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Regional Action Programme (RAP):

Water Resources Management and Water Saving in Irrigated Agriculture *(WASIA PROJECT)*

Editor:
Atef Hamdy

CIHEAM-IAMB

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Regional Action Programme (RAP):

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FOREWORD

The Regional Action Program on Water Resources Management (RAP-WRM) was developed on the basis of three major considerations:

water scarcity is one of the major limiting factors of agricultural, economic and social development in the arid and semi-arid regions of the Mediterranean;

an increasing number of developing countries of the Mediterranean are approaching full utilization of their available water resources which means that no room is left to increase the supply, as inevitable consequence of the amplified conflicts among sectorial water users;

the quantity of freshwater resources available to agriculture is diminishing while the use of lower quality water is increasing.

The Program was planned and implemented in its four successive years 1998-2002 using all the information, know-how and research findings achieved through the ample research program and the networking activities covering the major water resources management aspects in the agriculture sector, those leading to water saving in agriculture. As a matter of fact, RAP-Water Resources Management program is the continuity of Bari Institute activities in this field which started ten years ago and realized in tight cooperation with different scientific and research Institutions in the Mediterranean region.

After four years of intensive and hard work in full harmony with the National Water Research Center (NWRC)-Cairo, our partner in the program, and major involvement of the scientific institutions and personnel from the ten beneficial Mediterranean countries (Algeria, Cyprus, Egypt, Jordan, Lebanon, Malta, Morocco, Syria, Tunisia and Turkey).

We are holding today this Seminar pursuing the following objectives:

- to disseminate information and know-how achieved during the running of RAP-WRM project;
- to bring together experts on water resources development, planning and management to exchange experiences in their respective fields with those who were involved in realizing the RAP-WRM project;
- to discuss in details the research findings and the outcomes of the intensive research programme on Water Saving in Irrigated Agriculture (WASIA) with all its different components;
- to promote technology adaptation and its transfer for water saving perspectives in the agricultural sector;
- to evaluate the new management approaches for water saving implemented in the programme and its applicability;
- to discuss avenues of new cooperative research programmes on integrated demand water management for water saving in irrigated agriculture based on the know-how achieved and water saving management approaches followed in the RAP-WRM programme.

On this occasion, I wish to express my deep thanks and gratitude to Prof. Dr. Mona El-Kady, the Chairperson of the National Water Research Center, Cairo and her scientific staff for the immense efforts and fruitful cooperation during the four years of the RAP program.

It is my privilege to extend a warm welcome to the eminent scientists who, in response to our invitation, accepted to participate in this event; my deep thanks for their enormous efforts and their valuable contribution to achieve the program objectives.

I would like to express my sincere thanks to all the institutions and all the personnel contributing in this program for their fruitful cooperation and for sharing with us the responsibilities in implementing totally the program. I would like to emphasize that without their contribution and their involvement, it would have been difficult to hold the meeting of today.

Finally, on behalf of the CIHEAM-Bari Institute and in the name of all Institutions and personnel involved in the RAP-WRM, I would like to express sincere thanks to the European Commission-DGI for its financial support and valuable work in following the progress of the Program.

I am also hopeful that the opportunity provided by this meeting for mutual exchange of ideas between this top of experts and scientists in this field will help to develop our future cooperation programs for a better and more efficient water use in all sectors and in the agricultural one, in particular.

Dr. Cosimo Lacirignola

Director, CIHEAM-MAIBari, Italy

INTRODUCTION

In arid and semi-arid areas of the Mediterranean region, the availability of water resources and access to its utilization are crucial to economic well being not only of individuals, but also of entire region and are thus the corner-stone of peaceful co-existence.

The complex dimension of the Mediterranean freshwater, its scarcity and its prediction for new century have been highlighted and received considerable attention as a primary political, technical and scientific issue.

In most of developing countries of the Mediterranean, the dominant fact which will be strongly evident over the next few decades is the structural imbalance between the constantly increasing demand for water to meet the needs and the natural available resources.

Water shortage in the Mediterranean region has traditionally been addressed by increasing the supply of water. The most common approach was to extend exploration and make massive investments in water resources development. Over the years, such approach for the development of water resources infrastructures has already been implemented and a reliance on these solutions are nowadays facing increasing opposition. Review of current trends indicate clearly that increasing water supply following this traditional approach will be no longer adequate to meet the higher and higher water demands. For many countries of the region, most of their available water resources are already withdrawn and are under use and even for those countries that may have additional sources of water, the time period required to implement their water supply projects are likely to be much longer than expected at present. Moreover, relying on ever-larger number of dams, reservoirs and aqueducts to capture, store and move ever-larger fractions of freshwater run-off is beginning to fail for environmental economic and social reasons.

In the region, now, it is well recognized that the traditional approach through increasing the water supply to satisfy the basic human needs of water is questionable and to compete water scarcity and to achieve water security it is needed to search for an alternative new approach in planning and managing our limited available water resources.

This is the major topic, the running activities of water resources development and management network coordinated by Bari Institute with the contribution of 45 Scientific Institutions from the Mediterranean countries concentrated on. The major activities and the conducted research programmes are mainly focusing on developing new methods to meet the demands of growing population without requiring major new construction or new large scale water transfer from one place to another. The efforts were directed to establish a new soft path in managing water resources by increasing the water supply through: optimizing and economizing the water demand in all sectors, particularly the agricultural one; using different new approaches to explore efficiency improvement; implementing options for managing demand, the re-use and management of alternative water resources-the non-conventional ones- and reallocating water among users to reduce projected gaps and meet future needs.

The RAP-WRM which will be presented and discussed in our Seminar is a real interpretation of the know-how acquired from the network and the practical applicability of this new concept in water saving and management beside evaluating this soft path approach on economical, social and environmental basis.

Prof. Atef Hamdy

Director of Research, CIHEAM-MAIBari, Italy

REGIONAL ACTION PROGRAM ON "WATER RESOURCES MANAGEMENT": AN OVERVIEW OF ACTIONS TOWARDS BETTER WATER USE IN MEDITERRANEAN AGRICULTURE

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INTRODUCTION

The complex dimension of the Mediterranean freshwater resources, their fragility and scarcity have received considerable attention as a primary political, technical and scientific issue in many occasions during the last decade (Dublin, 1992; Rio, 1992; Barcelona, 1995; Stockholm, 1996 and 2001; Turin, 1999; the Hague, 2000) and also recently during the Johannesburg World Conference on Sustainable Development in August 2002 and the 3rd World Water Forum held in Kyoto in March 2003. All these Conferences and meetings have emphasized that the water perspectives in the Mediterranean region are concerned by two fundamental issues: the continuously growing water demand, on one hand, and the chronic water scarcity and expanding problems of pollution, on the other one. Both these issues are interrelated into the complex water functions and affected by unfavorable regional climatic conditions and other environmental and socio-economic factors having frequently triggering effects.

In fact, in the Mediterranean, water is the major factor limiting agricultural development under both “rainfed” and ”irrigated” conditions. In the most areas of the region, water resources development has reached near to maximum exploitation level and agriculture faces the challenges to produce more food for inexhaustible population growth, while maintaining almost unchanged land and water input. This challenge becomes exceptionally important for arid and semi-arid areas of the Mediterranean, where agricultural production is strictly related to irrigation and where, in many places, the maximum employment of resources has already achieved.

Nowadays, traditional solutions relying on the construction of dams, reservoirs and aqueducts to capture store, and move ever-larger fractions of freshwater runoff are questionable as most of the available water resources are already withdrawn and are under use. Moreover, this approach based on physical solutions is facing increasing opposition for environmental, economic and social reasons. Therefore, the resolution of the problem should be searched not in the increase of water supply for agricultural use but in "water demand management", i.e. in water saving and better employment of already existing resources. This requires considerable efforts in the modernization of irrigation systems and in the development of sustainable management activities which are compatible with the technical, financial and socio-economic capabilities of irrigation sector in Mediterranean environment.

Nevertheless, the lack of personnel with the appropriate technical and managerial skills for the use of advanced technological tools and implementation of modern management strategies are among the major constraints for achieving “more crop by drop”. Consequently, to achieve the goals of improved and more efficient agricultural production, it is needed to transform the concepts of water efficiency improvement and water saving in agriculture into implementation policies, programs and actions on the ground in the countries which are particularly affected by water shortage problems.

During the last decade, the Mediterranean Agronomic Institute of Bari (IAMB) has been developed several programs and research projects focussed on the water saving in irrigated agriculture in the Mediterranean region. Among them, a particular attention has been given to the Regional Action Program on "Water Resources Management" (RAP-WRM) carried out by the CIHEAM-Bari Institute within the frame of the EU DG I activities. This program, started in 1998 and lasted for almost 5 years, has involved , beside the Bari Institute, the most important scientific institutions and experts in irrigation sector from the Mediterranean region. This work aims to synthesize main considerations and objectives of the RAP-WRM program as well as to present the outputs and results achieved during its realization.

MAIN CONSIDERATIONS OF RAP-WRM

The Southern Mediterranean, comprehending the Northern African and Near East countries, is the poorest region in the world in terms of water resources, globally and per inhabitant. In many countries of the region, annual water withdrawal has reached or already exceeded total annual renewable water resources (e.g. Egypt, Libya, Palestine, Israel, Jordan, Syria, Malta, Tunisia) and further employment of resources is unrealistic from both technical and socio-economic point of view (Figure 1). In the region, population growth is among the greatest in the world (up to 2.5%) and agricultural production relies almost completely on irrigation: in the Northern African region, irrigated agriculture consumes in average about 85% of total annual water withdrawal (FAO, 1997), and, in some countries (e.g. Egypt, Morocco, Cyprus), water use for irrigation approaches even 90% as illustrated in Figure 2.

However, crop yield and efficiency of water use in agricultural sector are typically less than originally projected and less than reasonably achieved. As it is highlighted by the FAO (2000), average losses in irrigation projects is nearly 55% and only about 45% of water diverted or extracted for irrigation is effectively used by crops (Figure 3). The major causes of the low irrigation efficiencies are factors related to mismanagement of irrigation schemes causing deep percolation, waterlogging and evaporation, and the lack of adequate maintenance provoking deterioration of the irrigation systems, leakage and clogging problems, etc.

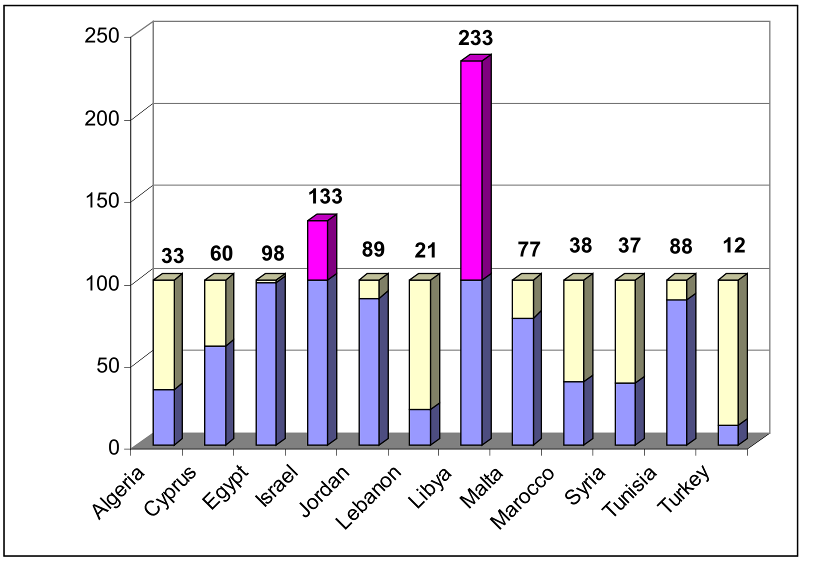

Fig. 1. Water withdrawal as percentage of internal renewable water resources (Sources: FAO, 1995, 1997; Hamdy and Lacirignola, 1999)

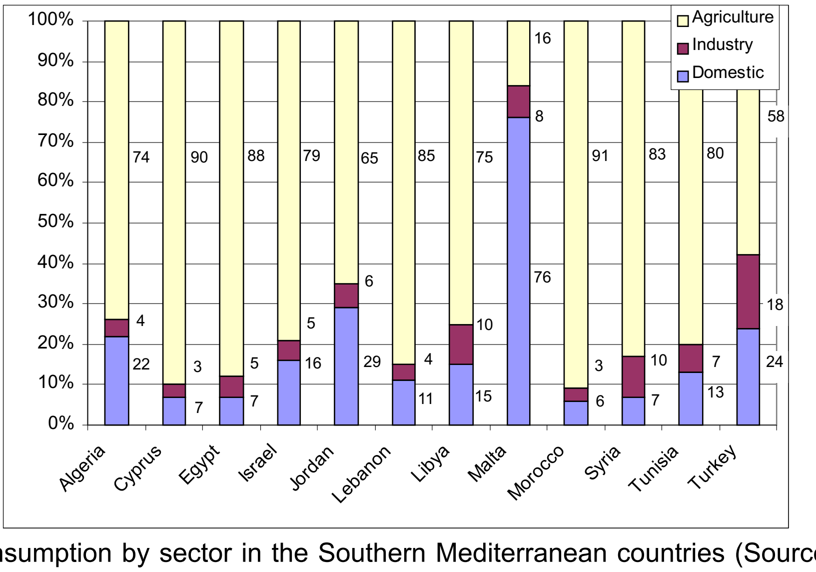

Fig. 2. Water consumption by sector in the Southern Mediterranean countries (Sources: FAO. 1995, 1997; Hamdy and Lacirignola, 1999)

The projections of food and water demand in the Mediterranean indicate, for the period 1990-2025, a population increase in the Southern Mediterranean countries of almost 100% with the corresponding increase of water demand of approximately 50% (United Nations 1994; World Bank, 1994). At present, the irrigated areas in the Mediterranean account for more than 16 million hectares with a growth rate stabilized, at the beginning of the nineties, to around 200,000 hectares per year. This requires an additional supply of water for agriculture by a rate of 2 km^3/year. However, regardless of these specific causes, existing situation is not amenable to cope with the spiraling increases in food and water demand due to water and land shortage in the region.

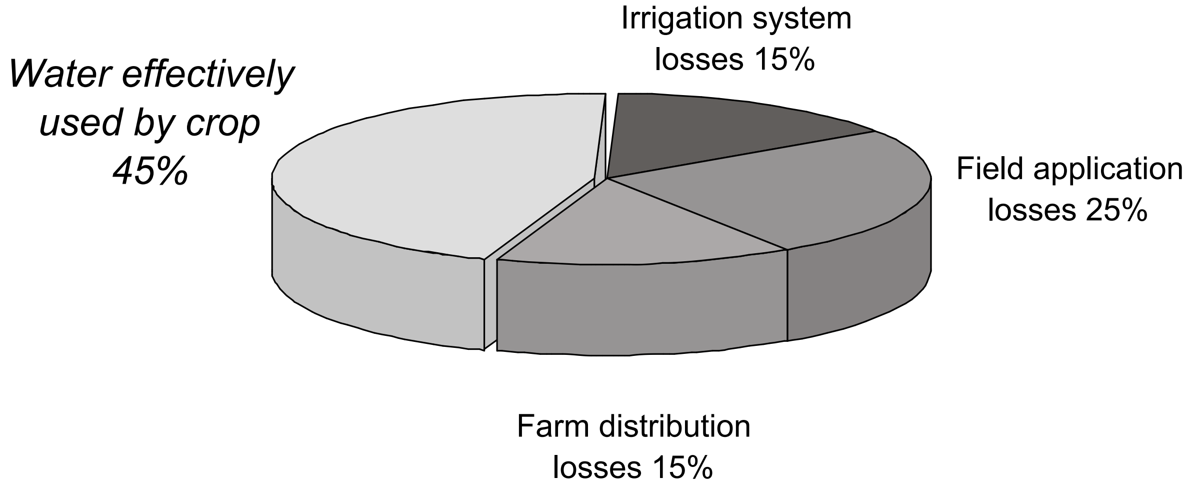

Fig. 3. Average losses of irrigation water (Source: FAO, 2000)

Therefore, most of the water savings would be made in the agricultural sector to meet the growing water demand for irrigation and other sectors. This is not only because irrigation takes the highest share of total water use, but also because it has considerable potential for efficiency improvement. In typical traditional irrigation schemes as little as 40 percent of applied water may be used for covering crop evapotranspiration, while modern schemes, and there are examples of this within the region, can achieve project efficiencies of about 65 percent. Assuming a typical situation where 80% of total water is used for agriculture, a 10 percent increase in the efficiency of irrigation would provide 40% more water for municipal and industrial use. This is a good illustration of the potential for water savings in agriculture and the need to press for it. The Regional Action Program on "Water Resources Management" (RAP-WRM) is based on the above considerations and aims at implementation policies, measures and actions for better management of water and land resources in irrigated agriculture.

RAP-WRM: OBJECTIVES, ACTIVITIES AND MANAGEMENT

The Regional Action Program on "Water Resources Management" (RAP-WRM) represents a part of a larger Program developed by CIHEAM and its four Institutes within the frame of EU DG I activities. The overall objectives of the whole program are human resources development, institutional capacity building and the improvement of regional cooperation in the agricultural sector through training, promotion of research and communication of scientific and technical information, with particular emphasis on sustainable agriculture and the transition to a more open and competitive market economy. The action programs are derived into 4 RAPs (each assigned to one of four CIHEAM Institutes) for training and for creation of research and information exchange networks based on the concept of "open centres" (centres without walls) in the following areas: water - irrigated agriculture (IAM-Bari), rainfed agriculture (IAM-Saragossa), food and agricultural policy including legislation aspects (IAM-Montpelier) and renewable natural resource preservation and utilization (IAM-Chania). The expected results of the whole program are: a better understanding of regional planning and its implementation, a more efficient regional cooperation and better information exchanges in the Mediterranean basin (South-South and North-South), an improved understanding and coordination of regional economies and compatible marketing policies necessary to facilitate economic transitions in the region.

The Regional Action Program on "Water Resources Management" (RAP-WRM), developed by MAI-Bari, aims to improve the institutional capacity building, human resources development and regional cooperation and exchange of experiences in the field of water resources and irrigation. The RAP-WRM is based on the concept of water demand management and it is oriented to the sustainable use of water resources in agricultural sector emphasizing technical, social and economic aspects through the following major issues (Figure 4):

Water use efficiency at farm scale;
Design, performance evaluation and management of collective irrigation systems;
Use of non-conventional water resources in agriculture;
Participatory Irrigation Management (PIM); and
Economic aspects of water mobilization and use.

The strengthening of regional co-operation and exchange of experiences between the Southern and Northern rim of the Mediterranean have been carried out through the following activities:

training (advanced short course and MSc mobility program),
promotion of research (networking and demonstration research projects),
workshops and courses for decision makers (in PIM, economic aspects of water mobilization and use and gender issues) and
logistic support - information technology development and transfer in Southern Mediterranean countries.

The program covers 10 Southern Mediterranean countries (Algeria, Cyprus, Egypt, Jordan, Lebanon, Malta, Morocco, Syria, Tunisia and Turkey) and is divided in two phases: the first, where it is coordinated exclusively by Bari Institute and the second, where a decentralization of activities towards Southern Mediterranean Institutions (National Water Research Center, Cairo, Egypt) has to be done.

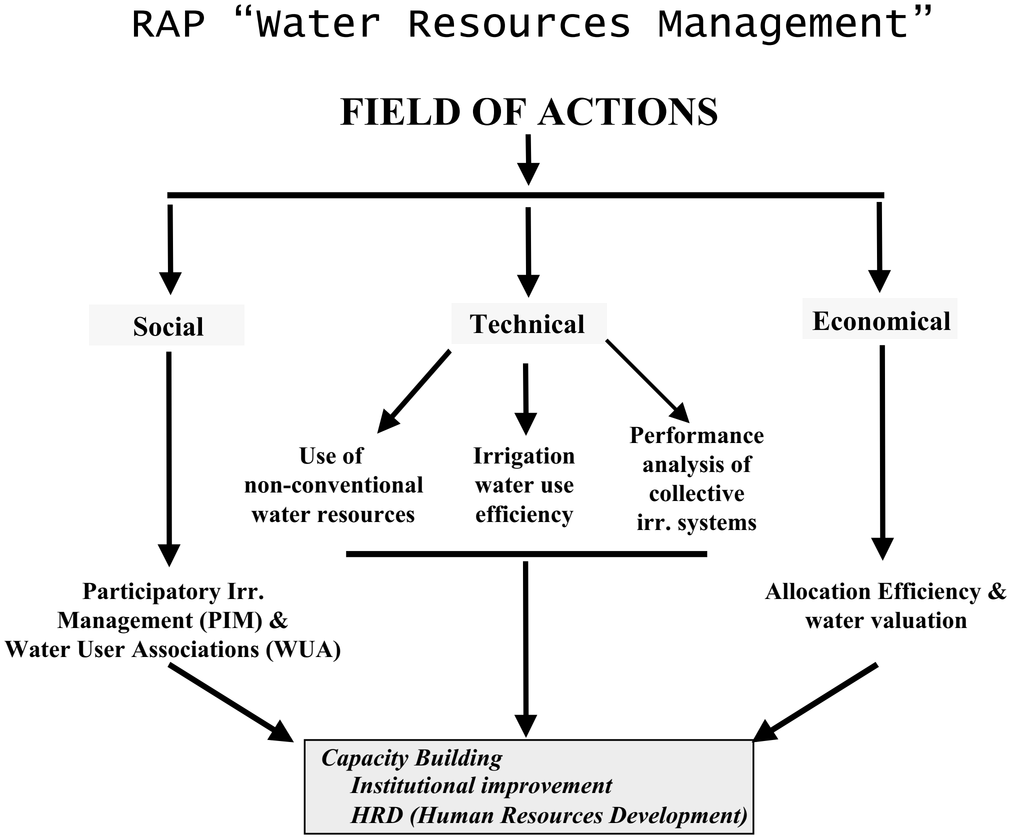

Fig. 4. Field of actions of RAP-WRM

The RAP is managed by two bodies, having complementary roles:

a) The Orientation and Management Committee (OMC)
b) The Thematic Work Group (TWG)

The OMC is composed of 13 members and activity is shared among the 4 RAPs. The role of OMC is to define:

the structure and modus operandi of the program
the basic outlines of the chosen themes
the nature and relative importance of proposed actions
the commitments of the main partners

The TWG is composed of 8 members and its role is:

to elaborate, on the base of the global framework proposed by the OMC, an operational structure for each RAP
to develop detailed actions programs as per directions laid down by the OMC
to define the structure and the mandate of the specialised ad hoc groups that will prepare each action
to specify the contribution and the role of each partner

The overall results and outputs of the activities carried out under the RAP-WRM Program are summarized here after:

RAP-WRM: OUTPUTS AND RESULTS

Training - Advanced Short Courses

In the period 1999-2002, twelve advanced short-term courses were carried out, three in each year, in eight different Southern Mediterranean countries (Algeria 1; Egypt 2; Jordan 1; Lebanon 1; Malta 1; Morocco 2; Tunisia 2; Turkey 2) beneficiaries of the RAP. The themes for each course were defined in accordance with the overall and specific objectives of the RAP-WRM and in cooperation and agreement with the regional partners taking into consideration:

the whole set of priority actions for water saving in the Mediterranean region as it has adopted in the logical framework - the course's themes were discussed recurrently and included the priority activities of national partners institutions,
specific interest of the countries hosting the course,
recommendations of Technical Working Group (TWG), and
thematic link among proposed topics and among them and collaborative research networks and overall RAP objectives.

