	Taiz	540	5400	148	2	0.80	
Millet	Al-Kod	300- 390	4286-5571	95	NA	0.31	
Sesame	Al-Kod	350- 450	5000-5952	95	2	0.34	
	Tihama	840	NA	110	2	0.13	Autumn
	Tihama	915	NA	108	2	0.13	Summer
	Marib	474 - 500	5930-6250	112	2	0.222	
Groundnut	Al-Kod	450- 600	5952-8571	135	3	0.432	
	Marib	495- 600	6188-7500	123	2	0.441	
Cotton/ g.hirsutum	Al-Kod	600- 700	8571-10000	240	3	0.28	
Cotton/	Al-Kod	450- 600	6429-8571	195	2	0.56	
g. barbadense	Tihama	718	680	130	1	0.59	Supplemental
Watermelon	Al-Kod	490- 600	7000-8571	100	2	9.1	

Source: El-Ghouri M. et al. Research on Irrigated Agriculture in Yemen, A Review and Future Perspective, May 2000.

Table 5. Assessment and Review of Research on Irrigation by Underground Water

Crop	Station	Water Require-Ments (mm)	Irrigation Water m³/ha	Irrigation frequency	Total growing period (day)	Years of Research	Water utilization efficiency kg / m³	Remarks
Sorghum	N.	NA	100	2	150	2	1.75	Supplemental
	highland	NA	350	6	160	2	1.11	supplemental
	Seiyun	466	4660	10	85	3	0.64	
Wheat	Marib	398-438	5820-6960	6-8	120	3	0.86-0.92	
	Seiyun	460	4600	10	120	3	0.64	
Onion	N. highland	NA	NA	15	165	3	NA	
	Al-kod	350-550	5000-7857	12	120	3	6.3	
	Marib	468-504	6800-7890	14-18	139	1	4.7-5.1	
	Seiyun	363	3630	11	150	3	12.4	
Banana	Al-kod	1970-2200	24625-27500	55	360	2	2.03-2.73	
Been	N. highland	NA	NA	NA	170	1	NA	
Tabacco	Al-kod	400-600	5000-7500	10	120	2	0.595	
Potato	N. highland	NA	NA	NA	NA	1	NA	
	Taiz	310	3100	6	126	2	5.8	
	Marib	423-485	5490-6380	6-8	125	3	5.13	
	Seiyun	340	3400	9	125	2	9.4	
Tomato	Al-kod	600-650	9429	14	120	2	12	
	Marib	459-585	6400-8150	12-14	134	1	3.5	
Garlic	Seiyun	435	4350	15	170	1	2.0	
Maize	Taiz	430	4300	8	135	2	1.6	
	Al-kod	400-450	5714-5952	5	110	2	0.8	
		293-359	3661-4176	5	110	3	1.72-2.01	border
	Tihama	460	4830	NA	102	2	1.3	Var. setilagus
		730	NA	NA	120	NA	0.9	Var. Tihama

Source: El-Ghouri M. et al. Research on Irrigated Agriculture in Yemen, A Review and Future Perspective, May 2000.

6. Research and Extension

The Agricultural Research and Extension Authority (AREA) did develop technologies on the improvement of irrigation water management at the field level as well as calculating crop water requirements for some crops and irrigation scheduling. However, these technologies are limited and cover some agro ecological zones. Despite efforts to test these technologies under farmers' conditions through joint efforts with extension agencies, the adoption rate of such interventions is very low so far. Reasons for the low percentage of adoption are various and will be highlighted further in this review paper.

Improvement of conveyance systems in irrigation as well as introduction of modern methods of irrigation such as: drip, bubbler and sprinkler techniques were carried out under farmer's conditions through joint efforts with the farming communities and the Soil and Water Conservation Project. In this regard, the Cooperative for Modern Irrigation Techniques contributed significantly. However, the adoption among farmers was mainly the installation of PVC pipes to improve conveyance of irrigation water from the well to the field.

Accurate calculations of water requirements and intervals based on local conditions are yet to be developed as part of the management of irrigation water at the field level. Irrigation and water extension are practically non-existent. The only information available to farmers is the interval between irrigation developed by the extension agencies as part of development project efforts in the early days that go back to the 1970s and 1980s. Farmers seldom visit extension centers to enquire about methods and issues related to the management of water for irrigation at the field level.

7. Policies Relating to Water

Since the country reunification in 1992, a number of policy documents have been produced by, and for, the Government (GOY), usually with the assistance of external agencies, including the World Bank, UNDP, FAO, other donors and various consultants.

The main policies documents are enclosed as the following:

7.1 First Five Year Plan / FFYP (1996-2000)

The GOY, recognizing the need for water resource management, outlined national development priorities in the FFYP. This had the goal of attaining sustainable development through the management and development of water resources in an efficient, equitable and sustainable manner.

7.2 National Water Strategy

This strategy was produced in 1998 to address the water crisis in Yemen arising from the scarcity of water resources, depletion of groundwater, low efficiency of use, and the low coverage of water and sanitation services. The strategy was to be supplemented by a set of policies and action plans to help achieve the objectives of the strategy, including policies on irrigation, water utilities and wastewater.

7.3 National Irrigation Strategy

The Cabinet of Ministers Decree No. 8 of 1999 approved Irrigation Policy Statements that are the basis of irrigation policy implementation action plans. Irrigation policy is a series of principles prepared and submitted to the decision-makers and the planners for approval and implementation. The irrigation sector is the major consumer of water, and is the most wasteful, with irrigation efficiency of about 35%. Over-exploitation of groundwater by farmers results in poor quality water, seawater intrusion, and a rapid depletion of some aquifers. Depletion will cause demographic changes with adverse socio-economic impacts in the rural areas. The continuation of this situation will make the sustainable and economical use of water in irrigation through a balance of supply and demand impossible. Agricultural production also has low yield and poor quality which impacts on the national economy and food security.

While few of the statements refer directly to the sanitation sector and effluent reuse, many of the statements, if acted on, would have a direct or direct influence. The most directly relevant statement is:

- Reuse of sewage treated water should be practiced in irrigated agriculture and used safely by farmers and agriculture laborers with no harm to human beings, soil fertility, and without pollution to the groundwater aquifers, and according to the accepted standards for sewage treated water reuse.
- The action plans developed for the implementation of the irrigation policy include the reuse of effluent (given short to medium term implementation timescales), and Development of Water Resources in Irrigation.

7.4 National Wastewater Strategy

A proposal for a national wastewater strategy was developed in 2000 under the ‘Watershed Management and Wastewater Re-use in Peri-urban Areas of Yemen’ Project. This project was conducted under the Ministry of Agriculture and Irrigation, and executed by the FAO.

The document analyses some of the problems and obstacles in relation to: wastewater collection; treatment and reuse; the difficulties of coordination and cooperation and of funding and human resources issues; as well as the problems of research related to technical, economic and institutional aspects.

The proposed strategy has not been acted on, developed further or adopted, and is unknown outside the MAI.

7.5 Water Law

The Water Law (No. 33), ratified in July 2002, sets the framework conditions for integrated national water management including water quality control, and harmonizes with the Environment Protection Law with regard to protection of water resources. The Water Law specifically refers to water quality protection – the first objective of National Water Strategy.

The law gives the National Water Authority a clear mandate for its leading role in policy, regulatory, and legislative functions related to water resources management including quality control, as well as the authority to implement and eventually enforce necessary action.

Second Five Year Plan for Social and Economic and Social Development 2001-2005
The SFYP represents the first circle in the chain of plans interpreting and implementing Yemen's Strategy and an assessment is made of the performance of the FFYP, and this is summarized as follows:

The Government established the Environment Protection Council, which has now become the Environment Protection Authority (EPA), and issued a law on Environment Protection. Further, it established special institutions, NWRA, NWSA and local water and sanitation authorities, with mandates on the various environmental issues, particularly on conserving water resources, coastal regions and natural habitats, ensuring proper management of hard-waste, toxic and hazardous waste, and monitoring air pollution.'

Due to the rapid growth of population (only 40% of total populations has access to safe water, and 6.2% are covered by sanitation and sewage system), expansion of human activities and urbanization, have led to the over-exploitation, depletion and pollution of the natural resources, particularly in the underground water.

The SFYP seeks to increase the water coverage to 69% of urban population, and in rural areas to 65%. The plan also includes building more WWTPs and increasing sanitation connections to 263,875 household by 2005, representing a total increase of 65% from its 2000 level, and hence bringing the number of beneficiaries to 1.7 million.