The co-organising institutions are selected among the national partners of RAP-WRM able to provide adequate logistic support, dissemination of information and visibility of activities at both national and regional scale.

The course's topics endorsed the most important subjects for the implementation of water saving strategies in the Mediterranean agriculture (e.g. agricultural water demand management, use of non-conventional water resources in irrigation, water use efficiency and water productivity, etc.) while introducing new modeling tools and information technologies (e.g. Geographical Information Systems, crop growth modeling, water distribution modeling, etc.). The themes of the courses have evoked the multidisciplinary approaches and they were strongly linked to the network activities of RAP-WRM which has affirmed the networks themselves and reinforced and enlarged their impact in the Mediterranean region. The emphasis was given not only to the technical aspects, but equally so, to social, economical and environmental aspects, the major components of integrated water resources management approach. Particular attention has been given to the capacity to create arrangements for, and launch a process towards, integrated water resources management (IWRM) as a basis for competition resolution and capacity for dealing effectively and efficiently with the complex water challenges considering broad socio-economic, environmental and political contents. Moreover, the hosting country specific water resources problems have been elaborated through the presentation of case-studies, visits to water conservation and distribution systems, water treatment plants, irrigation systems and hydraulic structures and local units aiming at the use of modern technologies. Furthermore, the courses have offered a practical technical program at the experimental fields, laboratory work and computer exercises. The discussion sessions, round-tables, and workshops organized within the frame of the courses with the local water authorities highlighted clearly weak points (nodes) of local water management strategies and helped to identify priority actions and programs for implementation. It is shown that the water resources problems in the Mediterranean region are similar elsewhere and that the strengthening cooperation and exchange of experiences could be one of the major forces in coping with water scarcity in the region.

The advanced short courses have generated high interest in the Mediterranean region. A total number of 709 candidates applied for admission to the courses which confirms the importance and attractiveness of proposed themes on water resources management. Among them, almost half (347) were selected to follow the courses. The participants in the courses belong to 15 Mediterranean countries and 3 other countries as illustrated in Figure 5. 318 participants (or 91.6%) belong to the beneficiary countries of the RAP which greatly exceeds the threshold of 240, posed in the RAP logical framework.

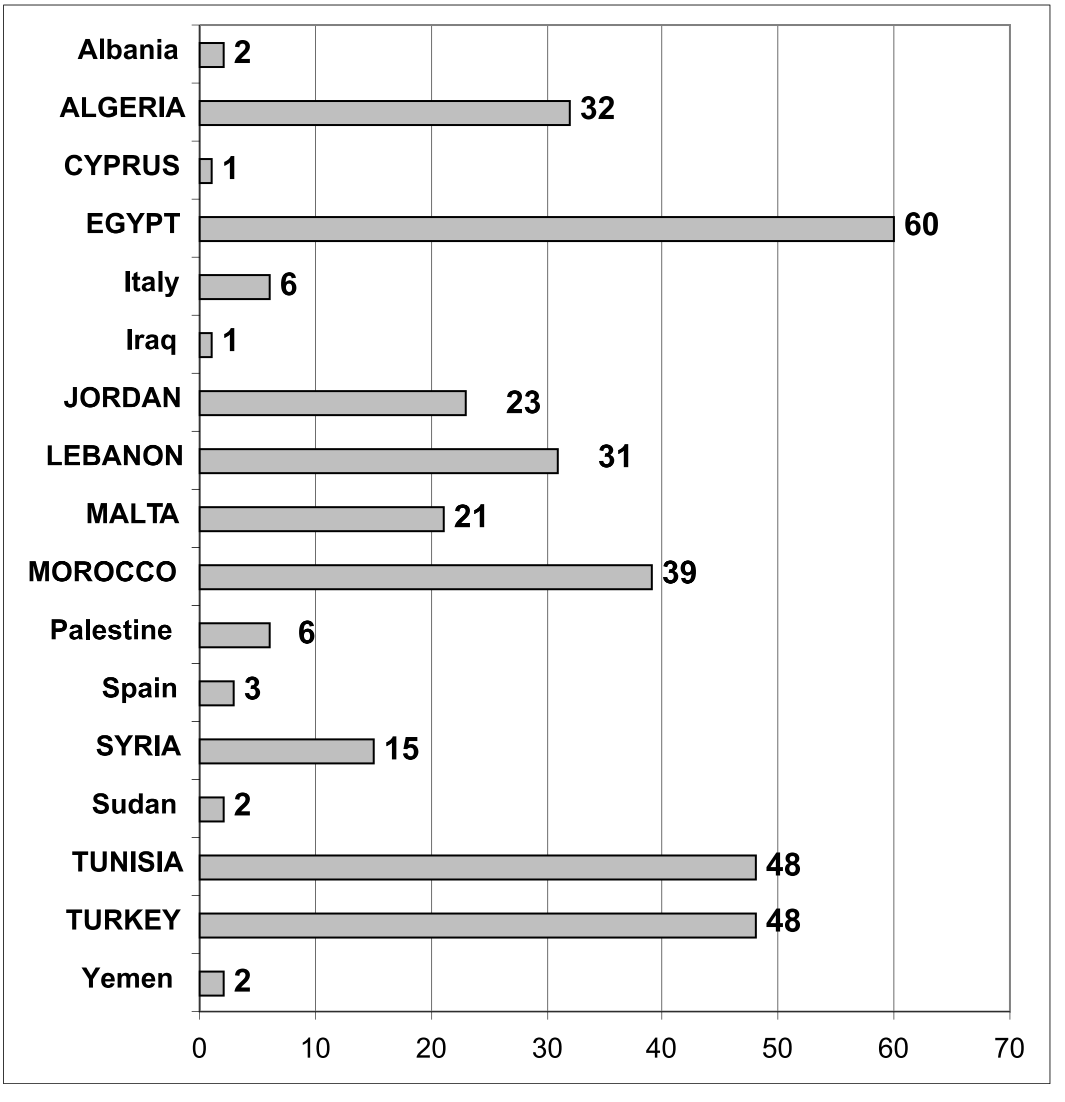

Fig. 5. RAP-WRM advanced short courses: participants per country (N.B. The countries beneficiaries of the program are written in capital letters)

The participation of the candidates from Italy, Spain and Portugal demonstrated the high interest for the course's topics in the Mediterranean region. Moreover, it has contributed to the exchange of experiences between participants from both Northern and Southern Mediterranean countries which, in turn, can reinforce the South-North cooperation in the Mediterranean region.

The profile of the course's participants ranges from researchers and university assistants to water and irrigation engineers, rural development managers and governmental officers, as well as the representatives of the private sector (Figure 6). Practically, the courses provide "training of trainers" of different profiles which should induce multiplier effects in the future.

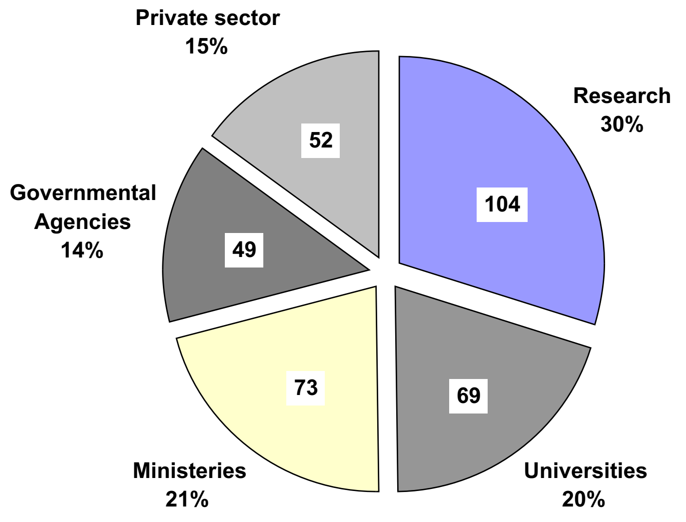

Fig. 6. RAP-WRM advanced short courses: professional profile of the participants

The lecturers were not only university professors but also high qualified specialist and researchers in irrigated agriculture, water development officers, irrigation managers and highly qualified personnel from the private sector. This allows for the elaboration of the problems from different points of view (i.e. an integrated approach) which has given an added value to the courses and has increased the interest to the courses.

The proceedings of the courses, prepared and distributed to the participants at the beginning of each course, consist of a complete documentation related to the course themes. High interest was expressed to the proceedings and they were distributed on request in more than 100 copies per course also to local scientific institutions and to some regional and international organizations (e.g. FAO, ICARDA, IFAD). Moreover, beside the participants, many lectures were followed informally by local scientists and managers. This additionally reinforced the impact of the courses and insured further dissemination of information related to the specific water management topics.

MSc Mobility Program

Mobility of trainees is a new strategy in training of water and irrigation professionals which should play an important role in the improvement of cooperation not only between Southern and Northern Mediterranean universities and scientific institutions but also among the Southern Mediterranean institutions themselves. The mobility scholarships had to enable trainees at Master level to undertake studies at institutions which will further strengthen their knowledge base and improve carrier prospects. This type of cooperation allows for exchange of researchers and, therefore, ideas which helps in development of better water management strategies and transfer and integration of local approaches into actions at the regional scale. Twelve eminent Mediterranean Institutions from Egypt (National Water Research Center - Cairo; Central Laboratory for Environmental Quality Monitoring - Kanater; Drainage Research Institute - Cairo), Italy (University of Catania; University of Trieste; National Research Center - CNR, Bari; Polytechnics of Bari), Lebanon (Saint-Esprit de Kaslik University, Beirut; ESIAM, Tamail), Morocco (IAV Hassan II, Agadir), Tunisia (INAT, Tunis) and Turkey (Cukurova University, Adana), are selected to host the fellows and assist them in conducting research programs. Research hosting institutions and research topics included in the mobility scholarship program were selected to fit into RAP research program and network activities and to improve the cooperation in the Mediterranean region.

The selection of mobility scholarships was done respecting the academic results of the DSPU course of the candidates, the coherence of the proposed thesis protocols with the objectives of RAP-WRM, the availability of necessary on-site equipment and the reference and scientific quality of the hosting centres. The emphasis is given to the cooperation between South-South scientific institutions, and thereby allowing the candidates to work under local conditions on some of concrete problems already existing in their countries of origin and highly related to the RAP program research activities.

The mobility program was fully completed with 19 trainees from 6 beneficiary countries (Algeria 1, Egypt 6, Lebanon 2, Morocco 4, Tunisia 3, Turkey 1) and Palestine (2), which is in agreement with the logical framework indicating a minimum of 16 Master thesis.

The research themes cover the most important subjects for the implementation of agricultural water demand management, improvement of irrigation efficiency and water saving in the region (e.g. use of saline water, treated waste water and recycled drainage water for irrigation) while introducing new information technologies and modern modeling tools (e.g. Geographical Information Systems, Decision Support Systems, expert systems, etc.). Moreover, the environmental (e.g. the case study of Aswan Dam in Egypt) and socio-economic aspects (e.g. the case study on Participatory Irrigation Management in Turkey) of water management in agricultural sector are treated within this program.

The mobility of trainees resulted in reinforcement of cooperation between Southern scientific institutions (e.g. IAV Hassan II, Morocco and INAT, Tunisia) and establishment of cooperation between Southern and Northern Institutions (e.g NWRC, Cairo, Egypt and University of Trieste and University of Catania). The mobility scholarships, particularly South-South mobilization, have created stronger linkages between scientific institutions and universities while giving the candidates better opportunity for working on concrete problems interesting the majority of developing countries in the region. Furthermore, it is expected that the mobility program contributes in the recognition of the MSc degree awarded by CIHEAM-IAMB in the majority of the Mediterranean countries and, also, in promoting the mutual recognition of diplomas obtained at different universities and scientific institutions throughout the Mediterranean region.

The mobility of trainees supports the "brain-drain" as some students continue their scientific carrier on the PhD programs in the EU universities. Finally, it is important to stress that the mobility program was opened also to the private organisations - however, there was no request from them to participate in it. The main reason for it could be the long duration of the mobility program which discourages the participation of the fellows from the private sector.

Cooperative Research Networks

The main objective of the "Water Resources Management" Collaborative Research Network is to provide scientific and technological know-how for investigated issues of water saving in the Mediterranean irrigated agriculture and, in such a way, contribute in improvement of human resources development and institutional capacity building in the region. Specific objectives are related to three Sub-networks of RAP-WRM (Figure 7)

Non-conventional Water Resources Management (NWRM);
Water Use Efficiency (WUE); and
Collective Irrigation Systems (CIS);

which, respectively, aims to promote:
sustainable use of non-conventional water resources, including brackish and treated wastewater and re-cycled drainage water;
increased crop water use efficiency and productivity in irrigation - more crop per drop;
improved water distribution management and performances of irrigation systems.

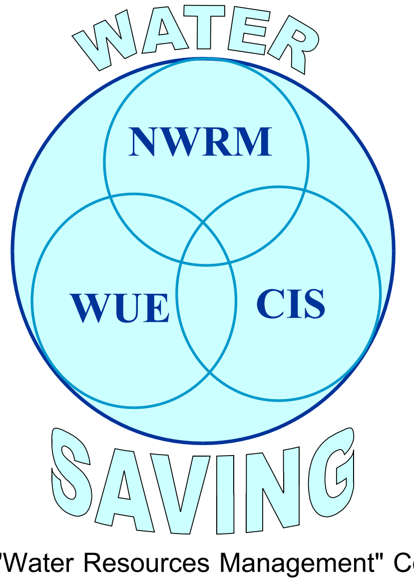

Fig. .7 "Water Resources Management" Collaborative Research Network: an integrated approach for water saving in irrigation agriculture

The research activities for each sub-network were planned in agreement to the specific objectives of each research theme and following the general and specific objectives of the Logical Framework of RAP on "Water Resources Management" and recommendations of the external Mid-term Evaluation Report (September, 2000). Four major lines of interventions are agreed with the network's members in order to alleviate some priority problems of Southern Mediterranean countries and to contribute strongly to the realization of the overall RAP objectives:

i development of human resources qualified and knowledgeable in understanding the basics of the network domains, using the data base information system and operating the information technology platform;

ii carrying out specific research works to fill in gaps in scientific information within the domains of interest;

iii realization of database information systems on each network domain;

iv implementation of an information technology platform for analysis, elaboration and interpretation of agricultural scenarios.

These Sub-Networks were already established before the RAP started and they represent the continuity with previous EU-CIHEAM programs, based on the priority issues of water management under scarcity conditions in the Southern Mediterranean countries, i.e. necessity for water saving in irrigated agriculture. During the Phase I of RAP (1998-2000), it is planned that the three sub-networks should act as three parallel research lines and in the second phase of RAP (2000-2002) they have to be integrated within one umbrella of research project WASIA to facilitate exchange of information and strengthen new strategies for water management in the region.

The rationale of the programd action-plan is in the recognition that fresh water resources are finite and limited, the potential for their further exploitation is marginal and the quality of water is continuously degrading. Furthermore, the management of collective irrigation systems requires revision and optimization of operation under dynamic changes of farming conditions and practices. Consequently, the NWRM-Net is engaged in water quality issues, the WUE-Net is engaged in water use efficiency issues and the CIS-Net is engaged in performance analysis of collective irrigation systems. They all integrated and exchange their approaches under the "Water Resources Management" Collaborative Network. The integration of Sub-Networks into an overall "Water Resources Management" Collaborative Network should denote the “soul” of RAP promoting, designing, generating, integrating, expanding and intensifying all other actions of RAP such as training and mobility, aid to decision making, workshops and seminars.

The overall results and outputs of the activities carried out within the all three sub-networks of the RAP-WRM in the period 1998-2002 can be summarized as:

the involvement of 32 scientific institutions from 15 countries (among them all 10 countries beneficiaries of the RAP) with the participation of 66 scientists;

experimental work has been carried out not only at the experimental fields, lysimeters and greenhouse of IAMB but also at the experimental sites in Morocco (IAV Hassan II, Agadir), Egypt (NWRC, Cairo), Syria (ICARDA, Aleppo), Tunisia (INAT, Tunis; IRESA, Bizerte), Turkey (Gaziantep Pistachio Research Institute), Italy (Faculty of Agriculture, Catania; Bonifica della Capitanata, Foggia), etc.;

a Crop Database containing information about 8 Mediterranean strategic crops was developed together with a crop growth and productivity model and an interface linking the crop growth and productivity model and the Geographical Information System (GIS);

a database on the performances of collective irrigation systems was developed together with a user friendly software package for the analysis of collective irrigation systems and demand hydrograph generation;

one Information Manual on the software package was published;

guidelines for the use of treated sewage water in agriculture has been prepared and published

68 MSc students from 9 countries (Algeria 4; Bosnia and Herzegovina 1; Egypt 15; Lebanon 12; Morocco 14; Palestine 5; Syria 1; Tunisia 11; Turkey 5) were completed their MSc work on the topics of the Network and under the supervision of the members of the Network

12 advanced short courses were organized with the participation of 347 trainees from 18 countries - more than 100 copies of proceedings are distributed in the occasion of each course

7 annual meetings of three Sub-Networks were held

23 bilateral meetings of the network partners were carried out

131 scientific papers were published in scientific journals and proceedings of conferences, workshops, advanced short courses, etc.

three books and 24 special publications are also published.

Research topics and activities, carried out under each of three sub-networks, have been tailored to the specific problems faced by the developing Mediterranean countries and aimed at satisfying the real needs of the region, for the benefits of development and cooperation, while maintaining the straight link with other activities within the RAP-WRM. Research activities have contributed for enhancement of cooperation not only with the national research institutes but also with some international organizations (FAO, ICARDA, IFAD) which have provided opportunities for expanding the action programs. For example, the NWRM-Network is one of the members of IPTRID (the International Program for Technology and Research in Irrigation and Drainage) Network - working actively with other IPTRID networking organizations and institutions (FAO, ICID, CEMAGREF, ILRI, HRW and IWMI). Also, the WUE-Network has established a concrete cooperation with the FAO in the field of water use efficiency and crop water requirements, through the exchange of information in this fields and the presence of Bari Institute, as observer, in the scientific meetings held by the FAO. Furthermore, the importance of the research results of CIS-Net have yielded in the joint publication of the FAO Irrigation and Drainage Paper N°59. The network activities are interconnected also with a series of other initiatives in the region including the Global Water Partnership - MED Network which has water saving in the Mediterranean countries as one of its primary objectives.

Whenever possible, the Research networks tried to mobilize the private sector to cope with certain problems which are of importance in water resources development and management. A successful example of this is the CIS-Net which, in cooperation with private companies, developed a new technology to improve irrigation management through automation system (AcquaCard), which is now introduced in several irrigation projects in Morocco and Tunisia.

The collaborative research networks will be continued on the base of voluntary participation of researchers and scientific institutions and universities. Several Research Projects were submitted and financed beyond the RAP to allow sustainability of network research activities. Among them, the project "BIOWATSYST - a system approach to wastewater biotreatment for the protection of Mediterranean coastal areas" is of particular importance since it was conducted within the frame of NWRM-Net with the participation of partners from six Mediterranean area (Spain, Italy, Greece, Jordan, Egypt, Morocco).

Research Project WASIA (Water Saving in Irrigated Agriculture)

The research project WASIA has been developed during the second phase of the RAP (2000-2002) when it was necessary to transfer some of research findings on the ground in Mediterranean environment. The main objective of the WASIA research project is to develop a conceptual framework for *water saving in irrigated agriculture* of the Mediterranean region through the *integration* of the activities which represent major topics of the three Collaborative "Water Resources Management" Research Networks and aim to:

Improve water use efficiency in irrigation practices (WUE_Net),
Improve performances of irrigation distribution systems (CIS_Net), and
Promote safe and sustainable use of non-conventional water resources (NWRM_Net),

Specific objectives of the project are addressed to the development of 8 (eight) research themes to be carried out at eight different locations in the Mediterranean Region:

1. Deficit Irrigation of orchards with low quality water, (Tunis, Tunisia)
2. Deficit Irrigation of pistachio with different fertigation practices (Southeast Anatolian Region, Turkey)
3. Hydraulics performances of irrigation systems under different irrigation practices (Ghezala-Teskraya, Tunisia)
4. Innovative approach for energy saving in irrigation systems (Souss Massa, Morocco)
5. Reuse of treated wastewater for irrigation of cereals, forage and vegetables by means of different irrigation methods (Agadir, Morocco)
6. Re-cycling of drainage water for sustainable irrigated agriculture (Nile Delta, Egypt)
7. Sustainable use of highly saline water for irrigation of crops under arid and semi-arid conditions: new strategies (Tarsus, Turkey)
8. Development of screening legumes and forage nursery for salinity tolerance (Aleppo, Syria)

The proposed research themes cover some of the most important aspect of water saving in the Mediterranean agriculture and represent the continuation of the collaborative research network activities carried out during the first phase of the RAP. Therefore, it is expected that the outputs of this project should provide a substantial contribution in tracing the way to achieving sustainable agricultural production and food security in the Mediterranean region.

A detailed presentation of the activities carried out under this project will be discussed during the meeting and are included in this volume.

Logistic Support/ICT Activities

The Logistic Support/Information and Communication Technology (ICT) actions aimed at the implementation of an Internet-based “Information System” to promote exchange and dissemination of scientific and technical information in the Mediterranean region. This system has to contribute to the establishment of a permanent co-operation network between Mediterranean institutions committed to develop training and research on “Water Resources Management”. For such reasons, the financial resources have been allocated to upgrade scientific equipment, hardware and software in the countries beneficiaries of the program and, in such a way, to contribute in the improvement of human resources development and institutional capacity building in the Mediterranean irrigated agriculture.