8. Services and Institutions

8.1 Public institutions

With donor support, Yemen has set up a dense network of regional development units from 1970s onwards to deliver agricultural producer services and in some cases to develop and manage irrigation infrastructure. These units, under Ministry of Agriculture and Irrigation (MAI), include three Regional Development Authorities, several regional projects, and local departments of agriculture. In addition, centrally organized and managed services were set up, notably (Agricultural Research and Extension Authority (AREA); Agricultural Credit Bank (CACB).

The public institutions, which gave irrigation services to the farmer, can be described as the following:

- General Directorate of Irrigation at the Ministry of Agriculture and Irrigation, which is responsible for preparing plans and programmes related to irrigation and water use in agriculture, in addition to the supervision of irrigation practices at the Governorates.

- Agriculture Offices at regional level, which also have a role in supervising irrigation in addition to their other agriculture activities.
- Irrigation Department in the regional zones, which are responsible for spates (floods) and regulate the distribution of these floods to the irrigation networks
- AREA has over 300 research workers in 13 research stations and centres at the different regions of the country. Among the professionals are 8 specialists in irrigation (3 PhD, 1 M.S, and 4 B.S level.)
- Extension has been the subject of considerable investment over the last twenty-five years. Now there are 294 extension centres throughout the country and 1,350 extension staff, including 475 graduates. The system is usually described as *"modified train and visit"* but it is acknowledged that there is virtually no extension being conducted these days.
- Agricultural Credit Bank (CACB): has a network of 22 branches in the country. CACB's interest rates are: 9 percent for short term loans (less than 1 year), and 10 percent for medium-term loans. CABC finances village merchants and is the major supplier of agricultural inputs in Yemen
- Corporation for Agricultural Services (Agriservices): The objective of this institution is to provide farmers with agricultural inputs, especially on irrigation pumpsets and spare parts for pumpsets
- Tehama Development Authority (TDA): This is mandated for the development of Tehama Region through the regulation of flood water by establishing networks for spate irrigation
- Northern Highland Development Authority (NHDA): This is mandated for the development of Northern Highlands through the regulation of flood water by establishing networks for spate irrigation
- Eastern Regional Development Authority (ERDA): This is responsible for Marib, AlJuf development and also for distribution of water stored at Marib Dam
- Irrigation projects: There are many irrigation projects spread through the country like soil water conservation projects that participated in establishing some water infrastructures and introducing some new irrigation methods
- Irrigation Department at Aden: This represents the remaining Yemen soviet projects. This department is responsible for maintenance works and tenders and contracts of water infrastructures in Abyan and Lahej regions
- Land and Water Conservation project (LWCP): Prior to adopting new irrigation techniques by farmers, this project set up some demonstration fields of new irrigation techniques (sprinkler, drip and bubbler). For this purpose the project supported a number of farmers by 30-50 percent of the cost of the pipe conveyance water and 60-80 percent of the cost of new irrigation techniques (sprinkler, drip and bubbler). The total area of conveyance system, which is covered by project, is about 10,600 ha. While the number of drip, bubbler and sprinkler irrigation systems is 31, 21 and 11 respectively. There are some problems, for example in Abyan a farmer who bought a drip irrigation unit from (LWCP) complained that the unit has insufficient pressure (emitters not dis-

charging). So he cut the PE pipes and now uses the system for surface irrigation. The reason for this may be one of the following:

An improper design: an irrigation unit that is too large, insufficient pressure because of improper sizing of the irrigation network, choice of the pumping plant, etc

A clogging problem: there were no filters, the farmer has never been told that he may have to add an acid solution to the irrigation water.

Operation problems: many manifolds being used simultaneously while the system may have been designed for supplying water to a single manifold at a time.

An extension problem: the total manpower and covered area at the different regions are shown in Table 6. The total manpower in irrigation is 562: 14 have Ph.Ds, 14 have High Diplomas, 221 have B.S, 110 have Medium Diplomas and 161 are secondary school graduates.

Table 6. Agricultural areas, holdings, manpower and budget of Ministry of Agriculture and Irrigation by regions

Source: Aden Agenda, Ministry of Agriculture and Irrigation, Yemen, April 2000.

8.2 Semi-public institutions

Irrigation association and water constructions: This institution provides farmers with irrigation equipments at a cost price.

Water users associations: The aim of these associations is to encourage participation of the beneficiary farmers in the management of spate irrigation water.

Agricultural associations: These institutions provide for the members some services regarding to irrigation such as machined farm operations and spare parts of pumps at a cost price.

8.3 Private institutions

In this sector there are many agencies supplying the market with irrigation equipment and spare parts for pumps and implements using branches all over the country.

9. Constraints

Natural
Drought which occurs often cause serious losses to rainfed agriculture.
Low rainfall forces people to rely heavily on the extraction of groundwater.

Flood overflow: Seasonal flood overflows affect the management of floodwater in a rational way.

Technical

Shortage of readily available research information on: crop water requirements, scheduling of irrigation water, suitable irrigation technologies for local Yemeni environment etc.

Lack of knowledge on management of modern irrigation techniques, suitable land preparation for rational use of water, maintenance of irrigation equipment by farmers. This is mainly due to a lack of proper extension and training in these fields.

Low efficiency of field distribution network of flood irrigation in wadis. Secondary distribution is carried out through earth canals with low discharge and low efficiency. Field distribution takes place from one field to another, thereby causing severe soil erosion and subsequent water losses.

Social

Limited awareness of water users. This reflects the limited response of farmers and beneficiaries to measures aimed at raising the efficiency of water use in agriculture.

Fragmented land ownership is typical. Land ownership in Yemen is important irrespective of the size of the land owned. This has a lot to do with social status of landowners in the community. Fragmented land makes the installation of irrigation networks rather difficult and expensive.

Economic

Lack of financial resources among farmers in many areas dramatically affects not only the adoption rate of irrigation technologies but also the ability of institutions that are dealing with the planning of water resource use and increasing water use efficiency among beneficiaries.

Land tenure and land ownership cast shade on the attitude of users towards water. Wells jointly owned by more than one farmer are managed on a daily basis. During the day when the farmer gets his share, he intends to use water irrationally only because that is his share in the particular day.

Legal

The lack of a clear policy in the water sector is evident, despite the fact that there are several legislative organizations looking into various aspects of water use and aiming at securing high levels of efficiency in water use. The lack of a clear policy adversely affects the implementation of any regulations.

Land owners are firm in their belief that water located underneath their land is their property and they have the right to use it any way they wish.

Institutional
Weak and scattered coordination between public and private institutions in the water sector have led to weak government interventions in securing high efficiency in water use. The weak database on water resources has led to scattered and fragmented information. In many cases the nature of this information makes them of no practical value to information seekers.

Lack of Subject Matter Specialists (SMSs) in extension agencies has led to limited information on water use and modern methods of irrigation. Equally important is the lack of training among SMSs in the maintenance of irrigation networks at the field level. In many cases, this leaves farmers alone in maintaining their irrigation networks.

10. Recommendations

10.1 Institutions and legislation

The importance of water in agriculture should be realized at all levels. Equally important, it must be admitted that agriculture is the major sector in water use in Yemen (93 percent). This fact should create awareness on the importance of supporting research in finding ways to use water wisely and to ensure sustainable use of this valuable resource. The formation of *a National Water Resource Research* Centre is considered essential and of high priority. This centre should be established under the umbrella of AREA being the only agriculture research institution in Yemen.

Organize training for SMSs in the field of irrigation management and maintenance of irrigation equipment. This is crucial given the fact that many farmers do not have sufficient knowledge of the installation and maintenance of irrigation units.

The research, extension and farmers linkage mechanisms should be supported to enhance joint activities under farmers' conditions and speed the development and transfer of technologies in water use and modern methods of irrigation.

10.2 Technical

Reactivate research programmers in the following fields:

- Crop water requirement of different crops
- Scheduling of irrigation water for different crops in different agro-ecological zones and soil types
- Introduce modern methods of irrigation (Drip, Bubbler and Sprinkler)
- Promote the introduction of PVC water conveying systems to minimize conveyance losses of water in irrigation earth canals
- Promote extension programs in the field of irrigation and water use among farmers

- Create a solid database on water use in agriculture to be used by service providers
- Broaden the joint efforts with farmers in conducting joint research programs in the area of improvement of irrigation water at the field level
- Formulate users groups and contact groups among farmers in the field of exchange information and experiences among users and beneficiaries of modern methods of irrigation and water use

10.3 Socioeconomic

Promote community efforts to invest in irrigation.
Promote and support the formation of irrigation cooperatives and irrigation water user associations.

Create awareness among water users of the importance of sustainable use of water resources. The efforts should address different segments of the rural societies via different means of communications and campaigns such as:

- Official communication media.
- Organize evening meetings and group discussions at the village level involving farmers' community leaders, local authorities and members of locally elected councils.
- Private and public press and newspapers.
- Schools and illiteracy campaigns curricula.
- Mosques
- Schools
- Youth promotional programs such as camping, sports, boy scouts involving m/f youth and young people.

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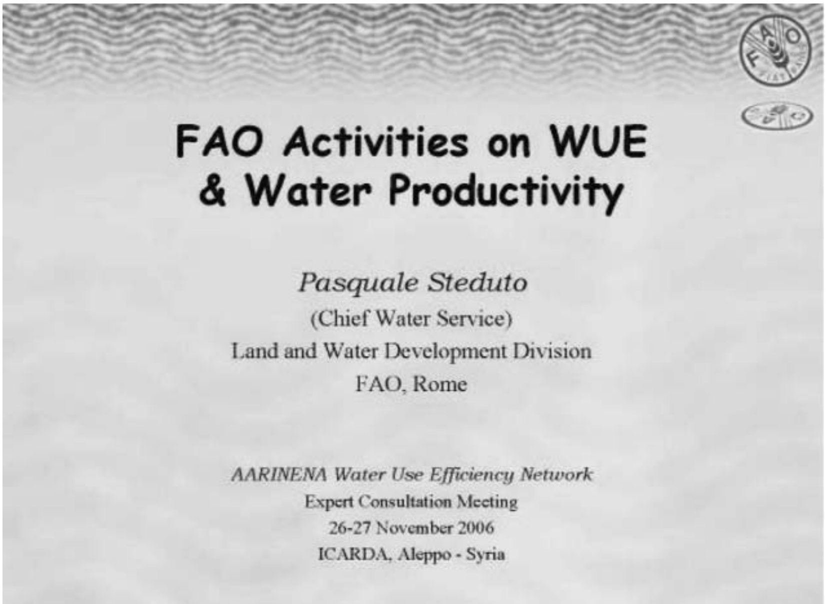
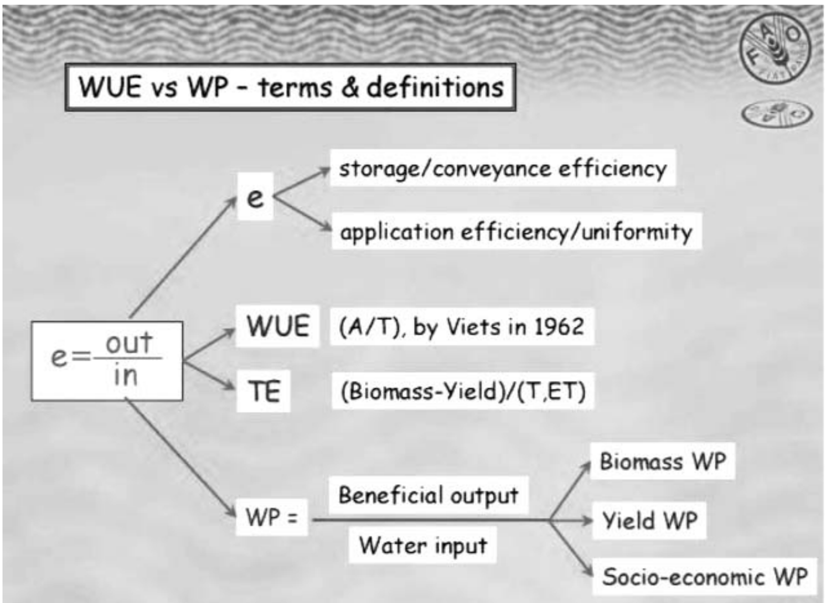
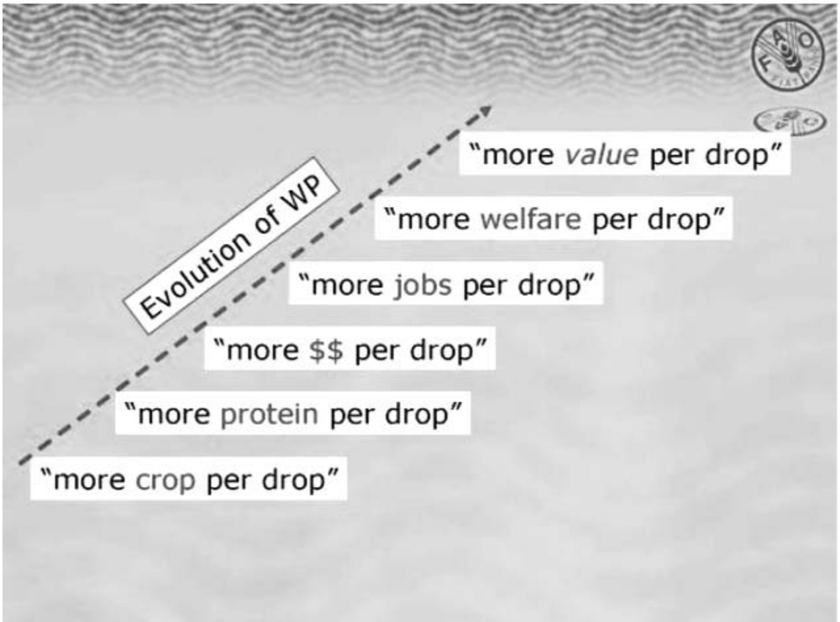
Annex 1

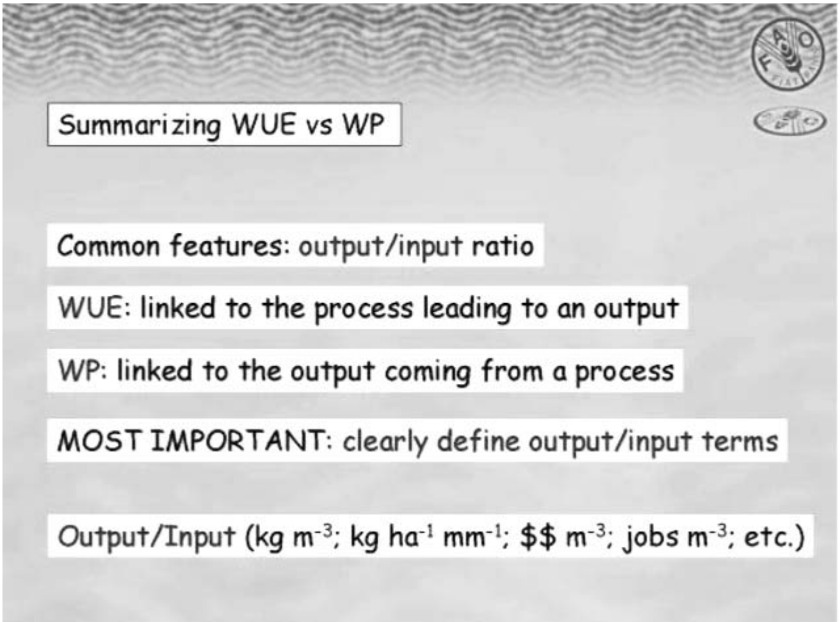
FAO Activities on Water Use Efficiency and Productivity

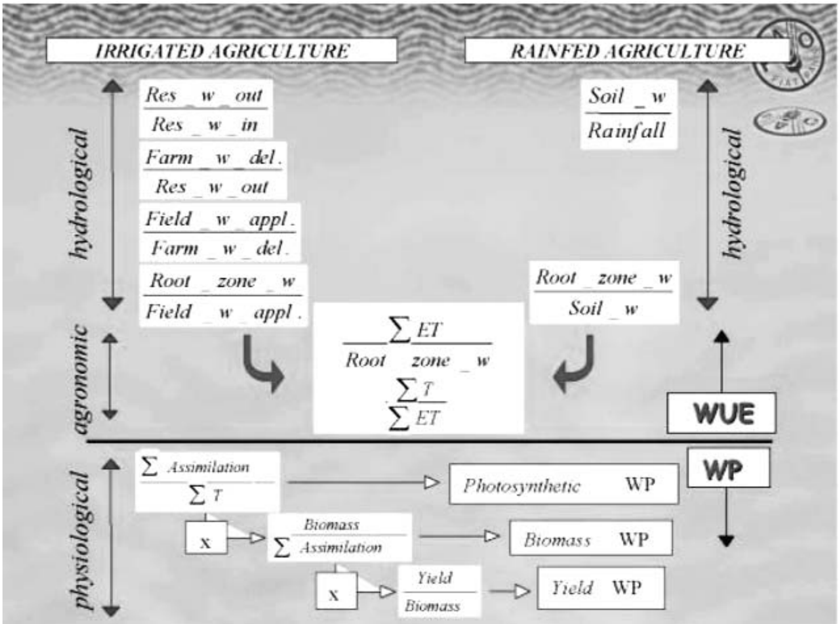
Pasquale Steduto, Water Resources Development Service Chief,
FAO, Rome