In the first year of the project (1998-1999), the Logistic support funds were partially allocated to supply of some testing equipment and on-field instrumentation needed for the realization of research activities within the RAP-WRM. Starting from the second year, the Logistic Support actions were only focused on the upgrade of ICT especially in the centers which did not have adequate hardware and software for proper network collaboration and appeared in a clear disadvantage in respect to other partner Institutions. Accordingly, the following activities have been carried out:

Installation of a web server at the National Water Research Center (Cairo, Egypt);

Supply of 2 internet workstations to the IAV Hassan II Centre Horticole (Agadir, Morocco);

Supply of an info-network to Lebanese Agricultural Research Institute (LARI) (Bekaa valley, Lebanon).

According to priorities determined at TWG level and due to particular request of IRESA (Tunisia), specific training was carried out in Tunisia where 4 short courses on the use of new information technologies, multimedia and distance learning were organized. Training has been mainly focused on the people charged with the management of the ICT and documentation facilities in the collaborating institutions while only 25% of trainees belonged to research sector (Figure 8). Furthermore, a workshop on "Meta-information system for Mediterranean region" was organized in Bari in 2000 with the participation of the persons involved in other RAP sub-projects developed by other CIHEAM Institutes. Moreover, training and cooperation activities have included also the participation on several workshops organized by other Institutions.

The RAP-WRM web site has been developed in both English and French and it is available at URL: http://www.iamb.it/par/. The web-site's structure encompasses the main project's objectives and activities and it is consistent with the other CIHEAM RAP web-sites. On the home page of the RAP WRM web site, a search engine enables the searching on the site with keywords and an e-mail link allow the visitors to send questions or comments. The site contains also the link to all partners participating in the program and to the WASIA research project. The RAP-WRM web is the project's general container of all detailed information and documentation sources and its role is not only the exchange of data among the partners in the RAP but also dissemination of information among all stakeholders involved in water sector in the Mediterranean region. In fact, the web-site has a role of information gateway among the partners and it represents an important data bank (of bibliographic data and research results) for scientific users. The updating of web-site is ensured by the CIHEAM-IAMB webmaster through an efficient information retrieval system agreed by all project's partners and actors.

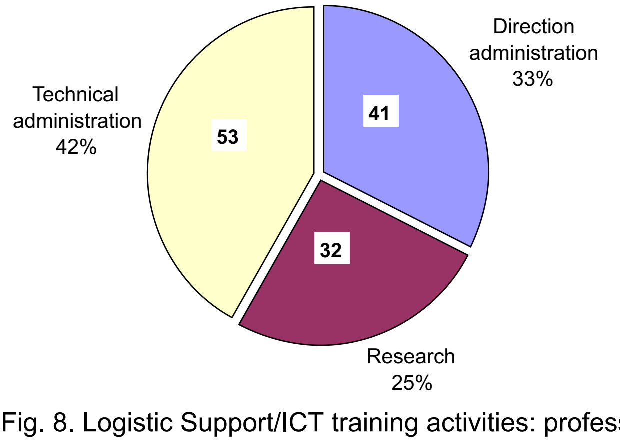

Fig. 8. Logistic Support/ICT training activities: professional profile of the participants

Aid to Decision Making

The aim of this action of the RAP-WRM is to give to decision makers guidelines and strategies for implementing new social and economic reforms in the irrigation sector via appropriate measures such as participatory irrigation management, water valuation and cost recovery, water allocation efficiency, etc. Consequently, two sub-programs have been developed:

Sub-Program I: Participatory Irrigation Management (PIM) and Water User Associations (WUAs)

Sub-Program II: Economic Aspects of Water Mobilization and Use

Participatory Irrigation Management (PIM) and Water User Associations (WUAs)

The overall objective of this program is to stimulate high level policy dialogue on Participatory Irrigation Management in the Mediterranean region leading to a policy commitment programming actions with the specific objectives to introduce policy-makers to the implementation of PIM, learn about best practices from other countries to select the most appropriate corresponding to the socio-economic situation of the majority of the developing countries in the region, and, as a pre-step, to formulate indicative action plan for enhancing participation in irrigation sector. These objectives had to be achieved through the exchange of experience and information during the training courses to be conducted annually at Bari Institute.

The promotion of training of high-ranking civil servants and exchange of information among them, decision-makers and senior managers should help politicians and decision-makers to set up the policies required for a proper PIM implementation at local level. Moreover, the courses organized at IAMB within the RAP-WRM should contribute in devising new training programs that respond to the prevailing socio-economic condition for each individual country parallel to the progressive process of the PIM reform implementation. In fact, on the *regional level*, many countries of the Mediterranean region (Egypt, Albania, Tunisia, Morocco, Turkey and, recently, Lebanon and Algeria) are on their way for PIM reforms and policies implementation with a gradual successful progress.

Three training of trainees (TOT) courses on "Capacity Building for Participatory Irrigation Management" were carried out at the IAMB in 1999, 2000 and 2001, in cooperation with the Economic Development Institute (EDI) of the World Bank, IFAD (International Fund for Agricultural Development) and INPIM (International Network on Participatory Irrigation Management). The World Bank is included in this program since it has a long experiences on the development of the PIM in different regions of the world. The CIHEAM/IAMB and the World Bank have started the cooperation on PIM in 1997 and the RAP-WRM courses on "Capacity building for Participatory Irrigation Management" have become a part of this cooperation since 1999.The program of the courses was composed of lectures, brain-storming workshops, discussion sessions and technical visits to the "Consorzio Bonifica Capitanata" offering to the participants a possibility to exchange the experiences with both technical and administrative staff of Consortia and farmers.

A total number of 209 candidates applied for the participation on three courses which confirms the importance of the subject for water saving and management especially in irrigated agriculture. 142 trainees (67.9%) from 20 countries not only from the Mediterranean region but also from some Asian and African countries are selected to followed the courses. Among them, 83 (or 58.4%) were from 7 Mediterranean countries beneficiaries of the RAP (Algeria 3; Egypt 27; Jordan 3; Morocco 8; Syria 4; Tunisia 21; Turkey 17). The greatest part of the participants from beneficiary countries came from the Ministry of Agriculture (the case of Tunisia and Syria), Ministry of Water Resources and Irrigation (the case of Egypt) and Ministry of Energy and Natural Resources (the case of Turkey). The rest of the participants from beneficiary countries work as coordinators or consultants of the irrigation projects and management units.

The proceedings of the courses, distributed to the participants and, on request, also to many governmental agencies and international organizations, contained five volumes of the complete PIM program including: Handbook on PIM, PIM Case Studies, Country overviews of PIM, PIM in the Mediterranean countries and The Experience of Consortia in Italy.

The courses, aiming at the training of trainers, have resulted in an increasing number of trained people on the national level, improving the local institutional capacity building and enhanced the irrigation management transfer process in many of the developing countries in the Mediterranean and other developing regions of the world. An analysis of the outputs and impacts of the activities on PIM realized in the period 1998-2002, indicated several important points:

a gradual increment, from year to year, in the number of candidatures and participants in the PIM coursesi s a strong indicator of the attractiveness and interest on the proposed program and its wide dissemination in the Mediterranean and other regions of the world (Figure 9);

high interest of the national governments of the developing countries in the running courses - it is the unique program where governments ask for the participation of additional number of candidates more than those officially accepted for the attendance of the course with full coverage of their expenses;

many participants came from the PIM Projects supported by the USAID in the region, as well as those supported by the International Organizations (FAO, World Bank, IFAD) with a complete coverage of the expenses of their participants;

on the request, within the frame of other programs developed by the World Bank, additional special training programs were organized for experts from Kirgyzstan and Uzbekistan in Italy;

the PIM Program of Bari Institute has been presented as a model for implementation in several African countries during the "National Conference on Irrigation" organized by FAO in cooperation with the Ministry of Agriculture and Food Security of Tanzania in 2001, where Bari Institute presented a keynote-paper titled: "Participatory Irrigation Management: Experiences, Gained Benefits and Arising Problems";

IFAD, where the PIM represents one of priority issues to implement in the developing countries of the region, asked Bari Institute to be the implementation agency for PIM in Egypt, Morocco and Tunisia. This program has started at the beginning of 2002 and it will last for four years, with a total budget of US$ 1,680,000.

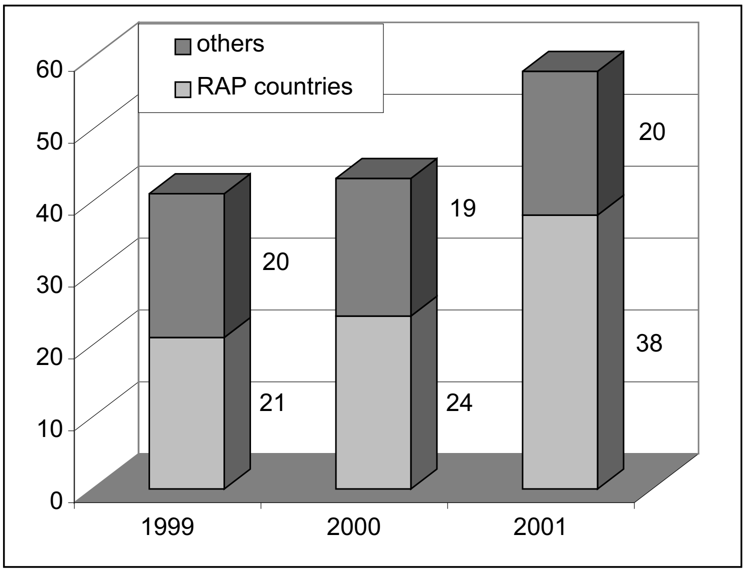

Fig. 9. Evaluation of the number of participants on the PIM courses 1999-2001

Economic Aspects of Water Mobilization and Use

The objective of this program was to give to decision-makers in the Mediterranean region, the opportunity to present, share and discuss various experiences relevant to the subject and to elaborate strategies and plans of actions for implementation of measures which could lead to a better valuation of irrigation water and appropriate cost recovery mechanisms. Furthermore, this program includes also the role of gender in the management of water resources in the Mediterranean and the involvement of women experts working in water sector. Accordingly, two Workshops have been organized:

a workshop on "Water valuation and cost recovery mechanisms in the developing countries of the Mediterranean region" , and

a workshop on "Gender and water resources management in the Mediterranean".

The workshop on "Water valuation and cost recovery mechanisms in the developing countries of the Mediterranean region", was held in June 2002 in Agadir (Morocco), as a special session of the International conference on "Irrigation water policies micro and macro considerations". The Conference was followed by more than 200 experts mainly from the Mediterranean region. Among them, 14 decision makers, engineers and economists from 8 beneficiary countries (Algeria 1, Cyprus 1, Egypt 1, Jordan 1, Malta 1, Morocco 3, Tunisia 1 and Turkey 1), Arab Organization for Agricultural Development (1) and

CIHEAM-IAMB (3) participated actively in the session. The session included the keynote presentation on water pricing, cost recovery and water valuation in the developing countries, the presentation of countries experiences and a round table discussion session tracing the guidelines and strategies for implementing new social and economic reforms in the irrigation sector with appropriate economic measures such as water valuation, cost recovery and water allocation efficiency. The decision makers from the Mediterranean countries underlined the importance of this session which gave them the opportunity to present, share and discuss various experiences relevant to the subject, and to elaborate strategies and plans of actions for the implementation of measures which could lead to a better valuation of irrigation water. Moreover, the participants of this session highly recommended the establishment of a network on "Water valuation and cost recovery mechanisms in the developing countries of the Mediterranean" as an appropriate approach to bring together the experiences in this field and to set viable strategies for implementation in the region.

The papers presented during the Special session on "Water Valuation and Cost Recovery Mechanisms in the Developing Countries of the Mediterranean Region" were included in the Proceedings of the Conference which was distributed to more than 200 participants of this important event. In addition, all contributions are published in a special volume of "Options méditerranéennes" (Hamdy *et al.*, 2002).

The recommendations from the Workshop on "Water valuation and cost recovery mechanisms" may be synthesized as the following:

- Irrigation policies should play a regulatory role with regard to objectives of equity, natural resources protection and water market creation;
- Tariffs will not be an effective tool for economizing on water as long as they do not relate available water volumes to irrigation water prices;
- Irrigation water tariff and recovery policies should aim to guarantee irrigation infrastructure maintenance and replacement, and, simultaneously, ensure sound water services for agricultural uses;
- Tariffs should have social, economic, political and environmental objectives and consequences;
- The application of irrigation water tariffs and charge recovery policies should take into consideration the local, regional and/or national and socio-economic conditions, as well as the macro-economic orientations of irrigation development. Water prices should integrate the elements adapted to the specific context of irrigation projects, simultaneously ensuring agricultural development, risk aversion and water saving.

The workshop on "Gender and water resources management in the Mediterranean", was held on October 12-14, 2002, in Cairo (Egypt), as a special session of the First Regional Conference on "Perspectives of Arab Water Cooperation: Challenges, Constraints and Opportunities". The Workshop was attended by more than 100 participants covering most of developing Mediterranean countries and representatives from different Arab countries, national, regional and international institutions, NGOs and several women organizations. 17 experts from all the beneficiary countries of the RAP (Algeria 1; Cyprus 1; Egypt 2; Jordan 2; Lebanon 1; Malta 1; Morocco 1; Syria 2; Tunisia 2; Turkey 2) and Italy (2) have contributed in the Workshop. The contributions to the session are published as a special volume (El-Kady and Hamdy, 2002) which included an Introductory paper and a keynote paper on gender perspectives in water resources management and it is followed by the case studies related to the experiences on the gender issues from each of 10 beneficiary countries of the RAP.

The challenges for the future are identified to overcome the considerable gap between positive policy intention to concrete action as well as to improve the current knowledge on gender issues in irrigation management. Among them, the participation, information and consultation are basic elements for gender development and implementation. In the region, there is an urgent need for the establishment of a network to put together the local institutions, NGOs, stakeholders and water user associations working on gender issues to gather the scattered information in this field and to set and formulate policies, strategies and implementation methodologies in view of social, cultural as well as religion conditions on both national and regional level.

This workshop had a very high impact in the Mediterranean countries since it was organised as a special session of an important regional event with the participation of decision makers and experts from the whole region and with full involvement of local governments and institutions. The importance of the topic and the necessity for exchange of experiences from different Mediterranean countries was recognized by all participants. After detailed discussion and debate, the participants of the workshop on "Gender and water resources management in the Mediterranean region" came up with the following recommendation to be taken as an aid for decision makers:

In the Mediterranean region, there is an increasing recognition that irrigation is a crucial part of the broader movement of gender mainstreaming in agricultural and rural development, and, indeed, seriously considered by a wide array of people from grassroots women's organizations to international development and financing agencies.

Case studies and experiences presented in the workshop highlight that thanking to the changes in cultural trends, women labor forces are growing in number, yet, the accumulated knowledge from presented case studies and experiences achieved did not give the appropriate insight that could effectively guide the policy and interventions.

In the developing countries of the region, the slow conversion of gender policies into practice, in particular in water resources management and irrigation, are the resultant of the followings:

- The lack of analytical tools and appropriate concepts;
- The lack of generic conceptual framework and appropriate implementation methodologies, beside the absence of gender performance indicators and above all the vague and week roles of irrigation institutions and agencies.

Studies

Furthermore, a study on the *"Production and exchange of virus-free plant propagating material in the Mediterranean region"* has been carried out within the RAP-WRM Programme. The study was held during the first phase of the RAP (1998-2000) and covered all ten beneficiary countries and Albania. The overall objective of this study was to define and propose common phytosanitary rules regarding production, conservation and use of plant propagating material in order to facilitate the movement of this material throughout the Mediterranean seen as a free-trade area and to support the transition of developing Mediterranean countries towards more open and competitive economy.

The specific objectives of the study were:

- to assess the current situation on factors (legislation, facilities, human resources, etc.) limiting implementation of an appropriate certification programs in participating countries;
- to analyse fruit industry, in particular the nursery sector in the different Mediterranean countries and the level of their self-sufficiency;
- to analyse the sanitary status of the main cultivated species with particular attention to the presence of quarantine and economic important diseases;
- to promote certification as the unique tool which guarantees quality of nursery productions and a key point for the development of fruit tree industry;
- to identify, for each country, the critical points which still obstruct the application of well-defined and internationally accepted rules related to the production of sanitarily improved plant propagating material.

Within the programme, a Round table Meeting was organised in Bari in 1999 with the participation of decision-makers appointed by Ministers of Agriculture of 11 Mediterranean countries and experts from international institutions (EPPO, IAMB and University of Bari). A country reports were prepared from all participants and a comparative analysis of the sector in the Mediterranean was accomplished. Finally, the study resulted in a phytosanitary project proposal for the Mediterranean seen as a free-trade area; covering a spectrum of topics: (i) phytosanitary situation of Mediterranean fruit tree industry; (ii) certification issues (legislation, facilities and human resources) in Mediterranean countries; (iii) legislation aspects and technical features of the certification service; (iv) proposal for the sanitary improvement of mediterranean fruit crops and actions to protect the health of typical productions. The results and outcomes of the study were published in a special number of *Option Méditerranéennes, Sér. B/n°35* Production and Exchange of virus-free Plant Propagating material in the Mediterranean Region (2001).

CONCLUSIONS

The Regional Action Program on "Water Resources Management" represents one of the biggest activities ever carried out by the Mediterranean Agronomic Institute of Bari. Thirty national institutions and Universities from 10 beneficiary countries, 7 Italian partners and 5 International organisations have been involved directly in the program (Figure 10) along with about 1105 persons from 31 countries around the world.

The orientation of the program towards the water problems in the Mediterranean irrigated agriculture has been confirmed by the fact that 1026 (or 92.9%) participants were from the Mediterranean region, while 887 (or 80.3%) were from 10 Mediterranean countries, beneficiaries of the RAP. A non-significant number of participants belonged to Asia (5.5%), Africa (0.9%) and America (0.7%). The greatest number of the participants came from Tunisia (240) and Egypt (190) and it is in agreement with the severity of the water shortage problems and overall strategic importance of the countries in the region (Figure 11). The particularly high number of participants from Tunisia is due to request of Tunisian government to organize, within the logistic support program, four training courses on new information technologies and internet communications for 109 Tunisian technicians and administration staff.

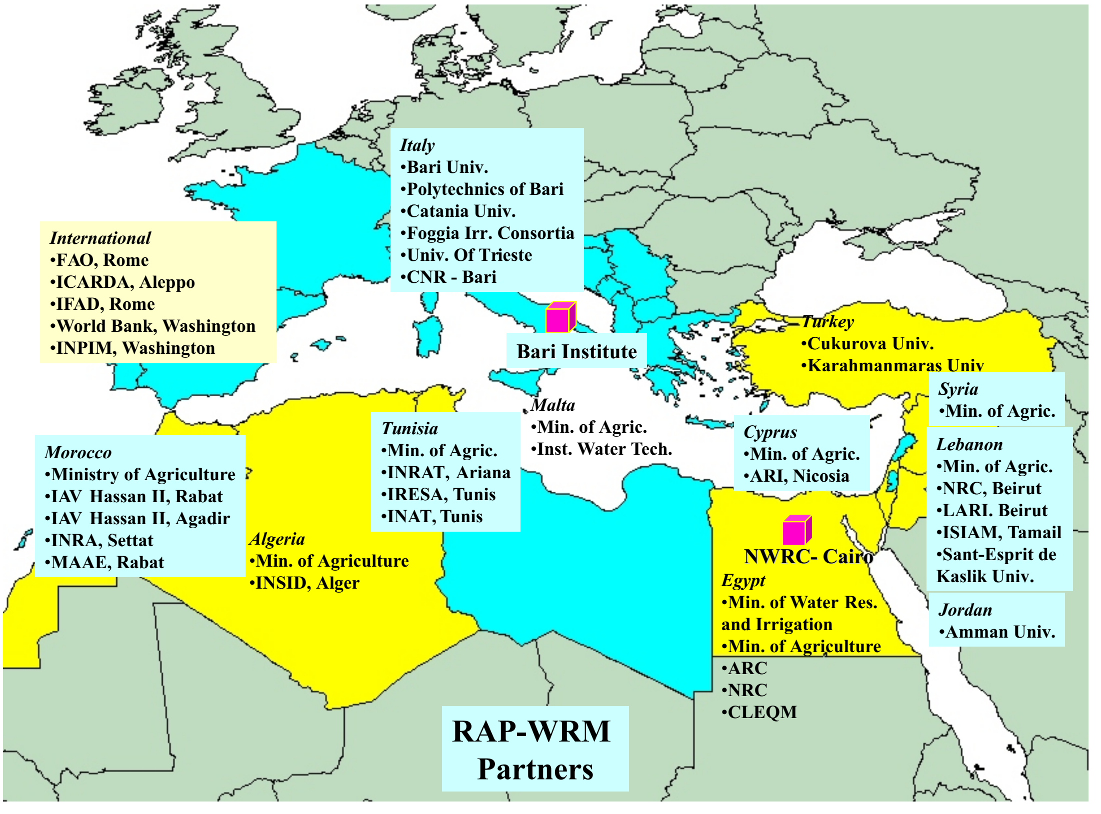

Fig. 10. The RAP-WRM Partners from 10 beneficiary countries and Italy

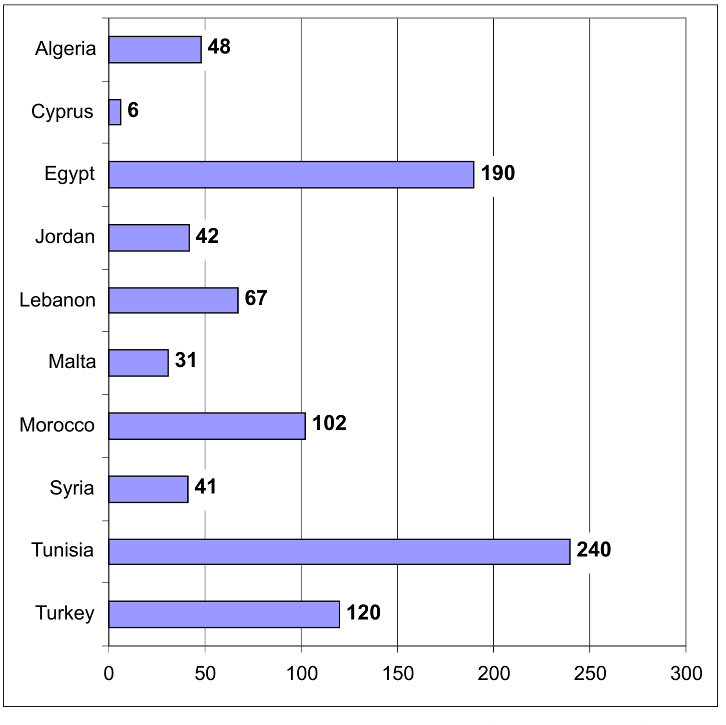

Figure 11 - The RAP-WRM distribution of participants from 10 beneficiary countries

The activities within the RAP-WRM have produced 19 short-term courses, tens of experimental works and 68 MSc theses, 19 mobility MSc programs, research works at seven pilot locations in the Mediterranean, two important workshops, numerous meetings and reports, 131 scientific papers, several research manuals, guidelines and databases, 24 special publications, 3 books, etc. These activities, following the recommendations of TWG and OMC, have been developed in agreement with other RAP programs and activities of other CIHEAM Institutes. The adoption of such approach gave the possibility to manage the activities within different RAP themes in a complementary way respecting the major necessities of each beneficiary country in the water resources management and agricultural sector. Certainly, this methodology, considering different aspects of water management in Mediterranean agriculture, has supported substantially the institutional capacity building process and human resources development in the beneficiary countries of the RAP. This is confirmed through the valuation of the progress reports and evaluation sheets of the training program of RAP-WRM which has underlined the following:

a) There is an overall appreciation of the topics and training approach implemented by the Bari Institute;
b) The majority of the trainees agrees that the knowledge acquired during the training is of great importance for efficient water use in irrigated agriculture and for practical implementation in their professional work;
c) The greatest number of participants work already at important positions at academic and governmental level and the latest know-how acquired during the training along with an international dimension of the courses should have a strong impact on the carrier of the trainees in the future and their ability to implement and transfer the knowledge;
d) Most of the RAP trainees represents the driving forces for the establishment and operation of the national networks on the major topics treated by the courses, regional network research project and other activities through the dissemination of information and bilateral research programs.

A particular emphasis have been given to the Aid for Decision Making Program which involved several international organisations and participants from other regions of the world. The sub-program on Participatory Irrigation Management is a realistic example of the international cooperation in the field of water resources management as it is fundamentally based on joint activities using the experiences in the field of CIHEAM-IAMB, the EDI (Economic Development Institute) of the World Bank, the INPIM and IFAD. The participation of trainees from different regions has created very fertile atmosphere for a worldwide exchange of experiences, transfer of knowledge and information and personal contacts.

Equally so, the International conference on "Irrigation water policies micro and macro considerations" was organised and sponsored by several institutions as: Ministry of Agriculture and Rural Development - Kingdom of Morocco; the International Center for Advanced Mediterranean Agronomic Studies (CIHEAM)/IAM-Bari Italy; the Moroccan Association of Agricultural Economists (MAAE), an organisation of 200 members from academia and government; the International Water and Natural Resource Economics Consortium (IWREC) representing about 50 water economists from more than 20 countries around the world; the Agricultural Policy Center, University of Minnesota, Saint Paul; the International Food Policy Research Institute (IFPRI), Washington, DC; and the World Bank. The involvement of such important institutions in the organization of the Conference and the participation of more than 150 experts have contributed that the Workshop on "Water valuation and cost recovery mechanisms in the developing countries of the Mediterranean region" had a very high impact in the region.

Finally, it should be highlighted that the Regional Action Program on "Water Resources Management" is not confined to itself but it should be seen as an opportunity to add durable values to the overall training, research and co-operation that CIHEAM is promoting within the Mediterranean Region, considering it as an Euro-Mediterranean space open for partnership and development. In fact, the activities carried out within the frame of the Water Resources Management Network have contributed in the generation of new programs and activities as it is the establishment of an additional *Network* on *Euro-Mediterranean Soils* addressing the problems of desertification and erosion in the Mediterranean Basin. During the last year of the RAP, the research network on "Water Resources Management" has presented for INCO-MED EU Program the project proposals for the establishment of two new thematic networks (on land management - MEDCOASTLAND and on water management - WASAMED). Both proposals, which should integrate the activities on "Land and Water Management" in the Mediterranean region, have been approved by the EU. The activities of the MEDCOASTLAND Thematic Network have started in October 2002, while the WASAMED Thematic Network has initiated at the beginning of 2003. The WASAMED (Water Saving in Mediterranean Agriculture) project comprehends 42 partners from 16 Mediterranean countries and has the 4-years budget of 1.5 million Euro, while the MEDCOASTLAND (Mediterranean Co-ordination of Land Conservation Management to Combat Land Degradation for the Sustainable Use of Natural Resources in the Mediterranean Coastal Zone) project involves 36 partners from 13 Mediterranean countries and has the 4-years budget of 1.3 million Euro. Certainly, these new projects have attributed an added value to the RAP-WRM since they will allow for the further continuation of cooperation among the Mediterranean Institutions working in land and water sector in the Mediterranean region.

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REGIONAL ACTION PROGRAMME (RAP)-WATER RESOURCES MANAGEMENT:

INTRODUCTORY PAPER ON: WATER SAVING IN IRRIGATED AGRICULTURE *(WASIA PROJECT)*

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1. INTRODUCTION

The Regional Action Plan (RAP) on Water Resource Management was developed on three major considerations:

Water scarcity is one of the major limiting factors of agricultural, economic and social development in the arid and semi-arid regions of the Mediterranean;

An increasing number of developing Countries of the Mediterranean are approaching full utilization of their available water resources, which means that there is no more room to increase the supply, inevitable following to amplified conflicts among sectorial water users;

The quantity of fresh water resources available to agriculture is diminishing while the use of lower quality water is increasing.

In the Mediterranean region, we are confronted with increasing population, fast urbanization and the associated expansion of economic activities, all of which require more water, putting strain on the already limited and fragile resources. Therefore, we need to elaborate the concept of demand management into implementation policies, programmes and actions in particular with irrigation as the main consumer (about 80%), where inefficiencies lead to major water losses (more than 50%), so that huge water saving could be achieved.

This is the fundamental scope of EU/CIHEAM-MAI.B RAP Programme (1998-2002) which is mainly oriented to the sustainable use of water resources in irrigation sector emphasizing the following major technical issues:

Non conventional water resources practices and management for sustainable use;

Water use efficiency;

Design, management and optimization through performance analysis of collective irrigation systems; and the aid to decision making through the themes of:

Participatory Irrigation Management (PIM); and

Economic aspects of water mobilization and use.

For the last 10 years, the Collaborative Irrigation Network has focused its activities on research related to the use of non-conventional water resources in irrigation, Eco-physiology and modelling for water use efficiency and assessment and improvement of hydraulics performances of collective irrigation systems. In these fields, great efforts have been carried out locally and at the regional, Mediterranean scale, resulted in numerous publications, organization of several conferences and workshops as well as realization of several research projects.

Nowadays, we believe that is essential to translate the ideas, conclusions and recommendations developed through these researches to actions on the ground in the Mediterranean region.

2. PROBLEMS TO BE ADDRESSED

With a view on the general aspects of water crisis in the Mediterranean Region, the following problems need to be addressed:

Inefficient use of water on farm scale due to inadequate cropping pattern and irrigation scheduling, considering hydrological, eco-physiological and economical aspects;

Poor performances and huge water losses of irrigation distribution systems due to scarce design, operation and maintenance;

Increased use of non-conventional water resources (wastewater, saline water and drainage water) in irrigation which may have adverse impacts on both the environment and the public health.

Therefore, selection of cropping pattern, irrigation method and scheduling criteria, use and recycling of non-conventional water resources in irrigation, operation and maintenance of irrigation systems and impact of such activities on crop eco-physiological parameters and production, on soil characteristics and surface and groundwater quantity and quality are essential components of the system for water saving in agriculture.

A proposal that considers all aspects of the above problems comprehensively would be possible only within the frame of a long-term research programme and would require significant resources. This is not possible in the frame of the RAP Programme at this stage. However it is important to start building up a deep insight of the issues.

3. OBJECTIVES

Bearing in mind the aforementioned problems and considerations, the main objective of the presented research project is to develop a conceptual framework for **water saving in irrigated agriculture**, through the *integration* of the activities which represent major topics of the three Collaborative Irrigation Networks and aim to:
Improve water use efficiency in irrigation practices,
Improve performances of irrigation distribution systems, and
Promote safe and sustainable use of non-conventional water resources,

Specific objectives of the project are addressed to the development of 8 (eight) research themes to be carried out at eight different locations in the Mediterranean Region:

1. Regulated Deficit Irrigation of orchards with low quality water, (Tunis, Tunisia)
2. Regulated Deficit Irrigation with low quality water by partial root drying of pistachio (Southeast Anatolian Region, Turkey)
3. Hydraulics performances of irrigation systems under different irrigation practices (Ghezala, Tunisia)
4. Energy saving in irrigation by means of improved irrigation practices (Souss Massa, Morocco)
5. Reuse of treated wastewater for irrigation of cereals, forage and vegetables by means of different irrigation methods (Agadir, Morocco)
6. Re-cycling of drainage water for sustainable irrigated agriculture (Nile Delta, Egypt)
7. Use of artesian highly saline water for irrigation of cereals and vegetable crops (Tarsus, Turkey)
8. Development of screening legumes and forage nursery for salinity tolerance (Aleppo, Syria)

The realization of each research theme at different pilot area - experimental site in the Southern Mediterranean countries will give an additional value to the Project through the possibility to exchange research experiences in different fields and under different climatic, soil and management conditions.

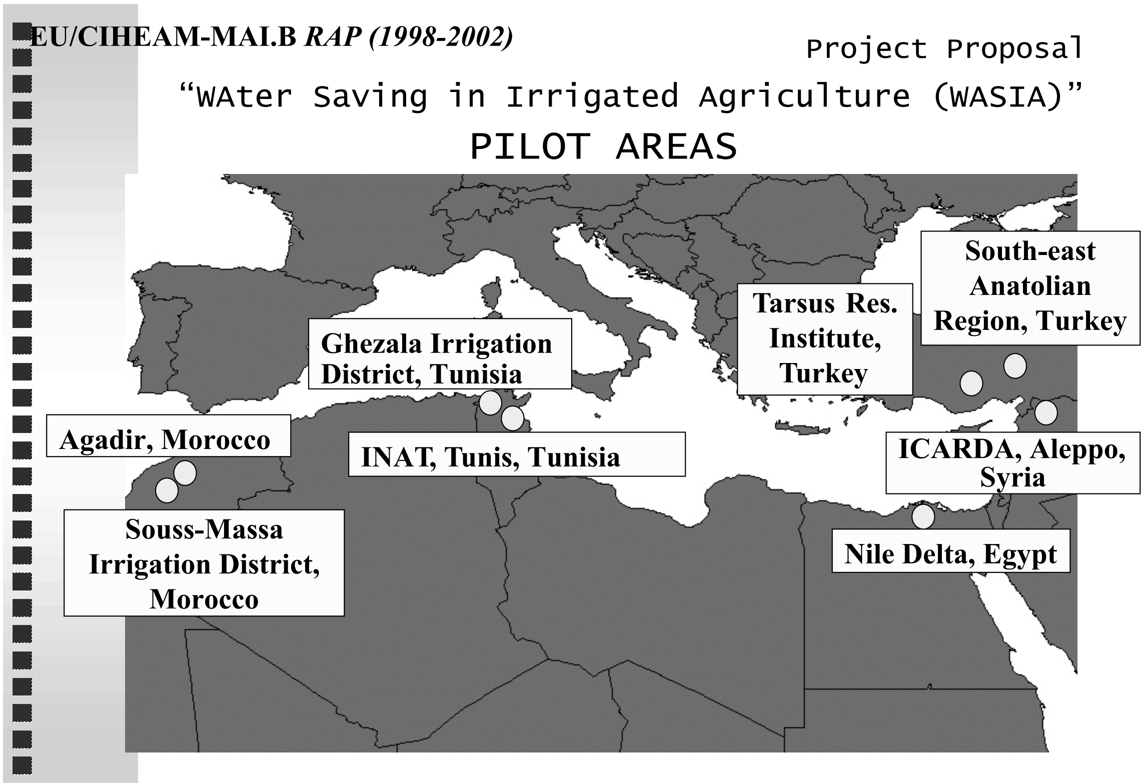
4. RESEARCH ACTIVITIES AND METHODOLOGY

Four Work Packages are established for the realization of the Projects. Three of them are tightly related to the three Collaborative Irrigation Networks with the task to coordinate and carried out the major activities under specific research themes:

Work-Package 1 Water Use Efficiency, WUE, guiding the activities under two themes:
- o Research theme 1, in Turkey (Gaziantep, Southeast Anatolian Region) and
- o Research theme 2, in Tunisia (Tunis, experimental field of INAT);

Work-Package 2 Irrigation System Performa nce, ISP, guiding the activities under two themes:
- o Research theme 3, in Tunisia (Ghezala Irrigation District), and
- o Research theme 4, in Morocco (Souss-Mossa Irrigation District);

Work-Package 3, Non-conventional Water Resources, NWR, guiding the activities under four themes:
- o Research theme 5, in Morocco (Agadir),
- o Research theme 6, in Egypt (Nile Delta),
- o Research theme 7, in Turkey (Tarsus), and
- o Research theme 8,in Syria (ICARDA, Aleppo).



An exchange of information and interaction of three Work Packages has to be established at different phases of Project realization and it is the major tasks of **Work Package 4.** Moreover, Work Package 4 is related to the overall scientific and administrative coordination of the Project.

RESEARCH LAYOUT and LEVEL of WORK PACKAGES INTERACTION

Pilot Area	Research Theme	Interaction Level		
INAT, Tunis,Tunisia	Regulated Deficit Irrigation of orchards with low quality water	WUE	NWR	ISP
Southeast Anatolian region, Turkey	Regulated Deficit Irrigation of pistachio with low quality water	WUE	NWR	ISP
Ghezala Irrigation District, Tunisia	Hydraulics performances of irrigation systems under different irrigation practices	ISP	WUE	NWR
Souss-Massa Irr. District, Morocco	Energy saving in irrigation by means of improved irrigation practices	ISP	WUE	NWR
Agadir, Morocco	Reuse of treated wastewater with different irrigation methods	NWR	WUE	ISP
Nile Delta, Egypt	Re-cycling of drainage water for sustainable irrigated agriculture	NWR	WUE	ISP
Tarsus Research Institute, Turkey	Use of artesian highly saline water for irrigation of cereals and vegetable crops	NWR	WUE	ISP
Tarsus Research Institute, Turkey	Development of screening legumes and forage nursery for salinity tolerance	NWR	WUE	ISP

Water Saving in Irrigated Agriculture

The scientific coordination of the Project is assigned to the Chairperson of the National Water Research Center (NWRC), Cairo (Egypt), in cooperation with the CIHEAM-MAI.B Network coordinators included in the Programme and local coordinators of different pilot areas cited here below. The Project will be financially administrated, along the whole duration, by the Administration Division of the CIHEAM-MAIB in cooperation with the person nominated by the NWRC, Cairo (Egypt).

The research activities and methodology are described for each selected pilot area in each Work-Package.

4.1 WORK-PACKAGE 1 - WATER USE EFFICIENCY

4.1.1 PILOT AREA: EXPERIMENTAL FIELD OF INAT, TUNIS

SPECIFIC PROBLEM

Fruit trees cover about 40% of the irrigated lands and represent an important component of the productive farming system in the country. However productivity is usually low and irrigation with waters having more than 1.5 g/l total dissolved solids is commonly practiced without provision of drainage and consequent high salination hazard in irrigated orchards. Any strategy that may help to save water and control salinity, while producing more fruits, is needed. In the absence of a drainage system, techniques based on irrigation restrictions seem to be reasonably appropriate. The Regulated Deficit Irrigation (RDI) can be used. RDI is based on the concept that water supply can be reduced to control vegetation growth during specific periods of the season, while fruit growth remains little or not affected.

Research work will be conducted mainly in the INAT experimental station located 15 km south-east of Tunis, in the middle of the plain of Mornag, where important cash crops are grown under irrigation with different water qualities (canal, deep wells and shallow wells). Because drainage systems are not implemented in the area, salinization and ground water contamination are major threats for this important horticultural area.

Participatory experimental work will also be conducted in the areas with motivated farmers for rapid integration of experimental findings.

The experimental site has:

1) 10 ha of irrigated fields comprising different water delivery systems
2) one automatic weather station
3) two water source qualities

Laboratory facilities at INAT are made of:

1) one soil characterization unit (texture, F.C., W. P., moisture content)
2) equipment for measuring water flow
3) computers GIS system
4) one weather station with two batteries of "concrete lysimiters”

Soils of Mornag are essentially alluvial soils (mostly heavy) and irrigation waters have an ECi of about 1.5 ds/m (deep wells) and 2.5 ds/m (canal).

Research work will benefit from an ongoing collaborative action that's conducted with the support of a private company and concerning "water requirement of peach trees".

ACTIVITIES

A.1.1) Data collection of available meteorological data and characterisation of the regional climate: rainfall frequency distribution, ten-days T°C averages and ETo

A.1.2) Characterisation of the soil of the selected region: sampling of typical soil, determination of Field Capacity, Permanent Wilting Point (PWP), Soil Moisture Release Curve

A.1.3) Surveys on irrigation practices in representative orchards

A.1.4) Development of phenological calendars on the basis of available data and set periods of growth stages suitable for deficit irrigation

A.1.5) Implementation of demonstration plots (amount of water usually delivered by the farmer will be used for reference). Restrictive treatments will consist in irrigation water cuts of 10%-50% at selected growth stages

A.1.6) Quantification of saved water volumes

A.1.7) Monitoring salt accumulation in the soil and developing strategy to prevent salinization

A.1.8) Alternate during the drought period using saline water to compare it to normal dry condition

A.1.9) Development of “Regulated Deficit Irrigation Guides” to be used by surveyed farmers for feed back and improvements

A.1.10) Dissemination of results

DELIVERABLES

D.1.1) Regulated deficit irrigation guides for fruit growers to save water

D.1.2) Regulated deficit irrigation criteria to control excessive vegetative growth and to produce fruits of a better quality

D.1.3) Salination hazards minimised on orchards

4.1.2 Pilot area: Southeast Anatolian Region (Turkey)

SPECIFIC PROBLEM

Many efforts have already been done by the central government to bring water in the Southern Anatolian Region, particularly through the realisation of reservoirs for multiple uses with the capacity of more then 5 billions m^3 / y. Pistachio is the most important crop in the area (Turkey is the third biggest producer and exporter of pistachio in the world), however field crops are also extensively present. The current crop water demand of the area is satisfied by water available in current reservoirs.

Nevertheless, the main future trend of the area will be characterised by an increase (horizontal and in varieties) of field crops together with an increase of the most traditional crop “pistachio” over the whole region. As a consequence, the total crop water demand will increase to a critical level in a region (Southern Anatolia) that experiences water shortages. Future total demand will unlikely be met with calculated existing freshwater yields [with consequent negative impact on agriculture production, socio-economic setting and freshwaters. All this could lead to water conflicts. Intervention of deficit irrigation management is needed today to prevent envisaged impacts.

Experiments have proved that the most appropriate programme of irrigation can be obtained for some major crops in an area under Deficit Irrigation conditions. In particular, Deficit Irrigation can be improved by the increased crop water use efficiency under Regulated Deficit Irrigation (RDI) and/or Partial Root Drying (PRD). Since pistachio is the most important crop of the area, the RDI and PRD techniques are thought to be experimented on this type of orchard with the aim of saving water and possibly re-use the saved water to reduce future deficit irrigation and mitigate pressure on freshwater, without influencing crop yield and quality.

ACTIVITIES

A.1.11) DATA COLLECTION OF AVAILABLE METEOROLOGICAL DATA AND CHARACTERISATION OF THE REGIONAL CLIMATE

A.1.12) Characterisation of the soil of the selected region

A.1.13) Assessment of water quality in function of the type of crop water quality requirement. Data will be used from available water quality analysis and some new sampled water

A.1.14) Geomorphological analysis over the region to select the most appropriate experiment site. Available satellite images will be used. The size of the experimental site will be about 1 hectare

A.1.15) Experiments will be carried out in the selected site on pistachio with restrictive irrigation treatments having water cuts of 20-50% or more

A.1.16) Monitoring of plant root zone soil water status with, plant growth and gas exchange will be carried out

A.1.17) Quantification of saved water volumes

A.1.18) Development of “Deficit Irrigation Guides”

A.1.19) Dissemination of results

DELIVERABLES

D.1.4) An appropriate deficit irrigation is adopted by PRD on pistachio orchards to save water.
D.1.5) Regulated deficit irrigation is used to control excessive vegetative growth and to produce pistachio of a better quality.

4.2 WORK-PACKAGE 2 - IRRIGATION SYSTEM PERFORMANCE

4.2.1 Pilot area: Ghezala Irrigation District (Tunisia)

SPECIFIC PROBLEM

Existing large-scale pressurized irrigation systems in the selected area operate at low performance level, with consequent high water losses and wastages. At the same time, the areas suffer of high water shortage and freshwaters are overexploited. Moreover, the low performance of distribution systems induces farmers to withdraw water through uncontrolled wells with consequent overexploitation of groundwater causing salination hazard. With this outlook on the existing irrigation systems, the main need is the development of criteria improving irrigation system performance and management activities to save fresh water from agriculture. The research will be carried out at district scale considering meteorology, hydrology, cropping system and physical characteristics of the network to calculate the saved water yield in relation to the net water balance of the irrigation scheme in the frame of different climatic, hydrological and cropping scenarios.

A research program concerning the analysis of large scale distribution systems already started in Italy, at the Consorzio di Bonifica of Capitanata. The experiences and the results carried out in this area will be taken into account for a better assessment of the Tunisian pilot area.

Site Description and Objectives

The selected irrigation district is located at about 60 km North-West of Tunis. The source of water is the Ghezala dam, having a capacity of about 6 Mm3. The irrigable area is 1000 ha, cultivated with vegetables (27%), tree crops (38%), wheat (16%) and fourage (19%). The irrigation systems was designed for on-demand operation but, specially during the peak period, important pressure deficits occur at the hydrants, don't allowing farmers to irrigate in an appropriate way.

The objectives of this work are:
understand the farmers behaviour by monitoring the irrigation system and by applying models able to simulate different scenarios;
develop a tool aiming at identifying the failure areas in the system and the importance of such a failure;
improve the capabilities of managers and responsibles of irrigation systems in identifying the problems and related solutions for improving the irrigation system performance.