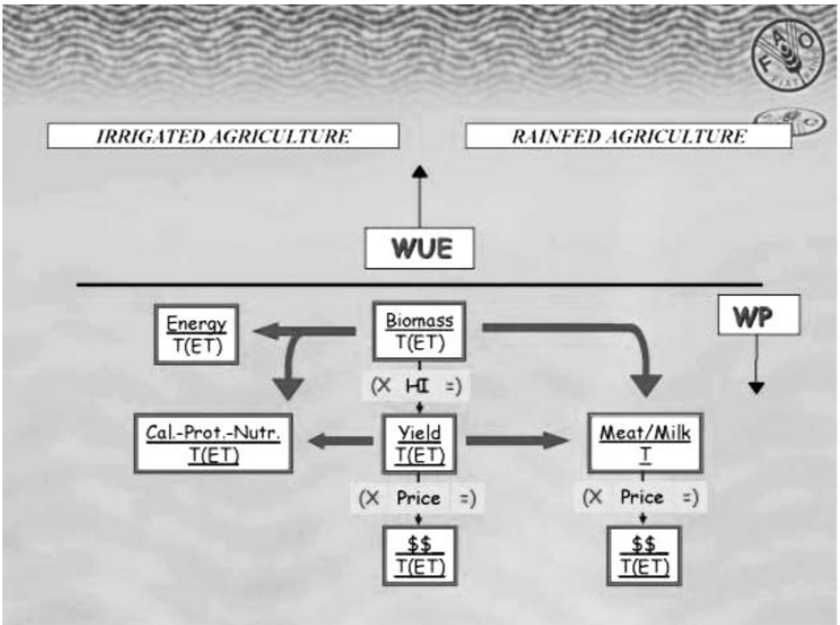





Evolution of WP
"more value per drop"
"more welfare per drop"
"more jobs per drop"
"more $$ per drop"
"more protein per drop"
"more crop per drop"


Summarizing WUE vs WP
Common features: output/input ratio
WUE: linked to the process leading to an output
WP: linked to the output coming from a process
MOST IMPORTANT: clearly define output/input terms
Output/Input (kg m-3; kg ha-1 mm-1; $$ m-3; jobs m-3; etc.)


IRRIGATED AGRICULTURE
RAINFED AGRICULTURE
hydrological
agronomic
physiological
Res_w_out / Res_w_in
Farm_w_del. / Res_w_out
Field_w_appl. / Farm_w_del.
Root_zone_w / Field_w_appl.
Soil_w / Rainfall
hydrological
Root_zone_w / Soil_w
∑ET / Root_zone_w
∑T / ∑ET
WUE
WP
∑ Assimilation / ∑ T
Photosynthetic WP
x
Biomass / ∑ Assimilation
Biomass WP
x
Yield / Biomass
Yield WP


IRRIGATED AGRICULTURE
RAINFED AGRICULTURE
WUE
WP
Energy / T(ET)
Biomass / T(ET)
(X HI =)
Cal.-Prot.-Nutr. / T(ET)
Yield / T(ET)
Meat/Milk / T
(X Price =)
(X Price =)
$$ / T(ET)
$$ / T(ET)

The efficiency chain framework

The efficiency (as output/input ratio) of an overall production process (e_{all}) can be split into many intermediary sequential steps

As long as the steps are sequential, the overall efficiency (e_{all}) can be expressed in terms of product of the efficiency of the individual steps (e_i),

$$\frac{W_{\text{farm gate}}}{W_{\text{reservoir}}} \times \frac{W_{\text{field}}}{W_{\text{farm gate}}} \times \frac{W_{\text{root zone}}}{W_{\text{field}}} \times \frac{W_{ET}}{W_{\text{root zone}}} \times \frac{W_{\text{transpiration}}}{W_{ET}} \times \frac{m_{\text{photosynthesis}}}{W_{\text{transpiration}}} \times \frac{m_{\text{biomass}}}{m_{\text{photosynthesis}}} \times \frac{m_{\text{grain}}}{m_{\text{biomass}}}$$

engineering — on-farm management — crop genetics

$$\times \frac{\$\$_{\text{grain}}}{m_{\text{grain}}} \times \frac{\text{Value}_{\text{final}}}{\$\$_{\text{grain}}} = \frac{\text{Value}_{\text{final}}}{W_{\text{reservoir}}} = \text{Overall efficiency}$$

economics

$$e_{\text{all}} = e_1 \times e_2 \times e_3 \ldots = \prod_i e_i$$

Peculiarity of the framework

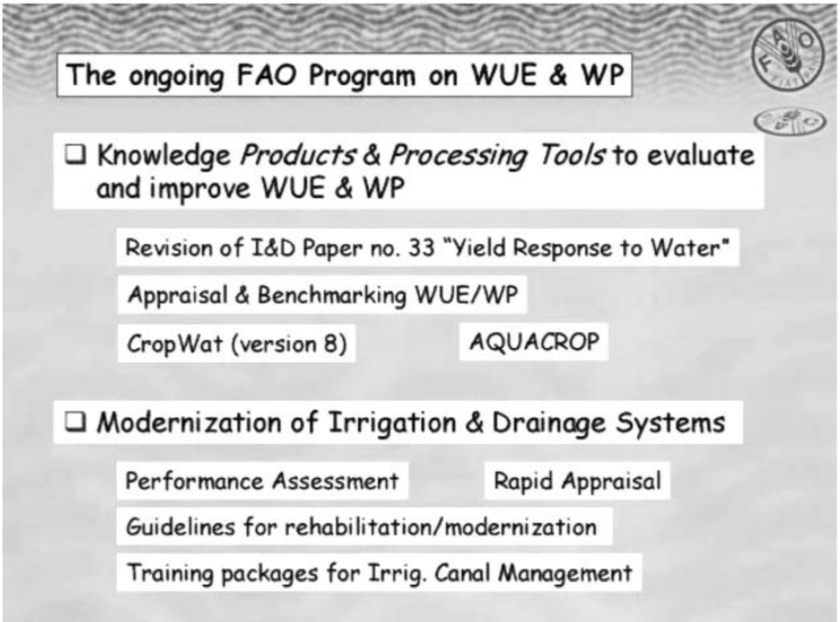
The production process can be divided into fine or coarse sequential efficiency steps according to conditions and needs

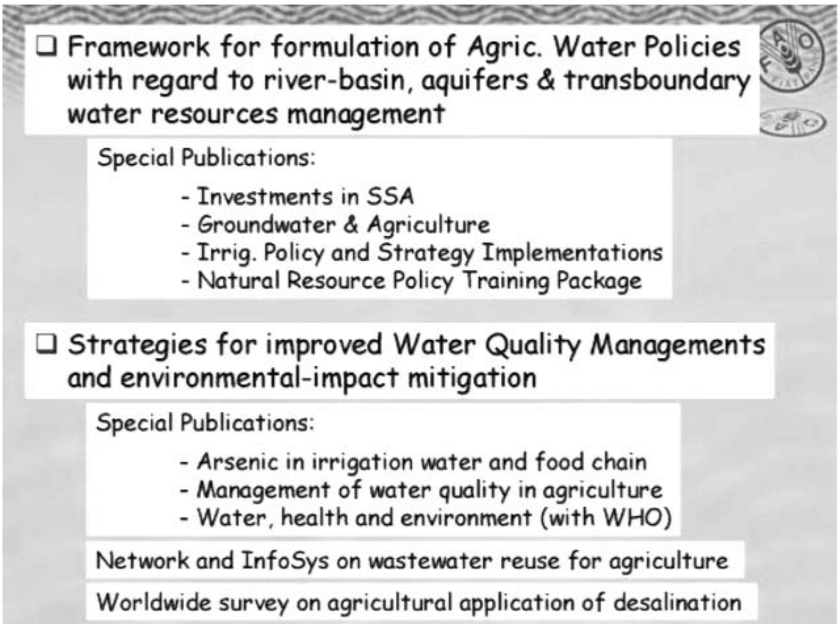
Even though the efficiency of each step (e_i) may be high, the overall efficiency (e_{all}) is considerably or much lower because of the multiplicative effect of individual efficiencies