ACTIVITIES

A.2.1) Data collection on climate, hydrology and hydrogeology, irrigation systems, water demand, cropping pattern.
A.2.2) Analysis of data and realisation of relevant thematic maps.
A.2.3) Development of models for simulating alternative cropping scenarios and for evaluating the farmers' behaviour through the generation of the hydrographs of withdrawals.
A.2.4) Development of models for the performance analysis and rehabilitation-modernisation of the selected irrigation scheme.
A.2.5) Application of models for performance analysis of the irrigation scheme
A.2.6) Quantification of total water losses
A.2.7) Identification of possible solutions through implementation of new technologies
A.2.8) Quantification of potential water saving within pilot irrigation schemes
A.2.9) Development of criteria for management of irrigation system.
A.2.10) Dissemination of results.

DELIVERABLES

D.2.1) Quantified degree of efficiency of irrigation system.
D.2.2) Defined solution schemes and measures to save water.
D.2.3) Quantified volumes of water saved in irrigation.
D.2.4) Developed criteria for management or irrigation system efficiency.

4.2.2 - Pilot area: Souss-Massa Irrigation District, Agadir (Morocco)

SPECIFIC PROBLEMS

The Souss-Mossa irrigation station in Morocco was designed for on-demand sprinkler irrigation during 1970. The design of the whole irrigation system (network and pumping station) was referred to the actual situation of the country but, after the crisis of petroleum (1974) the cost of the energy increased enormously, causing the increasing of the operating costs. In fact, actually, the cost of the energy represents about 60% of the total cost of the water. Therefore, all the actions aiming at reducing such energy cost represents a priority issue for the country.

Site Description and Objectives

The selected irrigation scheme, within the Souss-Massa region, is called " Ait Amira" and covers on irrigable area of around 3700 ha. It is managed by the ORMA-Souss Massa (Agadir). At the upstream and of the network a pumping station with a regulating water tower 90 m eight was installed. It is able to guarantee a minimum pressure at the hydrants of 4 hours, for a maximum discharge in the network of about 1800 l/s.

The objectives of this work are: set up an innovative methodology for reducing energy cost for the operation of the system; quantify the energy saving; improve the social conditions of farmers by reducing the water price.

ACTIVITIES

A.2.11) Data collection on the demand hydrograph, on the energy consumption and on the physical characteristic of the network
A.2.12) Set up a data-base on the demand hydrograph, on the energy consumption and on the physical characteristic of the network
A.2.13) Development of a methodology (including a software package) for the energy saving in irrigation districts serving by pumping station
A.2.14) Application of such a methodology to the "Ait Amira" irrigation scheme
A.2.15) Quantification of the energy cost saving for the Ait Amira irrigation scheme
A.2.16) Dissemination of results.

DELIVERABLES

D.2.5) A software package
D.2.6) Data-base on energy consumption and on the physical characteristic of the network
D.2.7) Quantification of energy saving

4.3 WORK-PACKAGE 3 NON-CONVENTIONAL WATER RESOURCES

4.3.1 Pilot area: perimeter located in Agadir region (Morocco)

Re-use of treated wastewater

Specific problem

South of Morocco has low rainfall, mostly seasonal and with eratic distribution. Moreover, due to the rapid development or urban and rural domestic water supplies, conventional water resources have been seriously depleted and wastewater reclamation and reuse for irrigation gained increasing role in the planning and development of additional water supplies.

However, the re-use of wastewater may have potential adverse impacts on the environment, soil and groundwater. During last six years of collaboration with IAM-Bari, field experiments have demonstrate the benefit of using treated wastewater to irrigation cash crops (vegetable and flowers) and cereal crop (bearly, wheat, mais). The use of drip irrigation increased water use efficiency in this cropping system and eliminated the health risk for labour and on the products.

Site description and objectives

Lately a wastewater treatment was developed by the rural Commune of Drarga about 4 km south of Agadir. The treated effluent will be used by 12 farmers in a perimeter of 6 ha. Our objective is to implement the finding developed under experimental conditions into on-farm level.

Three types of crops will be tested (cereals, forage and vegetables) and 3 systems of irrigation (sub-irrigation, drip irrigation and micro-sprinkler) will be tested.

The soil of this perimeter is sandy-loan and two irrigations will be used (well water, and treated effluent).

This research will benefit from the Master Programme developed between IAV Hassan II and IAMBari. The students will undertake their research thesis on this pilot to monitor crop development, eco-physiological data on the crop grown as well as the performance of the different irrigation systems at their impact on the soil characteristics and on the groundwater pollution.

ACTIVITIES

A.3.1) Data collection of available meteorological data (rainfall, temperature, ETo)
A.3.2) Plant productivity and product quality
A.3.3) Physiological data related to phytosynthesis evapotranspiration, water potential and osmotic potential under the different treatments.
A.3.4) Evaluation on the performance of the different irrigation systems (water distribution efficiency, clogging, etc.)
A.3.5) Impact on soil characteristics, soil aggregate stability using "Henin" method.
A.3.6) Quantification of water and nutrient saved for each cropping system.
A.3.7) Evaluation of alternating freshwater with Non-conventional water during the sensitive stage.
A.3.8) Development of guideline on the use of epurated water for different cropping systems.
A.3.9) Dissemination of results

DELIVERABLES

D.3.1) Guidelines for optimal use of non-conventional water resources in irrigation
D.3.2) Setting strategies for the recycling and re-use without any environmental and health hazards
D.3.3) Water saving potentiality through reuse of Non-conventional water resources
D.3.4) End-Users participation and creation of water user association for Non-conventional water resources
D.3.5) Cost benefit analyse for the use of Non-conventional water resources

4.3.2 Pilot area: Nile Delta (Egypt)

Re-use of Drainage Water

SPECIFIC PROBLEM

The irrigated agriculture of Egypt is sustained through provision of adequate land drainage systems. The drainage water in Upper Egypt is pumped of flow by gravity back to the River Nile. This drainage water flowing through the main drains, is rapidly available for farmers who suffer shortage in fresh water supplying. This involves the risk of using saline water that may be harmful to crops, or they cause salinization of soils on a lag turn. Since the early seventies, Egypt adopted a long term plan to reuse drainage water for irrigation on a more sustainable basis. The officially reused drainage water increased from 2.6 billion cubic meters per year in the eighties to almost 4.2 billion cubic meters per year in the nineties. Nowadays about 7.0 billion cubic meters are used for irrigation and according to the Egyptian Water Master Plan, a full use of drainage water will be achieved the year 2017.

SITE DESCRIPTION AND OBJECTIVES

National Water Research Centre of Egypt initiated a long term management programme on a small scale perimeter located in the central delta with 30 farmers in an area of 26 ha. The aim of this research is to overcome factors that threaten the sustainability of agricultural production in Egypt. Trials (with such variables as water quality and quantity, inputs, irrigation systems and crop rotation are conducted on the farm level and we will be testing different management practices and monitoring their impact on the soil, crop yield, and groundwater pollution. On a long term we will be proposed more efficient ways for the use of drainage water to maintain higher levels of productivity, while minimising adverse effects on the environment.

ACTIVITIES

A.3.10) Data collection of available meteorological data (rainfall, temperature, ETo)
A.3.11) Plant productivity and product quality

A.3.12) Physiological data related to phytosynthesis evapotranspiration, water potential and osmotic potential under the different treatments.
A.3.13) Evaluation on the performance of the different irrigation systems (water distribution efficiency, clogging, etc.)
A.3.14) Impact on soil characteristics, soil aggregate stability using "Henin" method.
A.3.15) Quantification of water and nutrient saved for each cropping system.
A.3.16) Evaluation of alternating freshwater with Non-conventional water during the sensitive stage.
A.3.17) Development of guideline on the use of drainage water for different cropping systems.
A.3.18) Dissemination of results

DELIVERABLES

D.3.6) Guidelines for optimal use of drainage water resources in irrigation
D.3.7) Setting strategies for the recycling and re-use without any environmental and health hazards
D.3.8) Water saving potentiality through reuse of drainage water resources
D.3.8) End-Users participation and creation of water user association for drainage water resources
D.3.10) Cost benefit analyse for the use of drainage water resources

4.3.3. Pilot area: Tarsus Village Affair Research Institute, Tarsus (Turkey)

Re-use of Artesian Saline Water

SPECIFIC PROBLEM

Salinity is one of the most serious problems facing the world irrigated agriculture. Conservation and enhancement of quality of natural resources particularly of land and water are basic to ensuring food security of the growing population. Increasing of these two primary resources is a major constraint on our ability to ensure food security. To prevent the productive lands from being salinized as well as to utilize the existing salty land and water, it is essential to correct the deleterious conditions through application of appropriate technology.

Salinity is reported to affect about 1 billion hectares, mostly located in arid and semi arid regions. It is estimated that 20 million hectares of land deteriorate to zero or negative productivity each year in addition to that already affected. Saline soils of various natures and degree occupy over 80 million hectares in the Mediterranean basin.

This situation is not only being made worse by further land deterioration but also by population increase, urbanisation and industrialisation, all of which require more water and thus impose a tremendous strain on the already limited and fragile fresh water source in the region. In the arid and semi arid regions of the Mediterranean supplied of good water quality are expected to decrease. The development of the available water resources is questionable; most of the available water resources have been mobilised.

The decreasing availability of fresh water for agriculture use, while the need for production of food and fuel from plants is increasing in Turkey, which is nowadays a problem common to many countries in the Mediterranean region. Under such condition of fresh water scarcity, agriculture is forced to use more and more waters of poorer quality or saline ones. Fortunately, there are abundant sources of those water sources that could be used successfully in irrigation, but they are still marginally used. Water availability for irrigation in Turkey could be enhanced through proper use and management of saline water.

In arid and semi arid countries of the Mediterranean, cereal, vegetable/fruit and fibre productions are of vital important to overcome the gap in food and fibre productions and to reduce the relatively high rate of these importations.

SITE DESCRIPTION AND OBJECTIVES

The experiments will be conducted in the greenhouse in of the Çukurova University and open air in the Tarsus Village Affair Research Institute (TVARI). In the greenhouse experiment, 0.08-1.0 cubic meter cylindrical pipes (named lysimeter or pots) and soil plots in the TVARI are going to use for the experiments. The major soil series will be considered to use in the researches (generally, the soils in the Cukurova region are heavy or medium-heavy texture).

Sea water and drainage water from Lower Seyhan Irrigation System will be used as irrigation water. Irrigation water will be mixed with fresh water, and mixing ratio and leaching fractions will be changed as plants variety and irrigation programs to be used. Dilutions, on the other hand, will be changed with respect to varieties and different growing periods of the plant to be considered. employed and irrigation programs. According to irrigation programs, saline and fresh water will be consecutively used in the growing periods of the plants.

In the proposed experiments, maize, wheat and tomato plants which are the grown wide spread in the Çukurova Region will be used as the experimental crops.

The main objectives of this study are:

(1) to investigate the possibility of using saline water for crop production;
(2) to obtain the characterizing the plant growing parameters of investigated varies as a function of irrigation with saline water of different salt concentration levels;
(3) to evaluate the yield production and yield loss in relation to the salt concentration level of irrigation water;
(4) to assess the salt balance under different irrigation programmes;
(5) to classify the investigated crops with respect to their salt tolerance degree;
(6) to obtain the suitable leaching fractions for getting high yield from investigated plants and unsalinisation of soils to be irrigated with saline water.

ACTIVITIES

A.3.19) Data collection of available meteorological data (rainfall, temperature, ETo)
A.3.20) Plant productivity and product quality
A.3.21) Physiological data related to phytosynthesis evapotranspiration, water potential and osmotic potential under the different treatments
A.3.22) Evaluation on the performance of the different irrigation systems (water distribution efficiency, clogging, etc.)
A.3.23) Impact on soil characteristics, soil aggregate stability using “Henin” method.
A.3.24) Quantification of water and nutrient saved for each cropping system
A.3.25) Evaluation of alternating freshwater with Non-conventional water during the sensitive stage
A.3.26) Development of guideline on the use of epurated water for different cropping systems
A.3.27) Dissemination of results

DELIVERABLES

D.3.11) Guidelines for optimal use of artisian saline water resources in irrigation
D.3.12) Setting strategies for the recycling and re-use without any environmental and health hazards
D.3.13) Water saving potentiality through reuse of artesian saline water resources
D.3.14) End-Users participation and creation of water user association for Non-conventional water resources
D.3.15) Cost benefit analyze for the use of artesian saline water resources

4.3.4 Pilot area: ICARDA, Aleppo (Syria)

Development of Screening Legumes and Forage Nursery for Salinity Tolerance

SPECIFIC PROBLEMS

Water is a scarce resource and has great strategic importance for most Mediterranean countries of West Asia and North Africa (WANA). At present, over half the region's crops are grown under irrigation, and agriculture accounts for around 85% of the total consumption of water. However, with rapidly growing industrialization, urbanization and population increase, economic realities seem certain that farmers have to look for crop varieties that could produce using saline water for irrigation. Moreover, opportunities for large captures of new water are now very few. Depletion of the flow to downstream users will become increasingly difficult to avoid and the quality of irrigation water is becoming a way of live require some agronomic adjustment at the farm level.

Sustainability of agriculture system requires balanced crop rotations. This means introduction of some legumes verities to the existing wheat-based and cotton-based crop rotations. Given that large areas of irrigated land in the WANA area suffer from salinity problems or the use of irrigation waters that have level of salinity, testing and introduction of legumes that tolerate salinity become a necessity. Around the world it has been numerous research efforts attempted to identify varieties that tolerate salinity and still economically produce yield. Legumes however, did not get the same attention as cotton or cereals. In dry areas of WANA legumes varieties such as lentil and chickpeas are important protein sources in the diet of the poor inhibitors of many communities in the region, particularly the ones that live in areas of salinity and or water quality problems and constraints respectively. Also, livestock industry is an important agriculture operation in the region of concern despite the shortages of healthy rangeland and enough winter forage and feed.

Therefore, the International Center for Agriculture Research in the Dry Areas (ICARDA) who has a worldwide mandate of these two crops is proposing to establish screening legumes and forage nursery for salinity tolerance that will be available serve not only the Mediterranean countries but also other places elsewhere interested in this field of study. Whereby, this nursery shall screen all verities of lentil, chickpeas, and selected forage legumes in three-step system.

This programme is a completion of the project “Salt tolerance degree for cereals and leguminous crops dominant in the Mediterranean region lasting for 4 years.

This programme started 2 years ago, coordinated by ICARDA and Bari Institute in cooperation with INRA France, ISA Bari and Wageningen University.

SITE DESCRIPTION AND OBJECTIVES

This project to be conducted at ICARDA facilities, capitalizing on the infra structure the Center have. Field test to be conducted at the farmers field with different irrigation water salinity levels farmers are using for irrigation to verify plant phonology and yield in compression to the green house results. The objectives of this work will be: screen lentil and chickpeas varieties available at ICARDA and National Programs for salinity tolerance; test 10 to 20 varieties of each under greenhouse condition for plant characterization and yield quantity and quality; test varieties at the farmer fields.

ACTIVITIES

A.3.28) Bench screening, available varieties of lentil, chickpeas, and at least one selected forage legumes will be test for three salinity levels 3, 4-5, 8 dS/m. This test will be conducted with three treatments:

Dry seed with three salinity levels and control

Pr-soaked seed with fresh water and then with three salinity levels and control

X-rated seed to study the impact of x-ray on plant salinity tolerance as dry seed and pre-soaked seed with three salinity levels and control.

A.3.29) Greenhouse screening study: top 10 to 20 (upon availability of varieties) verities will be tested with the same above treatments under greenhouse (controlled condition).

A.3.30) Top 3-5 varieties to move for field-testing at the farmers field

A.3.31) Dissemination of results

DELIVERABLES

D.3.16) Identification of lintel, chickpeas and some forage crops salt tolerant varieties.

D.3.17) Tested varieties of lintel, chickpeas and some forage crops salt tolerant varieties and their appropriate agronomic practices in cotton- and wheat-based rotations.

D.3.18) Provide degree- and/or non degree-training opportunities in the field of crop and water salinity management.

4.4 WORK-PACKAGE 4 PROJECT CO-ORDINATION

The whole project will be scientifically coordinated by the Chairperson of the National Water Research Center (NWRC, Cairo, Egypt) in cooperation with the IAMB (Istituto Agronomico Mediterraneo of Bari). The co-ordination will be carried out along the whole duration of the project.

The project will be financially administrated, along the whole duration, by the Administration Division of CIHEAM-IAMB (Istituto Agronomico Mediterraneo of Bari) in cooperation with the person nominated by the NWRC, Cairo (Egypt).

ACTIVITIES

A.4.1) contractual matter and project administration

A.4.2) maintenance of links among partners

A.4.3) maintenance of links with funding agency

A.4.4) scientific co-ordination and interaction of the Work Packages 1, 2 and 3

A.4.5) organization of projects and bilateral meetings

A.4.6) organization of seminars / workshops

RAP-PROGRAMME:
WASIA PROJECT IS A REALISTIC STEP TOWARDS A SOFT PATH WATER MANAGEMENT APPROACH

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INTRODUCTION

The increasing scarcity of water in dry areas is now a well recognized problem. According to the World Commission Environment and Development, approximately 80 countries with 40 percent of the world population already suffer from serious water shortages.

Presently, water shortages have led most of arid and semi-arid countries to increase food imports because the local agriculture sector is not able to produce sufficient food to fulfill the existing food gaps. The increasing food gaps is posing serious challenges beyond the economic and political capacity required for the necessary adjustments concerning the allocation and use of water in all sectors, particularly the agriculture.

Agriculture sector is by far the largest user of water in the world. On a consumptive use basis, 80 to 90 percent of all the water are consumed in agriculture . Unfortunately, the water use efficiency in this sector is very poor not exceeding the 45% with more than 50% water losses, and thereby, enormous water saving could be achieved in the agriculture sector comparable with the other sectorial water uses.

The growing water scarcity and the misuse and management of the available water resources are nowadays major threats to sustainable development for the various sectors, especially domestic, industrial and agricultural.

Today, in most countries suffering the water shortages, at the heart of the question of whether a water crisis can be averted or whether water can be made productive. Increasing the water use efficiency its productivity through effective water saving and by introducing non-conventional water resource as an additional irrigation water source are central to producing food, to fighting poverty, to reducing competition for water and to ensuring that there is enough water for the nature. The more we produce with less water and/or with the same amount of water, the less the need for infrastructure development, the less the conflicts among the sectorial water uses, the greater the local food security and the more water for agricultural, household and industrial uses, and the more remain in nature.

However, to achieve such goals, major improvements are still required in water resources use and irrigation technology and management. Meeting such challenges will require a far greater effort and significant changes in *how water is managed? What needs to be changed? What are the improvement required*? to cope with increased water scarcity.

Those are the issues to be discussed in this paper addressing the appropriate techniques and proper tools to be adopted for increasing the productivity of water through water saving and improving the rates in water use efficiency in the irrigation sector coupled with better management system for water conveyance, allocation and distribution, emphasizing the use of non-conventional water as an essential water saving practice.

WATER SITUATION IN THE MEDITERRANEAN REGION

It has been calculated that in 1990 approximately 280 km^3 of water were globally used in the Mediterranean region, including all the riparian countries and entities of the Mediterranean Sea, of which 99% came from natural resources. The demand has doubled in the 20th Century, and has increased by 60% in the last 25 years. In the last decades, water demand per capita (for all users) progressed differently in the various countries, depending on the conditions of demographic growth and economic development. By the year 2025, practically, no Southern Mediterranean country will have resources exceeding an average of 500 m^3 per capita/per annum (Fig.1) which clearly highlights that the problem will become increasingly acute.

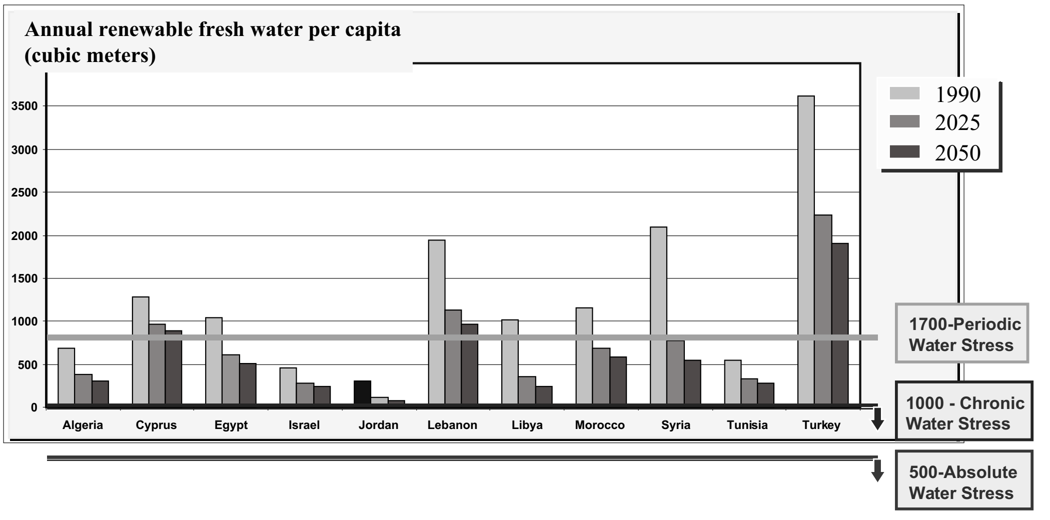
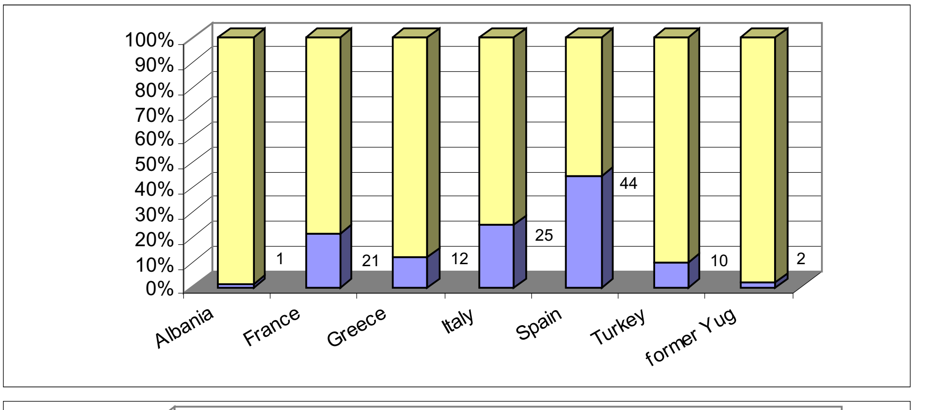


Fig. 1. Renewable fresh water availability per person in the Southern Mediterranean countries, 1990 to 2050

In view of the various proposed scarcity indicators, it is expected that "water shock" will occur when almost half of the Mediterranean population will have reached the water scarcity threshold in the year 2025. At this point, even in the optimistic hypothesis, the pressure on the resources is expected to grow and become more extensive and more serious at local levels in countries from Morocco to Syria, as well as in the islands. In the pessimistic hypothesis, more than 13 countries will use more than 50% of their resources and 6 more than 100% (Malta, Israel, Tunisia, Egypt, Syria and Libya). In order to meet water demand in those countries, per capita draw-offs on conventional resources will probably have to be reduced through various incentives, or supplemented with non-conventional or non-renewable resources.