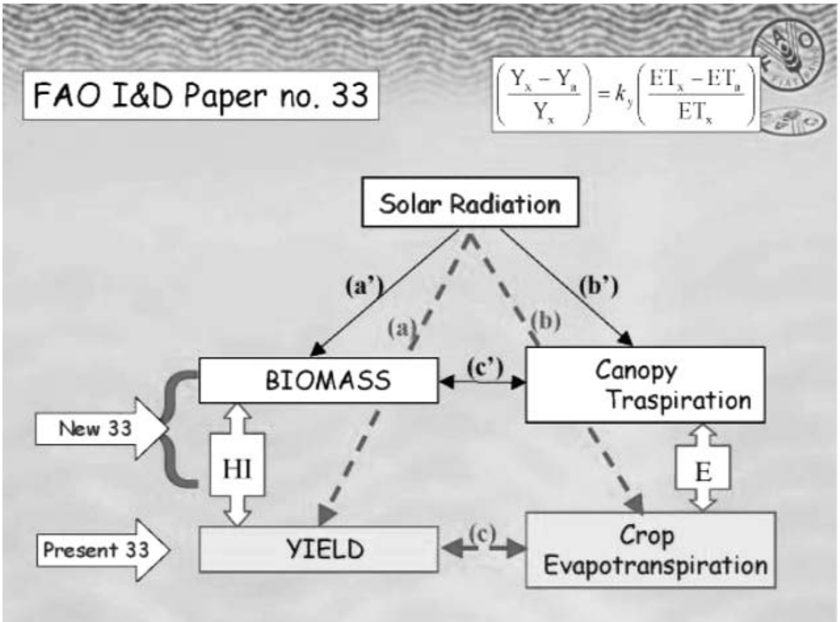
The same multiplicative effect makes it possible to improve the overall efficiency (e_{all}) substantially by making minor improvements in several of the individual efficiencies (e_i)

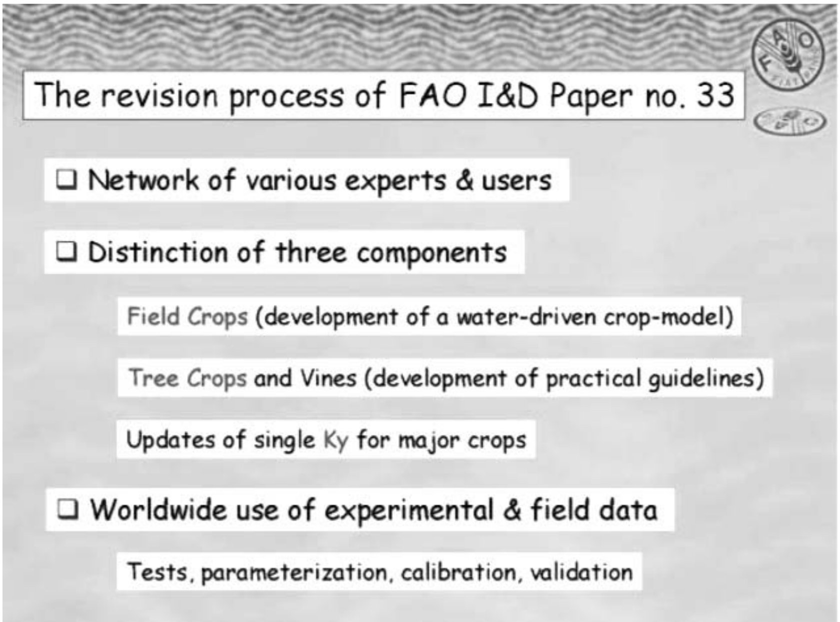
The framework makes it possible to examine a production system in step-by-step detail, systematically

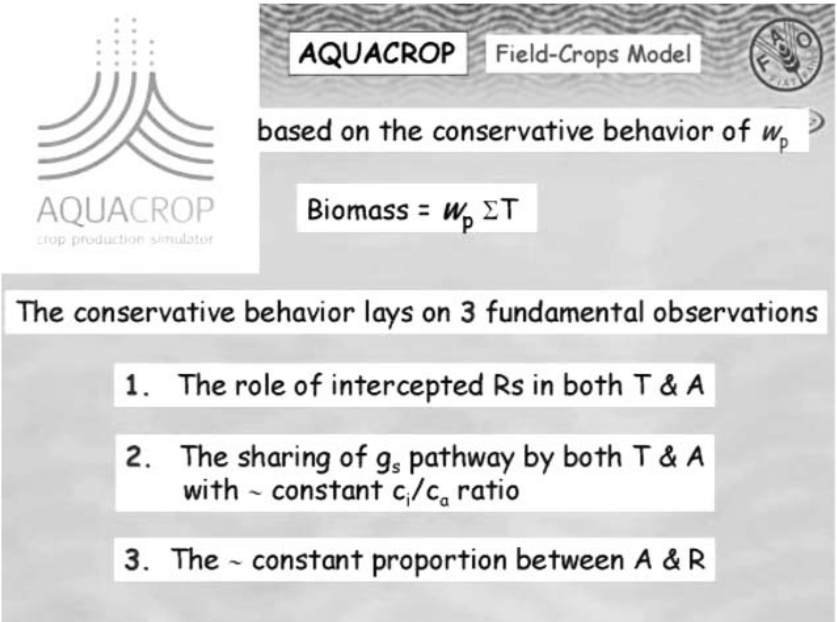
By assessing the cost of implementing improvement of each step and applying optimization techniques, the framework also provides the means to optimize the resource allocation to improve system WUE

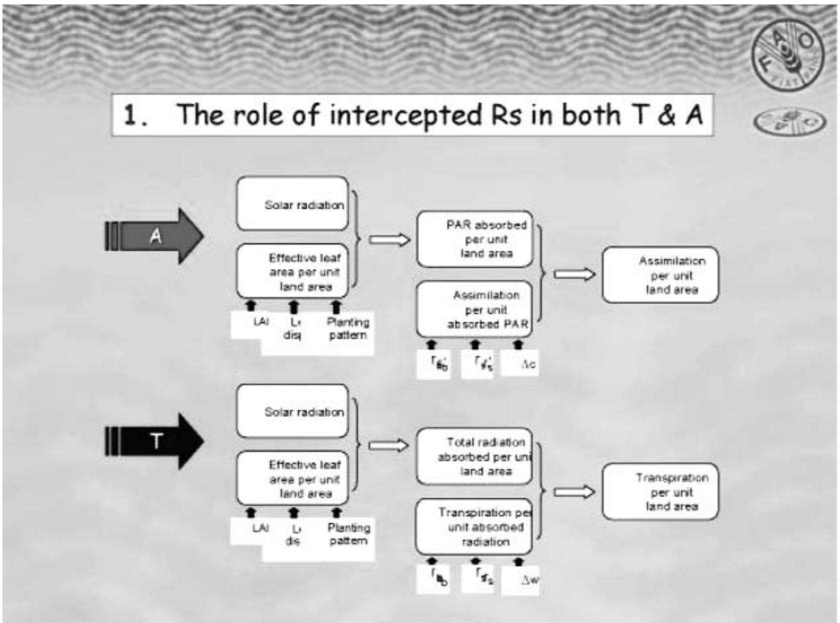

The ongoing FAO Program on WUE & WP
❑ Knowledge *Products* & *Processing Tools* to evaluate and improve WUE & WP
Revision of I&D Paper no. 33 "Yield Response to Water"
Appraisal & Benchmarking WUE/WP
CropWat (version 8)
AQUACROP
❑ Modernization of Irrigation & Drainage Systems
Performance Assessment
Rapid Appraisal
Guidelines for rehabilitation/modernization
Training packages for Irrig. Canal Management

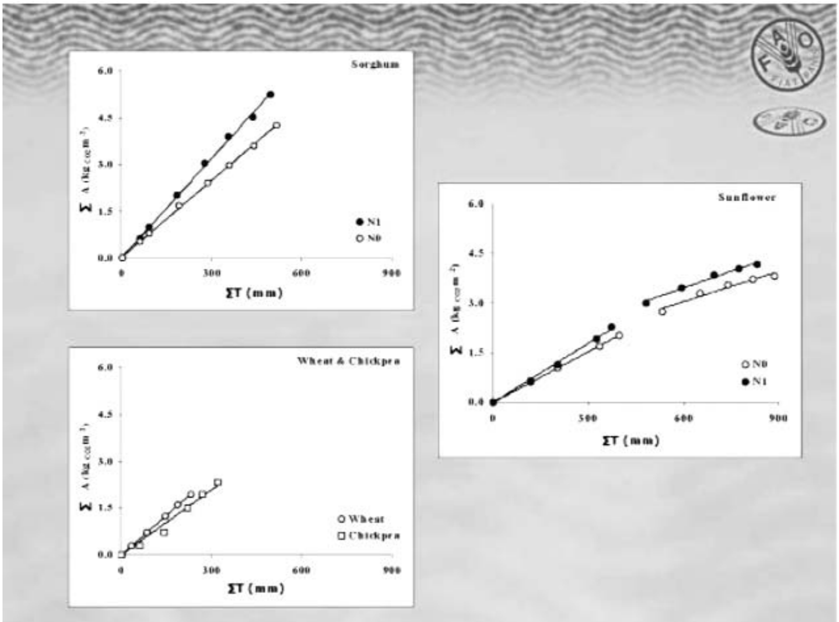

❑ Framework for formulation of Agric. Water Policies with regard to river-basin, aquifers & transboundary water resources management
Special Publications:
- Investments in SSA
- Groundwater & Agriculture
- Irrig. Policy and Strategy Implementations
- Natural Resource Policy Training Package
❑ Strategies for improved Water Quality Managements and environmental-impact mitigation
Special Publications:
- Arsenic in irrigation water and food chain
- Management of water quality in agriculture
- Water, health and environment (with WHO)
Network and InfoSys on wastewater reuse for agriculture
Worldwide survey on agricultural application of desalination


FAO I&D Paper no. 33
$\left(\frac{Y_x - Y_a}{Y_x}\right) = k_y \left(\frac{ET_x - ET_a}{ET_x}\right)$
Solar Radiation
(a')
(a)
(b)
(b')
BIOMASS
(c')
Canopy Traspiration
New 33
HI
E
Present 33
YIELD
(c)
Crop Evapotranspiration

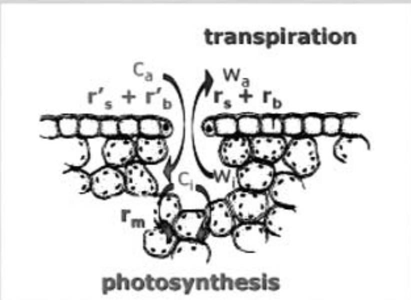

The revision process of FAO I&D Paper no. 33
❑ Network of various experts & users
❑ Distinction of three components
Field Crops (development of a water-driven crop-model)
Tree Crops and Vines (development of practical guidelines)
Updates of single Ky for major crops
❑ Worldwide use of experimental & field data
Tests, parameterization, calibration, validation

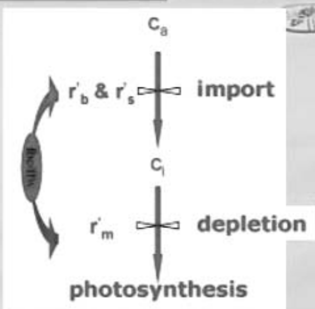

AQUACROP
crop production simulator
AQUACROP
Field-Crops Model
based on the conservative behavior of w_p
Biomass = $w_p \Sigma T$
The conservative behavior lays on 3 fundamental observations
1. The role of intercepted Rs in both T & A
2. The sharing of g_s pathway by both T & A with ~ constant c_i/c_a ratio
3. The ~ constant proportion between A & R


1. The role of intercepted Rs in both T & A
A
Solar radiation
Effective leaf area per unit land area
LAI
Planting pattern
PAR absorbed per unit land area
Assimilation per unit absorbed PAR
Assimilation per unit land area
T
Solar radiation
Effective leaf area per unit land area
LAI
Planting pattern
Total radiation absorbed per unit land area
Transpiration per unit absorbed radiation
Transpiration per unit land area



2. The sharing of g_s pathway by both T & A with ~ constant c_i/c_a ratio

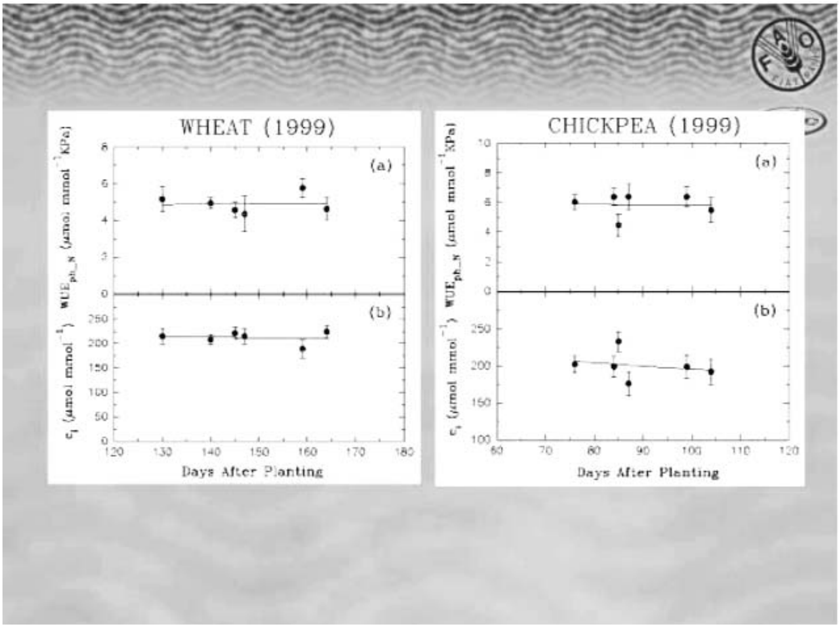


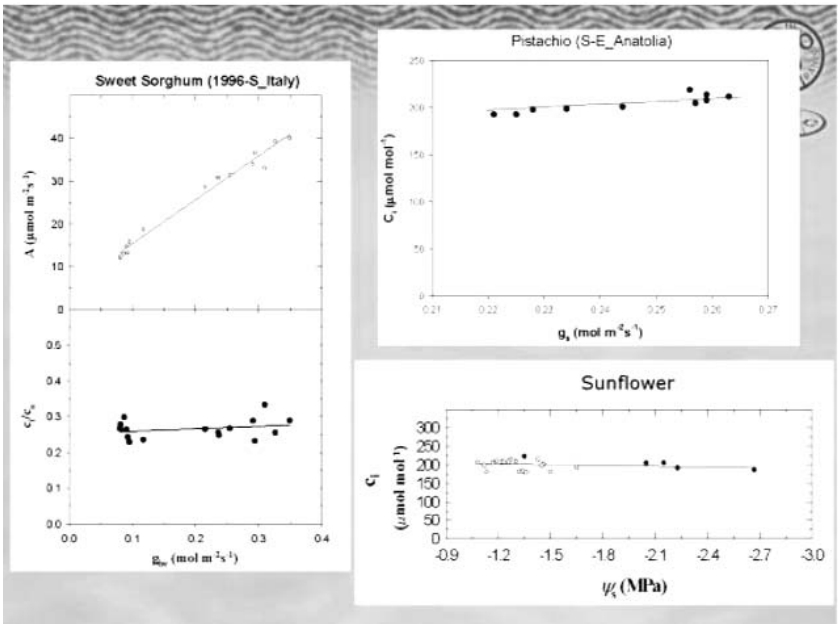


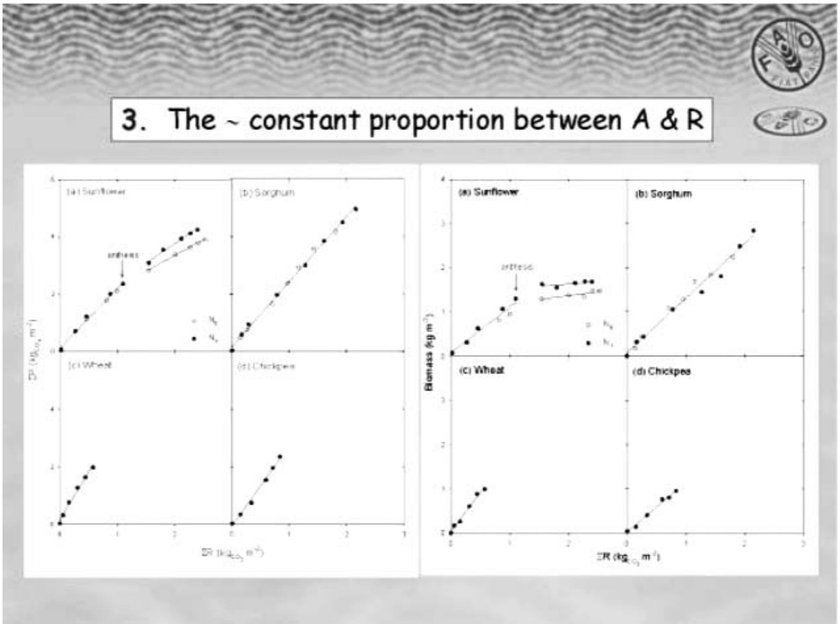
Plants have apparently evolved feedback and feedforward mechanisms to keep the import and depletion of CO_2 in balance most of the time