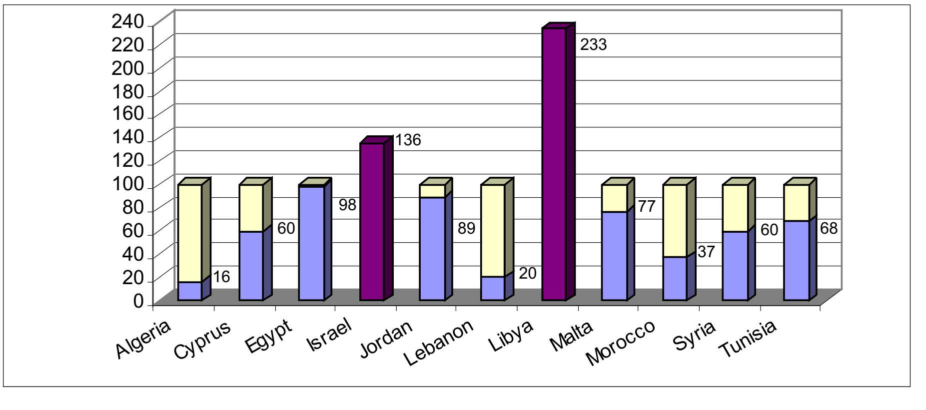


Fig. 2. The ratio between the total water withdrawal and average natural renewable water resources (in %)

The natural renewable water resources in the Mediterranean region account for 1,153 km^3/year. An approximate picture of each country's water situation is given in Fig. 2. In global terms per country, exploitation indices (the ratio of total water withdrawals/average natural renewable resources flow) (Fig. 2) already exceed 50% in 8 Mediterranean countries. That means tension at least locally or at certain times. When such rates reach or even exceed 100%, they indicate that the balance is disturbed or that there is a deliberate, but unsustainable use of non-renewable resource (Libya) or indeed reuse of part of the non-conventional resource such as treated wastewater or drainage water as in Egypt and Israel. However, those indicators refer to the totality of natural resources; the situation would appear more critical if the indicators referred only to those resources considered exploitable. In this case, a new picture will appear and the criteria will differ from country to country.

Currently, final consumption of water resources for the whole region is estimated at more than 130 million m^3/year (or 48% of quantities withdrawn), the majority of which is in the Southern Eastern countries (60% of the total) because of irrigation.

The increase in the consumption indicators (the ratio between the quantity of water not returned to the natural environment/average natural renewable resource flow) could be the result of the following two factors:

- the relative importance of agricultural uses, an avid consumer;
- the high proportion of waste waters discharged into the sea from cities, industries and tourist activities which reduces the amount of water returned to the rivers or aquifers.

WATER RESOURCES PROBLEMS AND ISSUES

In the majority of developing countries of the Mediterranean, the legacy of past and current practices that treat water as an unlimited resource is leading to a fast depletion of this valuable resource on which human life, food, security and ecosystems survival depend (Hamdy 2000; World Bank, 1993; UNDP 1996). This is not conducive to sustainability either from the economic or from the environmental perspectives.

The mismanagement of the water resources and the notable water losses in all sectors and, in particular, the agriculture one where efficiency below the 50% is a very clear indication of how weak the water sector is in the majority of the Mediterranean countries. This also leads us to the conclusion that the current water crisis is mainly a crisis of water governance. The water sector is still characterized by ill funded and badly organized institutions. Legislation is generally incremental and out-dated and relevant rules and regulations are poorly enforced. Water activities are fragmented and divorced from the environmental management where eco-system functions and services are ignored. Data and information on hydrologic, meteorological and socio-economic features are often inadequate, inconsistent and unreliable.

Furthermore, there is a chronic shortage of professionally trained human resources at all levels. Equally, lack of public involvement in decision-making and the absence of coordinated, comprehensive, integrated and system approach to problem-solving are perpetuating and aggravating the already precarious water situation. Those are some issues among others behind our failure in governing our water resources. In our opinion, the greatest water problem is the inability to link environmental security, water security and food security. Today we are witnessing the results of our lack of ability to properly balance economic growth, social development and environmental security.

STRUCTURAL IMBALANCE

The dominant fact that will be strongly evident over the next few decades is the structural imbalance between the constantly increasing demand for water to meet the needs and the natural available water resources (Fig. 3).

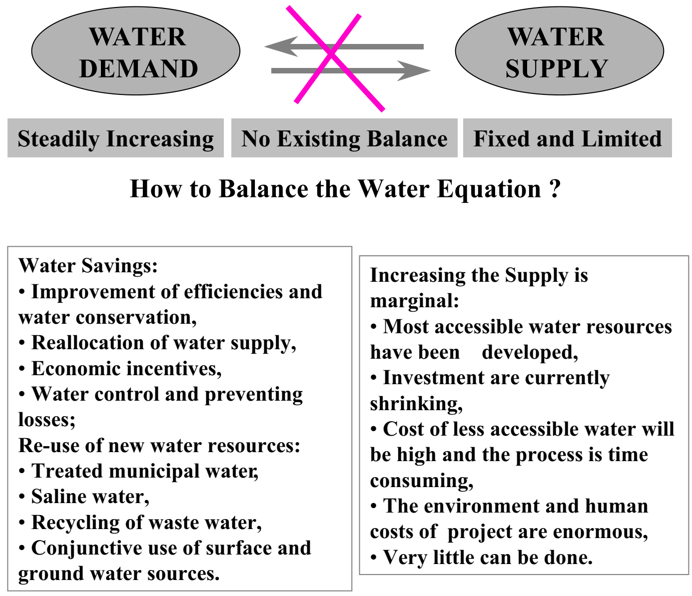


Fig. 3. Water resources dilemma in the Mediterranean Region

In the majority of countries in the Region, the imbalance has appeared around the year 2000 and beyond. These countries will be facing similar problems that could be outlined as follows:

- declining water resources per inhabitant both in terms of water availability and water withdrawals. It is expected that the available water per capita will be reduced by nearly 50% of the present one;
- exploitation of water at a relatively high rate with the risk of water quality deterioration;
- excessive reduction in water withdrawals per capita, which will impose its significant effect on the water sectorial use, creating notable competition and conflicts among users in the various sectors, in the irrigation and domestic sectors in particular. Priorities will be given to satisfy the drinking water demands to the expenses of the available water allocated for the irrigation sector with the consequence of less irrigated surface and more land degradation;
- progressive degradation in the quality of available water resources because of increasing waste load discharged into water bodies and the atmosphere.

Water demand for the years 1990 together with the projections for 2010 and 2025 are given in Figure 4. This figure clearly indicates that there will be a progressive increase in the water demand within the next 25 years. Globally for the whole Mediterranean countries, it is expected that water demand will be increased by nearly 50% in the year 2025 with respect to actual demand values (1990).

The question emerging nowadays is how to meet this ample water demand at a time when pressures on resources are increasing and it becomes increasingly expensive to mobilize these resources?

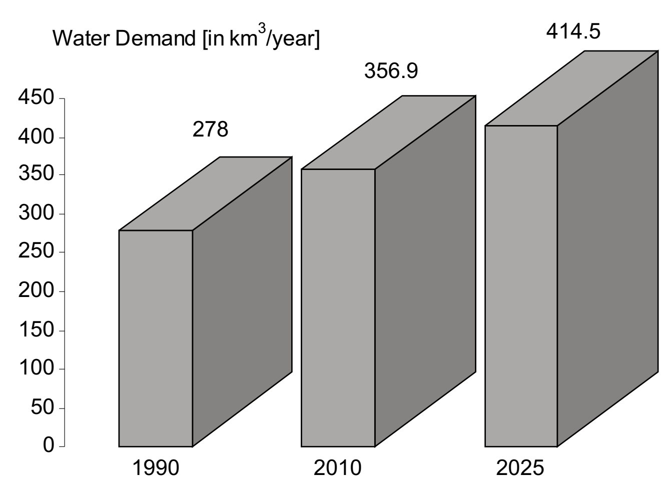


Fig 4. Actual water demand (in 1990) and foreseen water demand for 2010 and 2025, in km^3/year

The solution of those problems require new management strategies towards a more balanced approach which emphasizes:

allocation of an essentially fixed supply of water resources faced with rapidly growing and competing demands;

demand management strategies that involve policies and activities to reduce per person or unit-of-activity use rates especially for urban areas and the agricultural sector;

technologies and institutional instruments which together will enable principles of demand management to be integral to the allocation and management of water;

economic and financial instruments and regulatory and legal frameworks.

As demands on water supplies in the region increases, we need to spend more time thinking about how and what we use water for, a new approach for its management, the use of new ways for meeting basic human needs, water services and a conscious breaking of the ties between economic growth and water use.

There are many components to this change: a shift away from sole, or even primary, reliance of finding a new sources of supply to address perceived new demands; a growing emphasis on incorporating ecological values into water policy, a re-emphasis on meeting basic human needs for water services, a conscious breaking of ties between economic growth and water use.

Water planning and management traditional and new approaches

The traditional hard-way

Returning back to the twentieth century water resources planning and development relied on projecting future population, per capita water demand, agricultural production and levels of economic productivity.

Because each of these variables has always been projected to rise, water needs have also always expected to rise. As a result, traditional water planning regularly concludes that future water demands will inexorably rise and will eventually exceed developed water supplies. The water management problem then becomes an exercise in comping up with ways of bridging anticipated gap. Such traditional exercises were fully focusing on supply-side solution relying on ever-larger number of dams, reservoirs, and aqueducts to capture, store and ever-larger fractions of freshwater run-off. Such approach is now beginning to fail for environmental, economic and social reasons. Basic human needs for water still remain unmet. It is becoming harder and harder to find new, or even hold onto existing water resources to supply croplands.

Under such traditional approach, water planning efforts usually did not include a detailed analysis of what water is actually used. Equally, there was no clear identification of the common goals for water development to seek agreement on principles to resolve conflicts over water. In addition little attention has been paid to protecting natural ecosystem from which water supplies have been withdrawn. Those could be some of the driving forces beside others including high costs of construction, tight budgets, deep environmental concerns, new technological advances and the changing nature of demand for water for changing the way we are following in planning and managing our water resources.

The new soft path approach

It is well recognized that the reliance on physical solutions, although it is still continue to dominate traditional planning approaches, yet these solution failed in satisfying basic water requirements for human activities and above all the raise-up of several social, economic and environmental problems.

Nowadays many countries are changing the way of thinking and approaches in managing their water resources directed towards the soft path approach through developing new methods to meet the demands of growing population without requiring major new constructions or new large scale water transfer from one region to another.

This can be seen clearly in many developing countries and, particularly, those of arid and semi-arid regions where more and more water authorities and planning agencies are beginning to shift their focus and explore efficiency improvements, implement options for managing demand and reallocate water among users to reduce projected gaps and meet future needs. However, these shifts have not come easily they are still facing strong internal opposition and not universally agreed upon. Nevertheless, these changes represent a real shift in the human think about the way to tackle the increasingly water problems (Gleick, 1998, 2002 and RMI, 2002).

The new water management approach

Traditional approach to water planning while still firmly entrenched in many water planning institutions, are beginning to change. Continued investments in huge systems that provide more water for some is being challenged by those who believe a higher priority should be assigned to projects that meet basic unmet human needs for water.

There are growing calls for the costs and benefits of water development to be distributed in a more equitable manner and for unmet basic human needs of all affected stakeholders.

Economic factors are also playing a role in changing the way we think about water development. New water supply systems have increasingly become expensive compared to non-structural alternatives.

Another economic constraint is that almost all past water infrastructure development have been subsidized on fully paid by governments and international financial organizations, but, governmental budgets in the majority of developing countries are now under great pressure and there are serious constraints on new money for major water projects.

In this regard the question to be raised: *what is the alternative?* In our opinion, as an alternative, our efforts and re-thinking should be directed to change the traditional approach in managing and planning our water resources to a sustainable soft path putting greater emphasis on development principles that reflect environmental, social and cultural values. This new approach should include the following major common principles:

- *basic human needs for drinking water and sanitation services must be met*
- *basic ecosystem needs for water must be met*
- *the use of non-structural alternatives to meet demands*
- *economic principles to be applied more frequently and reliably to water use and management*
- *new supply systems, if needed, characterized by flexibility and maximal efficiency*
- *non-governmental organizations, individuals, private sector, research organization, regional and local institutions, and other affected stakeholders all to be involved in water management and planning decisions.*

Introducing such principles in any new approach are fundamental bases to a sustainable water use that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it.

Developing countries and the need to a new water management approach

Developing countries and particularly those of the Mediterranean region where water demand is tremendously increasing under the presence of very limited and fragile available water resources, and the arising water scarcity problems, most of those countries are already facing acute water shortages that require immediate actions and plans with an appropriate changes in the way they are using and managing their water resources.

In this regard, the question to be asked is: *what we mean by the changes in both water use and management?*

The changes does not imply to stop increasing the water supply through the traditional water approach. Some new dams, aqueducts, and water infrastructures will certainly be built, particularly in those developing countries where the basic water requirements for humans have still not been met. But, even in those countries, new approaches should be developed which permit water needs to be met with fewer resources less ecological disruption and less costly.

Future perspectives to meet human demands for water successfully will increasingly depend upon non-structural solutions and a completely new approach to planning and management fundamentally based on re-integrating water use with maintaining ecological health and environmental well-being. On the water use side still major efforts and hard work are needed with the objectives of increasing the productive use of water.

We have two approaches to be followed: the first, by increasing the efficiency with which current needs are met, and, the second, by increasing the efficiency with which water is allocated among different uses.

In those countries where new water supplies are still needed, new projects should be established with innovative small scale approaches, including micro dams, water harvesting, run-of river hydro, land management and other locally-managed solutions.

In those countries, non-traditional sources of supply including, saline, reclaimed or recycled water and in some limited circumstances, desalinized brackish water or seawater could play an important role not only in saving freshwater to be allocated to other sectors suffering water shortages, but also, in compensating partially the continuous increase in the water demand, particularly, in the agriculture sector.

Our success or failure in managing the water resources to meet the human basic needs is absolutely a matter of water-managers.

In the developing countries in the Mediterranean, we are greatly suffering big shortages in the water-managers who are capable not only to evaluate the problems, but to find the reasonable solutions; those with good understanding the connections between water and ecological health, and the links between the health of natural ecosystem and human well being to integrate ecological and human water needs in a comprehensive way. The capacity building in the water sector in the region is still weak. The human sources are the actual wears moving any expected changes and improvement in the water use and its management.

Non-structural water development: increase the efficient use and allocation of water

A key component of non-structural approaches to water resources management is a focus of using water more efficiently in all sectors and, in particular, the agriculture one where nearly more than 80% of the available freshwater are allocated to this sector (Fig. 5), but, with a very low efficiency not exceeding the 50% (Fig 6). Such saved water is then allocated according the demand needs of each individual

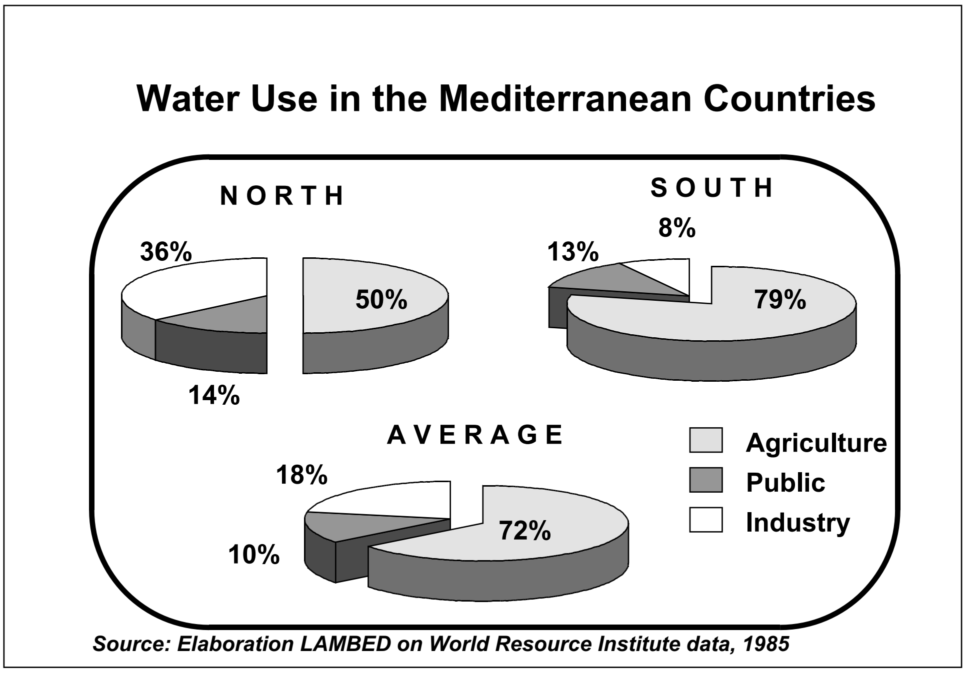


Fig. 5. Water use in the Mediterranean countries

It is well recognized that new sources of water supply can largely be avoided in many regions by implementing intelligent water conservation and demand management programmes, installing new efficient equipments and applying appropriate economic and institutional incentives to shift water among users.

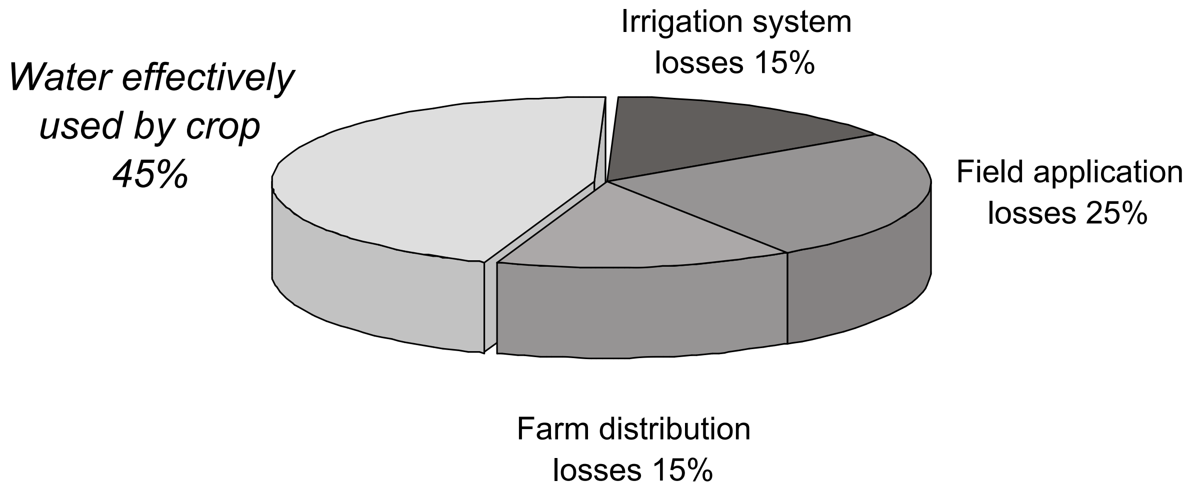


Fig. 6. The average losses of irrigation water (Source: FAO, 1994)

Improvement in water use efficiency is not an easy exercise, it combines beside the technical aspects, both, socio-economic and environmental ones. Improvements in this field will come about through changes in technology, economics and institution. It requires continuous and efficient training at all levels including the users to achieve the goals.

Vast improvements in water use efficiency are possible in almost all sectors. In both developed and developing countries, large losses occur in distribution systems, particularly on farm due to faulty or old equipment and poorly designed or maintained irrigation system. Within all the water sectors, the agriculture is the one with the highest potentiality for water saving, hence, the greatest water losses is manifested in the irrigation sector.

The largest single use of water is in agriculture and a substantial amount of this water could be used more productively. Water is lost as it moves through leak-pipes and unlined aqueducts, as it is distributed to farmers, and as it applied to grow crops. Some analysis estimate that the overall efficiency of agricultural water use worldwide is only 40 percent (Postel, 1997) meaning that more than half of all water diverted to agriculture never produces food.

This demonstrates clearly that, within all the water sectors, the agriculture is the one with the highest potentiality for water saving as water losses are enormous in this field. Increasing water efficiency in irrigation sector by only 10% in the developing countries of the Mediterranean can provide the domestic sector by nearly 50% of its water demand (Hamdy and Lacirignola, 1999, and Hamdy *et al*., 2002).

In water-short areas, new techniques and new technologies are already changing the face of irrigation. New sprinkler designs, such as low-energy precision sprinklers and drip systems can increase irrigation efficiencies from 60 to 70 percent to as high as 95% (Postel, 1997).

In the agriculture sector, even, where efforts to improve water use efficiency have begun, great potential still exists for reducing water losses without sacrificing economic productivity or personal welfare. There is great potential for improving the water efficiency with which we produce food, by changing cropping pattern toward crops that require less water, by reducing wasteful applications of water, by cutting losses between the field and the plate, and by alternating diets and functioning of international markets (Hamdy and Lacirignola, 2001).

Identifying technical and institutional ways of improving efficiency of agricultural water system will go a long way toward increasing agricultural production without having to develop supplies of water.

Furthermore, this also will address some of Mediterranean countries major environmental problems of waterlogging and salinity, declining groundwater tables, and shrinking lakes and seas. But finding such methods will require that a wider range of alternatives approaches such as small-scale irrigation and conjunctive use and re-use of non-conventional water resources, be developed, tested and implemented (Chambers, 1988).

This will require much greater imagination and flexibility of the part of irrigation policy-makers, managers and planners and it points to the need for technological, managerial and policy innovation and adoption. In particular, technologies, management practices and policies that lead to greater control by end users will be needed if the required increase in agricultural productivity are to be achieved.

This what is needed to answer to the question whether we will be able to produce enough food to feed the world's burgeoning population and get it to where it is needed.