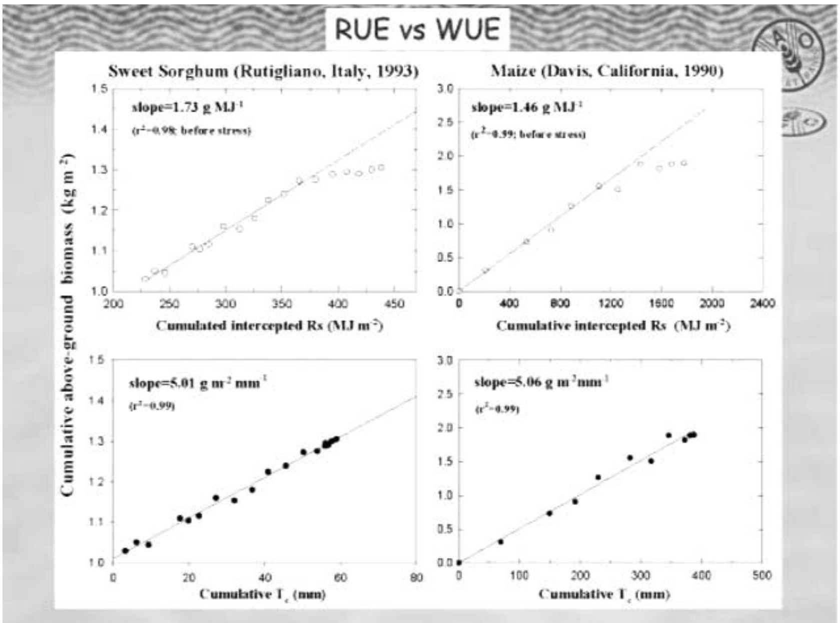
When one of the two opposing processes, import or depletion, is perturbed, the other adjusts to keep c_i nearly constant

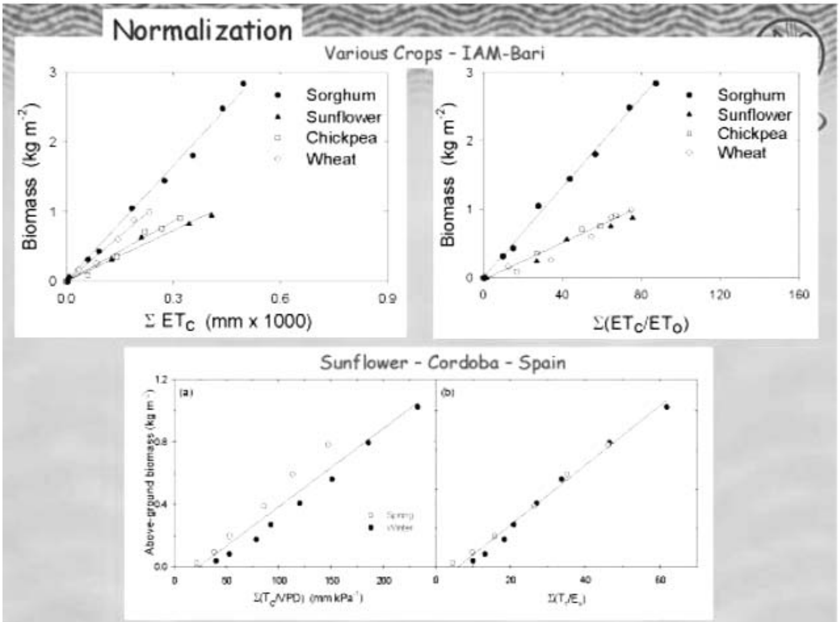
There has been substantial experimental evidence showing constant c_i/c_a ratio, under a range of conditions, such as: variations in temperature, radiation, water stress, leaf nitrogen content, CO2 and salinity stress

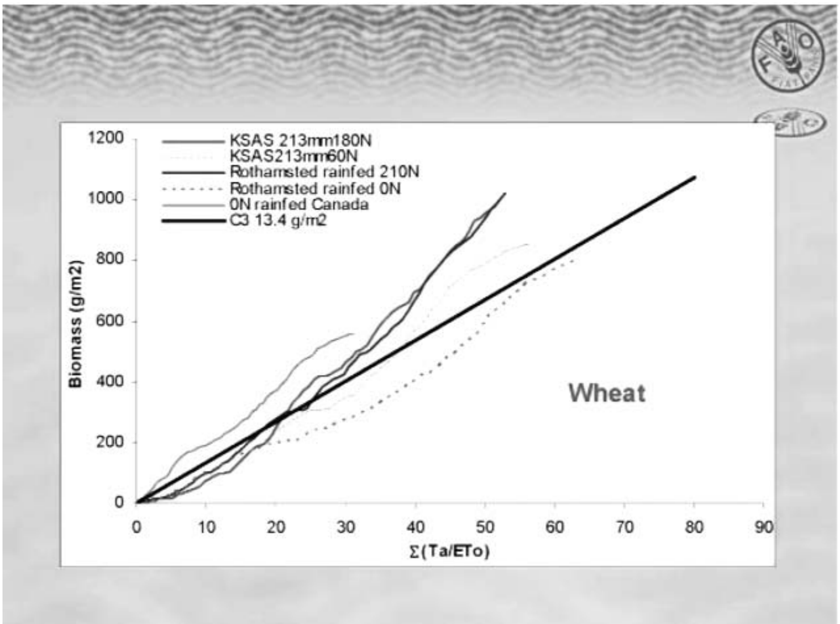

WHEAT (1999)
(a)
(b)
Days After Planting
CHICKPEA (1999)
(a)
(b)
Days After Planting

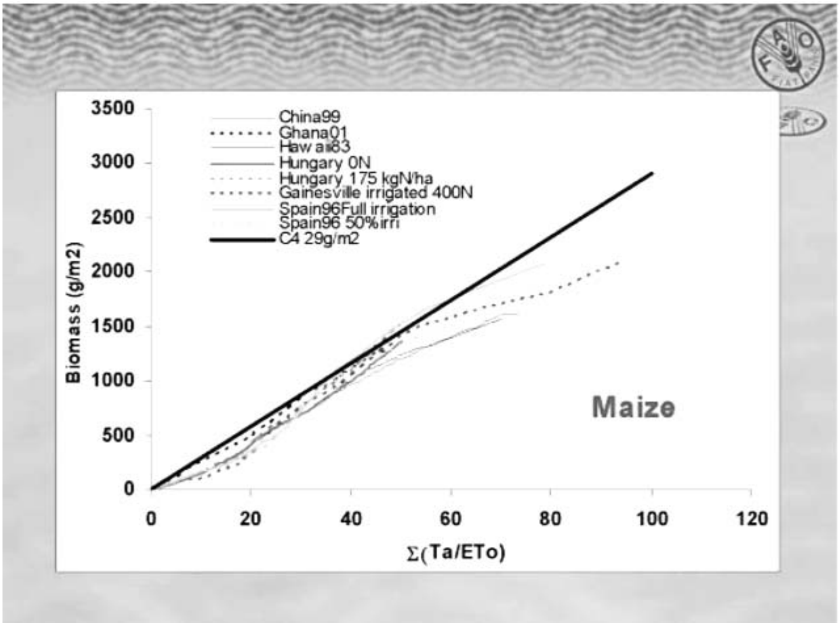

Sweet Sorghum (1996-S_Italy)
Pistachio (S-E_Anatolia)
Sunflower
ψs (MPa)

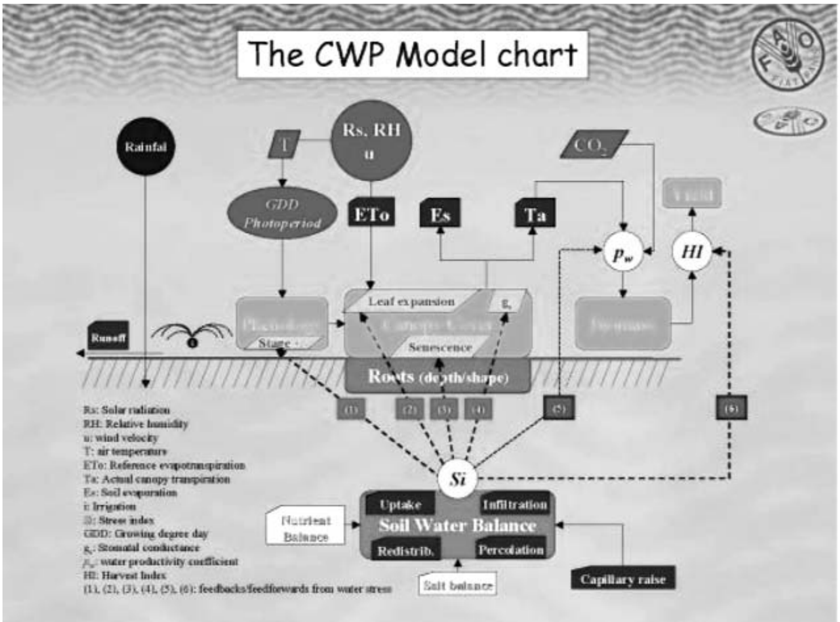

3. The ~ constant proportion between A & R
(a) Sunflower
(b) Sorghum
(c) Wheat
(d) Chickpea
anthesis
Biomass (kg m-2)
ΣR (kg m-2)


RUE vs WUE
Sweet Sorghum (Rutigliano, Italy, 1993)
Maize (Davis, California, 1990)
slope=1.73 g MJ-1
(r2=0.98; before stress)
slope=1.46 g MJ-1
(r2=0.99; before stress)
Cumulated intercepted Rs (MJ m-2)
Cumulative intercepted Rs (MJ m-2)
slope=5.01 g m-2 mm-1
(r2=0.99)
slope=5.06 g m-2 mm-1
(r2=0.99)
Cumulative Tc (mm)
Cumulative above-ground biomass (kg m-2)


Normalization
Various Crops - IAM-Bari
Sorghum
Sunflower
Chickpea
Wheat
Biomass (kg m-2)
Σ ETc (mm x 1000)
Σ(ETc/ETo)
Sunflower - Cordoba - Spain
Above-ground biomass (kg m-2)
Spring
Winter
Σ(Tc/VPD) (mm kPa-1)
Σ(Tc/Eo)


KSAS 213mm180N
KSAS213mm60N
Rothamsted rainfed 210N
Rothamsted rainfed 0N
0N rainfed Canada
C3 13.4 g/m2
Biomass (g/m2)
Wheat
Σ(Ta/ETo)


3500
3000
2500
2000
1500
1000
500
0
Biomass (g/m2)
0
20
40
60
80
100
120
Σ(Ta/ETo)
China99
Ghana01
Haw aii83
Hungary 0N
Hungary 175 kgN/ha
Gainesville irrigated 400N
Spain96Full irrigation
Spain96 50%irri
C4 29g/m2
Maize


The CWP Model chart
Rainfal
T
Rs, RH
u
CO2
GDD
Photoperiod
ETo
Es
Ta
p_w
HI
Leaf expansion
g_s
Senescence
Stage
Runoff
Roots (depth/shape)
(1)
(2)
(3)
(4)
(5)
(6)
Si
Uptake
Infiltration
Soil Water Balance
Redistrib.
Percolation
Nutrient Balance
Salt balance
Capillary raise
Rs: Solar radiation
RH: Relative humidity
u: wind velocity
T: air temperature
ETo: Reference evapotranspiration
Ta: Actual canopy transpiration
Es: Soil evaporation
i: Irrigation
Si: Stress index
GDD: Growing degree day
g_s: Stomatal conductance
p_w: water productivity coefficient
HI: Harvest Index
(1), (2), (3), (4), (5), (6): feedbacks/feedforwards from water stress

Model features

1 – Water-driven growth-engine (w_p)
2 – Retains the growing degree-day concept (GDD)
3 – Based on canopy ground cover instead of LAI
4 – Separation of E & T using Ritchie approach
5 – Decoupled from biomass partitioning
6 – Based on functional root/shoot relations
7 – Climate normalization of WP (ET_o & CO_2)
8 – Applies from rainfed to supplementary/deficit/ full irrigation
9 – Includes salinity, simple mulching, etc.

Concluding

The revision of I&D Paper no. 33 "Yield Response to Water", AQUACROP, Diagnosis & Benchmarking WUE/WP, Rapid Appraisal of Irrig. & Drainage Performances, Guidelines for rehabilitation/modernization, Water Policies for river-basin, aquifers & transboundary water resources management, and water Quality managements, are the main pillars of the WUE & WP Program at FAO

We would like to contribute to the AARINENA Networks by sharing our methods and products, finding synergies, and establish effective mechanisms of impact achievements in improving WUE and WP in the Region


Thank you
www.fao.org/landandwater

Annex 2

List of Participants

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15. Steduto, Pasquale	Chief Water Resources, Development and Management Service (AGLW), Land and Water Development Division, Agriculture Department, FAO	FAO, Via delle Terme di Caracalla, 00100 Rome, Room # B-721, Italy pasquale.steduto@fao.org
16.Yazar, Attila	Çukurova University, Irrigation and Agric. Structures Dept.	Attila YAZAR, Çukurova University, Irrigation and Agric. Structures Dept, Adana, Turkey yazarat@cu.edu.tr

Annex 3.

AARINENA Water Use Efficiency Network
Expert Consultation Meeting
26-27 November 2006
ICARDA Aleppo-Syria

Consultation Programme

Sunday, 26 November 2006

08:30 – 08:45 Registration

I) Opening Session

08:45 -09:00 - Statement of AARINENA
09:00-09:15 - Statement of ICARDA
09:15-09:45 - From Water Use Efficiency to Water Productivity: issues of *research and development* (Dr. T. Oweis)
09:45-10:15 - FAO Activities on Water Use Efficiency & Productivity (Dr. P. Steduto)

10:15-10:30 Coffee Break

II) Session on Status of Water Use Efficiency in the Region

10:30 – 11:00 Status of Water Use Efficiency in Egypt (Dr. A. Abu-Hadid)
11:00 – 11:30 Status of Water Use Efficiency in Jordan (Dr. A. Fardous and Dr. Mohamed Jitan)
11:30 --12:00 Status of Water Use Efficiency in Morocco (Dr. A. Bahri)
12:00-- 12:30 Status of Water Use Efficiency in Syria (Dr. M. Jamal)
12:30- 13:00 Status of Water Use Efficiency in Iran (Dr. F. Abbasi)

13:00- 14:00 Lunch Break

14:00 -14:30 Status of Water Use Efficiency in Lebanon (Dr. F. Karam)
14:30-15:00 Status of Water Use Efficiency in Libya (Dr. S El-Ghariani)
15:00-15:30 Status of Water Use Efficiency in Sudan (Dr. E. Ahmad)
15:45-16:15 Status of Water Use Efficiency in Turkey (Dr. A Yazzar)

16:15-16:30 Coffee Break

16:30-17:00 Status of Water Use Efficiency in Yemen (Dr. K. Atroosh)
17:00-17:30 Status of Water Use Efficiency in Oman (Dr. H. Al-Wahibi)
17:30-18:00 Status of Water Use Efficiency in Tunisia (Dr. M. Masmoudi)

Monday 27 November 2006

III) Session on Establishment of Water Use Efficiency Network

09:00 - 09:30	- Proposed Regional Water Use Efficiency Network (Dr. I. Hamdan)
09:30 - 10:00	- Discussion
10:00 -11:00	- Selection of Water Use Efficiency Network Officers

a. Secretariat Seat & Coordinator
b. . Coordinating Board Chairman
c. Technical working group leaders

11:00 - 11:15 Coffee Break

11:15 -12:00	- Group Picture and Tour of ICARDA Facilities
12:00	- Closure of the Meeting

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