Improvement of Irrigation Systems

In the developing countries of the Mediterranean, the major physical and technical problems and constraints in irrigation systems are as follows: efficient water use, shortage of water supply at the source, poor canal regulation, waterlogging and salinity, poor operation and maintenance, small-scale programs and scarce water resources. Such problems and constraints require a set of common supporting actions; namely, development of adequate data bases, adaptive research, institutional strengthening, human resource development, improvements in socio-economic analysis, environmental protection, technology transfer and infra-structure development.

In many cases, technology-related problems have been accumulating for long time and their adverse impact on system performance is increasing because solutions have not been found or proven effective, and maintenance has been neglected .

Operation and maintenance (O&M) is one of the most underestimated aspects of irrigation projects in developing countries. As a result, the efficiency of projects continues to decline, and during a crisis situation, problems faced become too complex to be resolved technically. Furthermore, solving these problems requires more funds than regular maintenance would have.

Utilization of Efficient Irrigation Technologies

In the majority of southern Mediterranean countries, any action aimed at economy in the use of water will have an important impact on preventing the destruction of the basic structures of development.

More efforts should be directed towards the introduction of modern irrigation techniques. The introduction of these techniques is still very limited. In Egypt, modern farm irrigation methods (sprinkler and drip) do exceed 27% of the total irrigation area; in Morocco they cover some 16%, and in Tunisia and Syria only 11% and 1%, respectively.

The major constraints to the expansion of such technologies mainly involve the high cost of operation, particularly the cost of energy. Another major constraint is the lack of appropriate maintenance services for modern irrigation equipment. So far, few countries have reached a reasonable level of self-sufficiency in modern irrigation equipment. Locally-made irrigation components are sometimes of poor quality due to lack of expertise, low quality row material and lack of coordination between research institutions and industries. Irrigation equipment manufactured in some Arab countries is too weak to provide adequate supplies for the development of modern irrigation systems.

Modern irrigation techniques need to be carefully selected and adapted to the local physical agronomic and socio-economic environment, as well as to the technical and managerial skills of local farmers. Upgrading existing irrigation schemes should, in most cases, be preceded by pilot schemes to test alternative design concepts. Costly improved technologies can only be justified if their agronomic and economic potential is fully exploited.

In this regard, the exchange of experiences and the transfer of the research findings from the northern Mediterranean countries as well as developing ones (Israel, Cyprus and Jordan) to the other countries in the region is very important for wider and proper use of such modern irrigation techniques in the area.

Water Optimization: Crop Water Requirements and Irrigation Scheduling

In order to optimize water application to different crops given different soil types, irrigation systems and climatic conditions, research should be continued to provide better knowledge on soil-water-plant relationships, reviewing the concept of an optimal water supply. The management of irrigated crops to cope with droughts should receive priority in research. In addition, the link between crop water requirements and irrigation scheme reliability should also be considered.

Reallocation of Irrigation Water Supply to Low-Water Consuming and High Value Crops.

Crop rotation is an essential part of proper irrigation water demand management. Cropping patterns should be modified through the use of less consuming water crops and high value crops.

In most Mediterranean countries, irrigation water allocations are heavily influenced by national policies seeking to achieve food self- sufficiency. As a result, the current cropping patterns contribute to the consumption of large amounts of water, at a time when we are seeking greater water savings and economizing irrigation water use to avoid the foreseeable conflicts among water users.

For instance, cereals -especially rice and sugar cane- dominate agricultural production in Egypt and are allocated 25% to 30% of the irrigation water. Free water supplied to farmers in Egypt makes the crops profitable to them. Wheat is also a major crop in the region, accounting for 35% of the total agricultural production in Morocco. Where cropping patterns lead to the use of more irrigation water, measurements of the cost of water allocated to crop production should be considered.

In the Mediterranean region, new strategies are needed for changing cropping patterns to suit future water allocation. Such strategies should be based on the availability of water supply and applied through economic reforms and structural adjustments, including private sector development, privatization and trade and price liberalization. They should also focus on lifting controls on agricultural crop patterns and shifting production towards more profitable crops.

Conjunctive use of water supplies

The conjunctive use can be defined as the development and management of multiple water resources in a coordinated manner such that the total yield of the system over a period of years exceeds the sum of the yields of the individual components of the system resulting from an uncoordinated operation. The objective of conjunctive use implies not only the combined use of water resources of more than one type but also their exploitation through efficient management in techno-economic terms by taking advantage of the interaction between them and the impact of one on the others.

The conjunctive use planning must include principles involved in the two water systems considered independently, but must also include principles to guide the optimal development of the complementarity of the two systems. Conjunctive use is planned and practiced with the following objectives:

- mitigating the effect of the shortage in canal water supplies often subject to steep variation in river flow during different periods in the year;
- increasing the dependability of existing water supplies;
- alleviating the problems of high water table and salinity resulting from introduction of canal irrigation;
- facilitating the use of poor quality water which cannot otherwise be used without appropriate dilution;
- storing water in ground water basins closer to the users, to ensure water supply to the users in case of interruption of surface water supply;
- minimizes drainage water disposal problem.

To overcome the shortage in available freshwater resource in arid and semiarid countries, particularly those of the Mediterranean and for a better reuse of low quality water and for a more freshwater saving through conjunctive water use nationally, it is needed a critical review of the prevailing situation vis-à-vis available water resources and their use in the cropping pattern now being followed. Such an exercise should ideally be focused on the following requisites:

1. definition and delineation of appropriate agro-climatic irrigation zones for current assessment and future planning of water resources with respect to the use of irrigation;
2. assessment of the quantum of water available for irrigation in different zones;
3. estimation of the irrigation requirements on the basis of cropping pattern and recommended irrigation practices;
4. assessment of the current utilization of irrigation water and ascertaining the magnitude of its over and under use in different zones as in 1) above;
5. determination of alternative pattern of cropping, irrigation practices and supply of irrigation water together with related policy measures such that available water is optimally used to maintain groundwater level within safe limits and to keep the short and long-run economic effects in proper balance.

Optimizing the conjunctive use of water is defined as using available waters to their maximum potential. This requires defining water needs not only in terms of water quantity but also in terms of water quality required, neither better nor inferior quality, to satisfy the defined need.

The question to be raised here is: *how to make the conjunctive use of water fully operational?*

We cannot answer positively this question unless we have fully in hand the following:

- policies and regulation must be in place and enforced to ensure waters of varying quality are used in accordance with approved standards of use. Difficulties often lie in the enforcement of legislation within an administrative structure, translating the regulatory objectives into a decentralized strategy;
- scientific based standards for water use and standards for discharge to water system must be prepared, confined and placed into effect;
- regulation to enact water use standards must be flexible to allow a structured phase-in of the final standards; it is not rational to expect standards significantly different from operating practices to be followed in a very short time period. A strategy to reach compliance over a specified time period should be built into the phase-in programme or there is a danger that compliance will never occur;
- a precise data is needed on the availability of each water supply, in quantity and quality, temporally (when it is available) and spatially (where it is located);
- economics comes into the planning process when water supplies are linked to potential water uses. There is costs to transport water from the source to the user and it costs money to purify water both before and after use. For instance, in some cases it could be more economically to move water of appropriate quality from a more distance source than to use a nearby water supply of higher quality than needed.

Such forementioned prerequisites indicate clearly that conjunctive use of water supplies is not a simple matter, but, relatively a complex one.

However, the availability of some computer software that combines engineering and economic data with stakeholder negotiated environmental and sustainability constraints could be very helpful in aiding the decision-makers, water planners and managers in optimizing best use of available water supply.

What we like to emphasize here is that the soft path of water and conjunctive use of all water supplies are core components of an integrated water resources management program that looks at water sources in the context of the entire economic, social and eco-system of the nation.

Alternative water supplies (Non-conventional water resources)

In different regions, particularly the arid and semi-arid ones, new supplies of water will continue to be required to overcome the severe shortages in freshwater sources.

For those regions, rather than seeking new pristine sources from far away, however, a wide range of alternative water supplies (non-conventional water resources) will be increasingly used to meet certain demands. Meeting different needs with the appropriate quality of water may prove to be economically beneficial and at the same time reduce the need for new supplies at a higher and higher marginal cost. Reclaimed water, gray water, recycled water, brackish water, salt water, or desalinated water may all be considered usable for some needs and in fact may have environmental, economic or political advantages.

Reclaimed wastewater

Reclaimed water, in particular, has some remarkable advantages, including a high reliability of supply, a known quality, and often a centralized source urban demand centers.

More recently, attention has focused on treating this water and using it as a resource rather than considering it extraneous waste (Asano and Levine, 1998). Drought conditions limiting supply, environmental problems with sewage disposal and growing demands have all made water reclamation more appealing.

It is now widely recognized that treated wastewater reuse constitutes an important and integral component of the comprehensive water management programs of the majority of countries, more so in the water scarce ones. This implies that these countries should have national policies and strategies relating to wastewater management, in general, and wastewater reuse for agriculture, in particular, in order to guide programs, projects and investments relating to wastewater collection, treatment, reuse and disposal in a sustainable manner.

This requires the establishment of a clear policy with regard to TWW management.
- Modalities for strengthening the national capacity building in this sector.

Such policy should be accompanied by an appropriate national strategy for wastewater reuse characterized by the following features:
- spelling out ways and means of implementing policy directives;
- defining the nature and mechanisms of inter-institutional collaboration, allocation of funds, establishment of pilot wastewater reuse demonstration sites of good management practices and phasing the implementation of wastewater programs;
- fostering the share of responsibilities between involved ministries, agencies and authorities, and the way to link and integrate the activities among them, individually and in combination;
- identifying an economically feasible, safe and socially acceptable set of standards, regulations and codes of practices for sustainable use.

Ideally, policies of TWW reuse and strategies for its implementation should be part of water resources planning at the national level. At the local level, individual reuse projects should be part of the overall river basin planning effort.

Economics and water valuation

In appropriate pricing policies and economic subsidies encourage wasteful use of water and inhibit efficiency and conservation programmes. There are growing efforts, however to treat water as an economic good and this was one of the four principles adopted at Dublin Conference (1992). While there is disagreement about how to define “economic good” or to apply the concept, a variety of new economic and pricing approaches are now contributing to the shift in water resources development approaches.

In the Mediterranean countries and particularly the developing ones, the cultural and socio-economic values of water are still very elusive subject. Several learned meetings stressed the economic value of water, while others stressed its social and cultural values.

The relationship between the cost of goods and their market price is well known in economics. Water should be no exception if it was treated as an economic good and sold in a competitive market.

However, that is seldom the case. In many cases, irrigation rates do not have a significant impact on irrigation efficiencies because they represent such a small proportion of total production costs. This situation can encourage an over use of water.

In the Southern Mediterranean countries, irrigation water is provided either free or for less than the full cost of providing irrigation services. Such extremely low cost of water encouraged the production of crops that are both low-valued and highly water intensive and did not provide any incentives to use water efficiently.

In the Mediterranean region, the introduction of irrigation charges is a very important pre-requisite to good management of irrigation demand because it is noticed that despite the observed water shortages, misuse of water in agriculture is widespread in current irrigation management practices. This due mainly to the failure in the past to recognize water's economic value and the real cost of water services provision. Therefore, it is now widely believed that managing water as an economic good is an important tool of achieving efficient and equitable water use as well as encouraging conservation and protection of scarce water sources. In this direction some changes are already beginning to occur in some of the developing countries in the region, but, the process is still very slow due to a number of economic, cultural, social and institutional problems.

However, to promote the process successfully, water pricing must be based on principles of fairness, transparency and equity. In this regard, to achieve this, the water pricing policies should include the following (Hamdy and Lacirignola, 2002; and Hamdy, 2002):
- flexible rules must be adopted in determining reasonable tariffs closely related to farm economies, such that farm activity results encouraged rather than limited; tariffs should be determined on the basis of farm net profit, in such a way that the burden does not become excessive to the point of obliging the farmer to abandon or reduce the activity;
- tariffs can be based on a fix, flat, very low rate common to all, plus a variable rate depending for example on progressive water volumes (with unit cost increasing with volumes) and/or on the period of the year (with unit costs increasing in the peak consumption period);

- tariffs must be based also on water quality: if it decays along the season (e.g. for a progressively higher salt content), a parallel decrease in price must be associated to it;
- the farmers have a right to get a premium price for the use of primary or secondary- treated domestic wastewaters, since so doing they polish wastewaters and avoid their release in watercourses, protecting the environment and reducing treatment costs to the community;
- it is unreasonable to expect that farmers pay for the amortization of existing structures, designed and implemented without their participation and often with optimization criteria different from those of farmers themselves;
- it is unfair that farmers be called to participate in the expenses to maintain overstaffed administrative offices, with armies of people hired without their consent, from persons extraneous to the agricultural world;
- an intense action of information and formation should precede and follow the introduction of water pricing;
- participatory water management is of a paramount importance to stimulate farmers awareness for the necessity of a wise water use, their willingness to participate in the expenses and their acceptance of constraints in water allocation.

Water withdrawal and sectorial water use losses

Overall, for the majority of Mediterranean countries, a large part of the water extracted appears to be badly or little used. Even, if there are shortages, the efficiency of use is far from being satisfactory in the drinking water and irrigation sectors.

The major water losses and badly used water in the different sectors (Fig.7) could be outlined in the following:

- Drinking water sector
At least one third of the volume of water produced and distributed as drinking water in towns and villages leaks out through the network or is wasted by misuse, thus, billions of dollars are wasted each year on producing and supplying water that is not used.

- Industry Sector
Many industries use volumes of water that by far exceed their needs, lowering its quality. Here again there are defects in recycling, leakage, loss and inefficient production processes.

- Irrigation Sector
Almost one half of the volume of water supplied for irrigation through systems that are costly for local community is not actually used in the field. This is due to leakage during its transport, badly adjusted modes of supply to the fields, low efficiency of irrigation systems and excessively consumer-oriented crops.

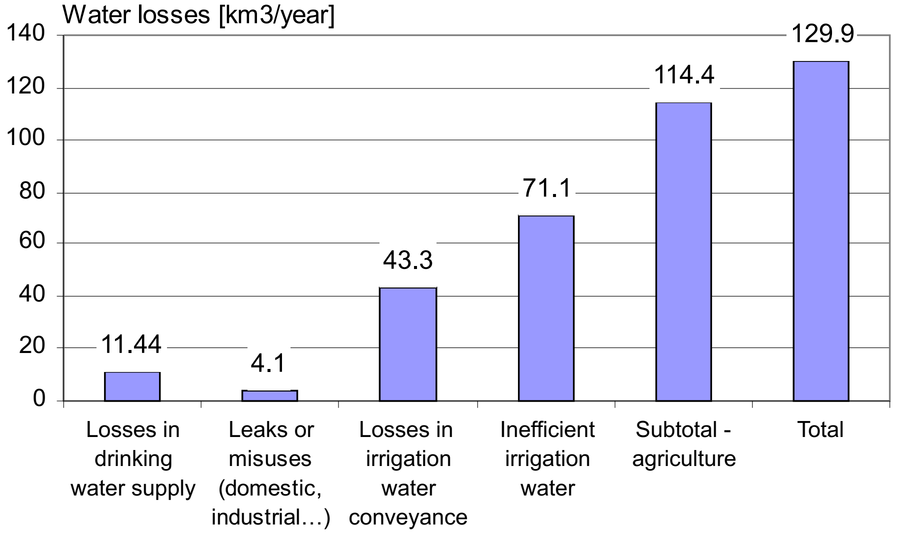


Fig. 7. Actual losses of water per sector (in km^3/year)

Possible Water Saving

Precisely how to save and whenever possible to re-use water is still not certain. From a purely technical point of view, important water savings are possible, if one thinks that under realistic conditions water efficiency can vary from about 75% to 25%, depending on the cases, the modes and the equipment, understanding that moving from the former to the latter value means to triple the irrigation surface at equal water use efficiency. With the technologies and methods available today, agriculture could cut its water demand by 10 to 15%.

Water saving is a complex problem. First, one should consider not only crop requirements and the pedological environment but also the fact that quite often water saving techniques are labor- capital- and energy- intensive. One must also consider new environment concerns and social problems related particularly to the frequently low education level of farmers.

The sound and efficient use of water for irrigation with better water savings will require::
deeper scientific and technical knowledge which is far from perfect at the present time. However some clearer modules are available (Ait Kadi, 1992);
a more systematic and permanent monitoring and collection of unbiased data at a reasonable cost;
closer participation and collaboration of the technical group and the involvement of farmers in the implementation of the program for determining water charges including an improvement in the modes of water use (Abu Zeid, 1990; 1992). A great equilibrium and flexibility are necessary in the evaluation of the needs of the different users' groups.

The way to water saving and whenever possible to its re-use, is still open.

Regarding the major water losses in the different water sector uses in the Mediterranean countries, a high proportion of those water losses could be saved and used through the implementation of the technologies and methods available today.

It is recognized that water conservation efforts almost show decreasing profitability and increasing cost. It is then necessary to estimate exactly how much of the water not used could be saved and how much this would cost. There is a need for quantification of the gains expected by reducing losses in production/distribution system, reducing wastage by consumers and by modifying exploitation system especially in agricultural sector.

For the majority of the Mediterranean countries, there is a high opportunity for saving significant volumes of the water losses through a better use of the technical and economic tools, as well as, the institutional and human resources capacities we already have. It is possible to reduce losses and leaks in drinking water by at least 50% in the industry, through recycling it is visible to reduce the water consumption by nearly 50%. However, in spite of the water saving could be achieved in both drinking and industrial sectors, yet, the most beneficial saving in terms of volume would be in irrigation sector (Fig. 8).

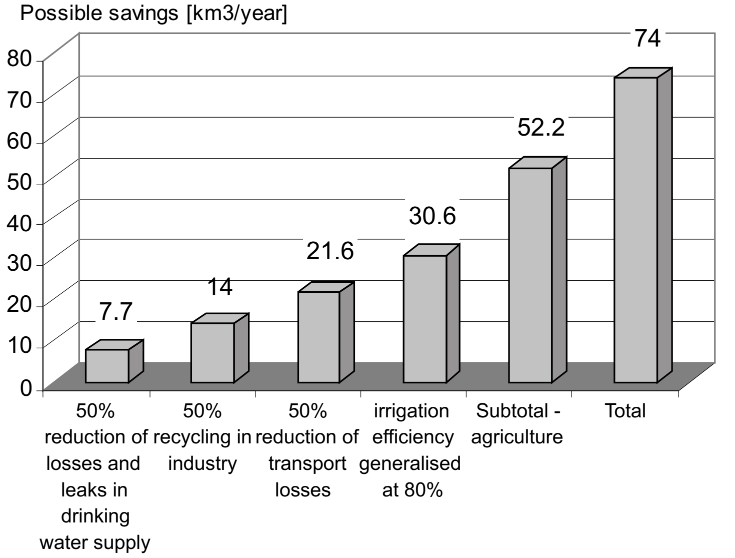


Fig. 8. Possible water savings by sector with reference to the current water demand (in km^3/year)

In the Southern Mediterranean countries, where more than 80% of their water resources are allocated to agriculture, major efforts should be directed to increase the efficiency in the irrigation field, as the opportunity of water saving is notably higher compared to the other water use sectors.

For instance, in the irrigation sector, the reduction of the transport losses by nearly 50% and the improvement of irrigation efficiency from 40-50% to 80%, could provide water savings of nearly 52 km^3/year, corresponding to more than 40% of the total actual water losses in the region and giving an additional supply of nearly 20% of the actual demand.

Possible saving in irrigation represent more than 70% of total water saving.

Although the contribution in drinking water sector with respect to the total water to be saved is the lowest among to other sectors (Fig. 8) yet, it would be of greater value in view of the higher cost of producing and distributing drinking water.

These figures are only indicative ones, but they quantify the potential gains achievable within each water sector. However, water sectorial use should be subject to feasibility studies to be carried out in each country in the light of its socio-economic and political situation.

The whole situation of water resources in the Mediterranean region which is nowadays dramatic and complex, particularly in the arid and semi-arid regions, could be completely changed, showing a new promising picture with more available water, less water losses and misuse and smaller foreseen demand (Fig. 9).

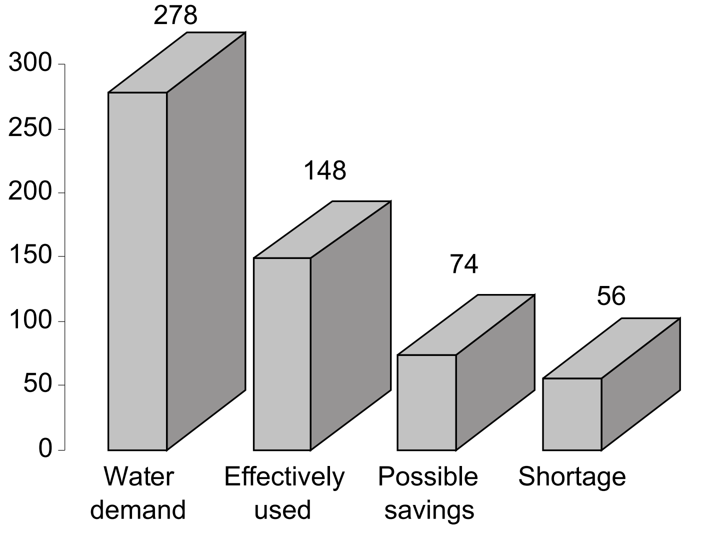


Fig. 9. Summary of the situation in the year 1990 assuming the possible savings [in km^3/year]

Water Saving and Needed Elements to achieve

The greatest is the water saving and, particularly, in the irrigation sector the greatest will be our capability to meet the increasing water demands in all water use sectors. However, to achieve this objective a better water extension service and training programmes on efficient irrigation are needed. The formation of effective farmer's organizations and raising environmental awareness are other factors that should be considered very carefully.

Strengthening Capacity

Improvement of irrigation management in the Mediterranean region requires the implementation of a set of technical actions such as the introduction of modern irrigation technologies; irrigation scheduling techniques, and introduction of economic and fiscal incentives. These options are indeed necessary but cannot achieve the expected goals without strengthening the capacity of the irrigation sector to improve the efficiency of national institutions in charge of irrigation and to upgrade the scientific and technical knowledge of the technical staff in charge of the irrigation sector.

Capacity building in the developing Mediterranean countries should be expanded and improved, and interdisciplinary training of water experts should be promoted.

To best utilize water resources, it is desirable to find and introduce new ways of interdisciplinary educational transfer of knowledge to developing countries. It should always be realized that traditional approaches used in developed countries may not be effective in finding solutions to problems in developing countries (UNDP 1992).

An important aspect of institutional arrangements is to create the capacity to implement effective irrigation water demand management.

Capacity building refers to strengthening the financial, administrative and technical capabilities of the institutions involved.

WHO and UNESCO (1991) stated that an important aspect of capacity building is the ability of a water authority to collect, analyze and elaborate on information on water resources. This should include environmental and socio-economic information that is essential for sustainable irrigation water demand management.

Training Activities

Technical training in the field of irrigation in the developing Mediterranean countries should be strengthened, and training programs should be updated and directed to the development of sustainable utilization of land and water resources under irrigated agriculture.

International, national and regional institutions could play a great role using their training programs and research activities in the development of national capacities to sustain the long-term research needs of developing countries in the Mediterranean: they can also help orient research to practical and cost-effective solutions that benefit of water users and field practitioners.

The Mediterranean Agronomic Institute of Bari, one of the operational institutes of CIHEAM, will be taken as an example. The Institute's activities and programs are mainly directed towards training, research and cooperation in the field of irrigation and water resources development and management, particularly in the Mediterranean region.

Beside offering upgraded annual courses on irrigation and its related aspects, attended by technicians and university graduates from Mediterranean countries, the Institute provides support for designing and organizing regional and national advanced short courses, seminars and conferences for senior researchers, experts and managers working in this field in Mediterranean countries.

Other Institute activities involve:

- facilitating the creation of networks among institutions in charge of irrigation in the Mediterranean region;
- designing and producing training materials (including audio-visual and printed materials);
- providing assistance to national Mediterranean institutions in developing their training programs;
- conducting surveys and investigations in the Mediterranean region to assess the existing training programs and identify prospective training strategies to improve irrigation management projects in the region.

Strong, Effective Extension Service

If there is real interaction between research and extension, then the research is easily interpreted and the extension workers can concentrate on a wider adaptation of the improved technology. Some research staff and extension workers feel that only research should pass its results to extension. The implication of a one-way process, however, should be dropped. The development and transfer of technology must be an on going interactive process with continuous dialogue between the research team, the extension team and the farmers.

A strong and effective extension service is essential to meet this objective. To be a strong organization, an extension service must:

1) have a dedicated, professional staff oriented towards understanding and serving the farm family;
2) maintain a current research-knowledge base through links with research organizations;
3) have adequate financial support;
4) have a continuous and effective service training program; and
5) have a competitive salary system with incentives for professional advancement.

Farmer Participation: Promotion of Water Users' Associations (WUA)

Participation of farmers in managing large irrigation projects has proven very beneficial in improving irrigation efficiency in many parts of the world.

In all developing countries in the Mediterranean region, the overall management of large irrigation schemes is still handled by public irrigation institutions that take control of water delivery and distribution as well as of the operation and maintenance of irrigation networks. In addition, in some Mediterranean countries, the definition of cropping patterns and the collection of irrigation charges are under the responsibility of such public institutions.

Unfortunately, the participation of the farmer and his role in agricultural irrigation management are completely ignored.

To improve management of the agricultural water demand and to better save water use in irrigation, the following actions should be implemented:

promote of water users associations (WUA) to ensure a real participation of farmers in managing irrigation schemes;

move towards transferring the services of operation and management from the public institutions to the users in order to improve the management of irrigated networks and to widen their role in the management of the overall system; and

transfer control of each individual irrigation scheme to local WUAS, including the responsibilities for providing of agricultural inputs, and marketing as well as authority to borrow funds and finance various operations within the irrigated scheme.

FOOD SECURITY PERSPECTIVES

Before discussing this issue we still need to have a precise answer to the question: *how much water do we need for agriculture to achieve food security in the region and to stipulate national self-sufficiency goals for essential crops, particularly the cereal ones*? As a matter of fact, over the last 20 years there have been tremendous advances in the estimation of crop water requirements at a field scale (Allen *et al*., 1998). However, as we move up from field to regional, from regional to national and from national to global levels, the degree of uncertainty also grows. Moreover, our estimates of irrigated area, while they have recently improved (Doll, 1999) are still uncertain. In addition, although groundwater has played a major role in food production, the sustainability of this is already questioned. At present, advances in biotechnology may play a major role in increasing food productivity through having new crop varieties that could tolerate water and salt stress conditions, highly resistant to diseases as well as of lesser water consumptive use. Those are the new features that could be expected with the further progress in biotechnology, but till now, its potential remains uncertain. Also the vital role of irrigation in increasing crop productivity is well acknowledged, but the exact extent of this is debated. The debate is concentrated on our ability to increase crop productivity on primarily rain-fed areas and thereby lesser is the need for additional irrigation.

Those uncertainties illustrate the complexities and inherent problems associated with regional projections of the water to be allocated for agriculture to achieve food security in the Arab region. This is also the case on the global level where estimates of the additional water requirements for food and fibre production in 2005 vary widely: 4 percent (Alcamo et al., 2000), 11 percent (Rosegrant and Ringler, 2000), 12 percent (FAO, 2000), 17 percent (IWMI, 2000) and 22 percent (Shiklomanov, 2000).

Food security: major barriers and constraints
Water management in irrigation sector

The greatest water problem in the Mediterranean which made most of the developing countries in the region still far away from achieving water security is our failure and inability to link environmental security, water security and food security (Fig.10).

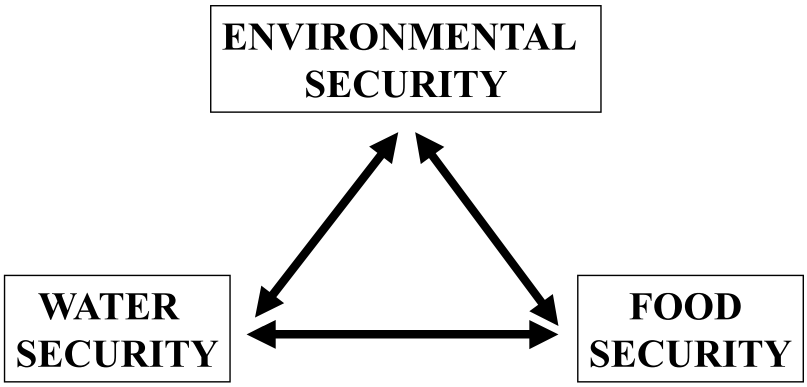


Fig. 10. Food security, water security and environmental security relationship

From a deep analysis of this triangle with its three components, we can say, conclusively that the irrigated agriculture is occupying the centre of this triangle and is directly or indirectly connected to each component included in the triangle. The reason behind this is that water allocated to the agriculture sector represents 80 up to 90% of the available water resources in the Mediterranean region.

Therefore, if we are looking for water security which provides the food security, the way to this is mainly a matter on how we are using and managing our water in the agriculture sector and how much water saving could be achieved in this sector.

The experience gained and the lesson learned emphasise clearly that the fragmented approach we are still implementing in managing water resources in the agricultural sector resulting in enormous water loss will never provide the region with both water and food security, but rather widens the gap with enormous difficulties to achieve our final goal.

A revolution is needed in the way we are managing the water resources in the irrigated agriculture through an integrated approach based on demand water management rather than the supply one.

However, achieving water security through an appropriate irrigation water management is not an easy process (Fig. 11).

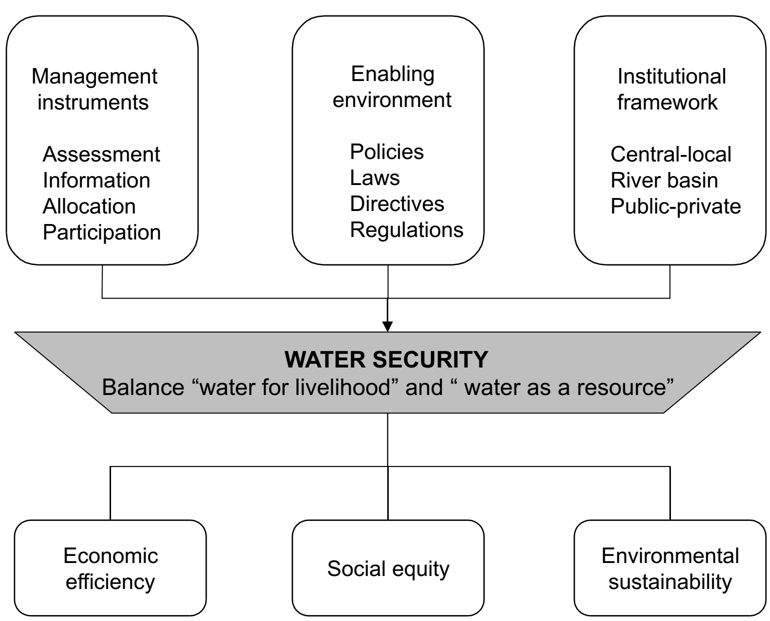


Fig. 11. Water security balance

It requires having in hand the management instruments, the establishment of the enabling environment together with an appropriate updated institutional framework.

Those are the instruments needed to properly balance economic growth, social development and environmental security that we are still unable to realise.

Policy impediments

In most of the developing Mediterranean countries, sectoral interests often dominate the policies that influence food security issues. Generally, managers in the agricultural sector are not aware of the policies in the other sectors even though both are water dependent and impact food security. Moreover, in most countries of the region, water rights to assure access and allocation policies are often lacking and even if they exist, enforcement of such policies remains a problem due to the differential application of policies by different players. In this regard, quality of the Institutions and overall governance in the agricultural sector including irrigation could play a significant role in implementing and enforcing the policy agenda already in place.

Strategy shortcomings

In most of the countries of the region, greater attention has been given to improving irrigation and agricultural water management.

In spite of such efforts, many development strategies have been impeded due to the lack of agreement on how to achieve the goal of food and environmental security. Furthermore, because of the lack of integration with the other water sectors as well as between public and private water development, we are still far away from what was planned in spite of the huge investments dedicated for the agricultural development, in general, and irrigation projects, in particular.

We are in need of changing the way of thinking and establishing the enabling environment for a better water management evidenced by the development and implementation of the concepts of integrated water management in the river basin.

Institutional challenges

Generally, there is a pervasive weakness in the majority of Mediterranean countries in performing irrigation management tasks, including mobilisation of resources for operation and maintenance. With increasing competition among the water users, the operating institutions are often inadequately equipped and have acute shortages in the human resources to meet the challenges of equitable and sustainable water allocation.

In the region, maintaining national food security or water security should be considered a public good (collective action) which means that there is no separation between security and political process, and both have to be linked together.

As a matter of fact, in the last few years significant and unprecedented institutional changes have occurred in many countries of the region. However, what has been done is not sufficient to meet the challenges of providing equitable access to food and water to all members of society in a world moving very rapidly towards globalisation.

Investments decline and financial shortages

In the developing countries of the region, it is commonly observed that there is under-funding of operation and maintenance of irrigation facilities in both public and private sectors and this is now evident because of the decline in public and international funding for infrastructure and support services. Inadequate support services, coupled with insufficient public and private sector financing, beside the decline in international investments are nowadays major constraints to achieve water and food security in the majority of the developing countries in the region.

A survey on investments in large irrigation projects (Rosegrant and Ringeter, 1999) indicate that during the 1980s, investments fell by more than 50% with respect to the ones during the 1970s and continued declining in the 1990s.

The situation now is much more complicated due to the tremendous increase in development costs for new irrigation lands. In recent years to put further lands under irrigation in the developing countries, the costs are nearly double and in some case triple of those of the years 1970s. In addition, and faced with declining cereal prices, it is harder to justify new irrigation development based on financial costs and benefits to face such difficult constraints call for an effective private-public partnership.

This is the way to alleviate the burden of the governments for the investments needed to water related infrastructure projects through partial and/or full cover by the private sector. In this regard, institutional changes in the private sector as well as the public one are urgently needed to establish the appropriate conditions under which the private sector can operate successfully.

Today, the annual cost of water services for developing countries is about US$ 70-80 billions per year, but to achieve water security about US $100 billions of additional investments per year may be required (GWP, 2000). Considering that such estimates are reflecting the actual and needed investments to achieve water security, the question is *how to fulfil the gap between both.* Immediate answer to this question lies in the way we are evaluating the water resources, policies and regulations implemented for the different water users including payment for water services and payment for water resources.

In the Mediterranean countries, this subject has received the attention of politicians, decision-makers and the users due to its vitality as a fundamental approach smoothing and facilitating the uneasy way towards water and food security. However, in spite of the ample studies, numerous approaches and hypotheses for implementation, yet, up till now we did not success in having an appropriate solid policy that could be implemented satisfactorily in most of Arab countries. The difficulty we are facing lies in the fact that "payment for water resources" is a concept culturally, politically and practically difficult to implement in many of the Moslem Arab Countries. However, efforts should continue to establish, on the national level, the appropriate approach for evaluating the water, the cost recovery mechanism to be implemented that, on one hand, favours the poor and, on the other one, copes with the prevailing socio-economic conditions.

FOOD SECURITY AND MEANS TO ACHIEVE

Under the acute water scarcity in the arid and semi-arid countries of the region, the subject under debate is food security visibility to be achieved in the region in spite of the shortage in the available natural resources (land and water) characterising the region and the increasingly constraints surrounding its realisation. The opinions are contradictory, some are insisting that food security is questionable and doughty-less, whereas others are oppositely arguing that using appropriately and correctly the knowledge, tools and experiences in the region, it is possible to achieve food security in the Arab region.

We add our voice to the latter optimistic group, but to be realistic, we must have fully in hand the approaches and the alternatives, the actions needed and, above all, we should know how to proceed and implement both approaches and actions on the ground.

For achieving food security in the developing countries of the region we are proposing the following:

- *Efficient water saving programmes*

Unfortunately, among the different water users sectors, the agricultural one is the highest in its water losses. On-farm irrigation efficiency is around 30 to 40% with more than 50% losses. We have the knowledge and tools to increase the irrigation efficiency, reduce losses and save more water in the agricultural sector. Each drop of saved water could be used for irrigating new lands and having more food production. However, we have to learn the lessons that putting much stress on only technical aspects for water saving will not yield the results desired, it should be coupled with economic initiatives to reduce the increasing water demand and to use water more wisely in the agricultural sector.

- *Improving crop productivity*

Yield expressed in terms of production per unit of land has been the traditional measure of productivity in agriculture, but as water is becoming a scarce resource, production per unit of water has emerged as an important concept. The United Nations Secretary General, Mr. Kofi Annan, reflected this in his statement to the Millennium Conference in October 2000: *"We need a blue revolution in agriculture that focuses on increasing productivity per unit of water - more crop per drop".*

By improving the productivity of water in rain-fed and irrigated agriculture, we can have more production in food with less needs to expand irrigated area. There are several means to increase the productivity of water: higher yields using the same amount of water through improved varieties, improved soil and fertility management practices, practices that save water through reduction in non-productive evaporation or flows to sinks in excess of environmental requirements, and reallocation of water from lower to higher value uses. In a broad sense, increasing water productivity in agriculture contributed not only to the overall food security equation but also to water security.

- *Rain-fed agriculture and how to improve*

Generally, rained agriculture is often ignored in the water and food security puzzle. In the Arab world, rain-fed agriculture contributes by about 60 percent to cereal production and about 70% of the total cereal area. Consequently, a one- percent increase in rain-fed cereal production would have one and half time the effect than a similar increase in irrigated cereal productivity. This illustrates clearly the influential role that the improvement in rain-fed agriculture could have on the overall food security in the region.

As a matter of fact, in the Mediterranean region rain-fed agriculture and its improvement has an important water and food security relevance for the following reasons:

- most of the food for people in rural areas is dependent on rain-fed agriculture;
- most of existing rain-fed lands have low productivity and if more could be produced, we could, on one hand, reduce the increasing water demand for agriculture and thus increase food production substantially reducing the food gap to achieve food security and a competitor for scarce land and water resources;
- practically, several tools that could be implemented to improve cereal production under rain-fed agriculture include:
  - ° the development of drought resistance crop varieties, alternate tillage practices to conserve water and low cost technologies or simple water harvesting structures to provide access to water at the critical growth stages of the growing crops.
  - ° another technical approach which gave very promising results in cereal production under rain-fed agriculture, increasing production up to 30%, is through supplementary irrigation with freshwater and even with low quality and saline or treated waste water at the critical growth stages of cereals and, particularly at the flowering and seed filling stages (Al Arawi, 2002).

The re-use and recycling of wastewater

For most of arid and semi-arid Mediterranean countries, re-use of wastewater may contribute more towards future water availability than any other technological means of increasing water supplies.

In the region it is now well recognised that the amount of collected and treated wastewater is expected to increase substantially with population growth, rapid urbanisation and improvement of sanitation service coverage. Although the quantity of wastewater available for re-use accounts for a small fraction of total water requirements, it represents an attractive option for water scarce countries, since it is a renewable and valuable source of water. In spite of that, unfortunately, in the majority of the countries in the region, a relatively small portion of wastewater is treated and used. To get full use of this additional water resource, it implies that these countries should have national policies and strategies relating to wastewater management, in general, and wastewater re-use for agriculture to substitute the fresh one.

At present, due to the severe water scarcity most of the countries in the region are facing, governments have included wastewater re-use and, particularly, the sewage one, in their water resources planning. Policies have been formulated, but few have had the capacity to implement them in terms of action to deal with water pollution control and waste disposal.

To overcome the present water crisis that will also severely affect the welfare of new generations and to achieve water and food security in the Arab world, the option we have and that should be followed is only through the use, the re-use and the recycling of each drop of wastewater.

Supporting tools

Beside the previously discussed technical and practical approaches leading towards the achievement of water and food security, it is equally important to couple those approaches with the promotion of the following policy imperatives:

- to increase public participation in the management of irrigation systems and decision-making about water and resources;

- to establish mechanisms for effective cost recovery to pay for water services;
- to establish actually acceptable water rights and allocation mechanisms;
- to establish means of accountability between service providers and users;
- to promote local management of irrigation systems with a strong emphasis on farmer participation, the establishment of Water User Associations (WUAs) and acceleration of Irrigation Management Transfer (IMT) programmes.

CONCLUDING REMARKS AND RECOMMENDATIONS

In the Mediterranean region, amongst global natural resources, water is the most critical. The complex dimensions of the freshwater in the Arab world, its fragility, its scarcity and its prediction for the next century had been highlighted and received considerable attention as a primary priority issue politically, technically and scientifically.

Managing water scarcities with inherent uncertainties in resources, involves new visions for innovative technologies, institutional reforms and reallocation policies; including valuation of water, enforcement of national and regional laws and other policy interventions that appear likely to result in structural changes or adjustments in the economy.

Agriculture and water management adjustment programmes may have to be developed to assure positive effects on investments, farmers income and water resources development; equally agricultural policies have to be changed that stress high water use crops (cotton, bananas, alfalfa, etc.) based on extensive irrigation using subsidized cheap water. Also policies that effect indirect subsidies to well drilling, pumps, engines and energy will have to be changed.

The new strategies would emphasize high water production efficiencies through water conservation technologies, intensive irrigation of high value crops, expanded supplemental irrigation in rain-fed farming zones, reuse and recycling of wastewater and improved irrigation methodology. Such adjustments have major social and economic implications; they would be expected to impact employment, income, prices of agricultural products, consumers eating habits and other outputs that have never been considered.

Several programmes and projects had been realized and others are on the way to solve the water problems and to satisfy the water needs. Some progress is now felt, however, population growth, lack of proper management mechanisms and weakness in public awareness, all call for an efficient and tide cooperation on the national, regional and international levels, to avoid water crisis already started looming in the region.

The ultimate challenge for all water professionals, decision makers and politicians is to put into practice what we all very well know. It is essential that we translate the ideas, conclusions, recommendations to action on the ground. This is the only way of reducing the loads of the present, pushing back the dates of disruption and preparing the resources of the future.

Towards water and food security in the Mediterranean region and in view of the frame of the actions needed, those actions should be translated into programmes dealing with the following major issues:

- *Integrated water resources management: demand water management*, particularly in the agriculture sector as nearly more than 80% of the water resources is allocated to irrigation with relatively high losses exceeding the 50% and, in the meantime, with very high potentiality in water saving to satisfy the increasing demand in other water sectorial uses.
- *Water productivity improvement*: *high crop per drop*. This programme should be based on using new technologies to achieve higher water production efficiencies through water conservation technologies, intensive irrigation of high value crops, expanded supplemental irrigation in rain-fed farming zones, and improved irrigation methodology. Such adjustments have major social and economic implications; they would be expected to impact employment, income, prices of agricultural products, consumers eating habits and other outputs that have never been considered.
- *Re-use and recycling of wastewater in the agriculture sector.* This is the most reasonable approach, to increase the water supply by saving a part of the freshwater already allocated to agriculture; expanding the irrigated area and reducing food gap in the region and overall to sustain the environment without degradation.
- *Capacity Building.* Such programmes or any others should be packed with capacity building development programmes to improve the institutions functions and the human resources, the real wear for water resources development and management in the region.

In this regard, it is suggested a plan of action having two levels of initiatives:
at the country level, and
at the international level.

The First Initiatives at the country level. They may include:
1. *Efficient use of scarce water and monitoring and reduction in pollution through:*
irrigation efficiency
demand management
sustainable groundwater use
improving water quality
use of high technology in irrigation application

2. *Alternative sources of water supplementation Initiatives may include:*
evaluation and identification of supplementation of existing supply with alternate resources (the non-conventional water resources)

3. *Integrating water resources management through:*
promotion of conservation and improvement in sectoral allotments
investigation of resource utilization and water audits
institutional support
preparation of a national water conservation strategy including water law and water valuation and cost recovery mechanisms
preparation of plans for decentralization and turnover

4. *Mobilizing country effort by:*
Public awareness campaigns
Local participation
Involvement of water user associations
Promoting NGO forums for a two-way communication between the government and the community
Establishing the appropriate conditions under which the private sector can cooperate successfully

The Second: Initiatives at regional and international levels these may include:
capacity building through international cooperation
transfer of latest technology in the water sector
liaison with donors
organization of workshops for international experience sharing
cooperation with other water-related organizations like Global Water partnership and the World Water Council
development of data and institutional research network through IPTRID, IWMI, CIHEAM and other research institutions.

This outline plan only proposes key areas. It is unlikely that a “blue print” approach can devise a strategy for water conservation under varied conditions since country requirements are different and each country should set its own target. This requires a concerted and sustained effort with set objectives and clearly definable targets.

However, the successful implementation of such proposed programmes to attain major benefits from higher efficiency in irrigation sector, the efforts should be directed towards:
Development of human resources
Improvement of institutional capacities
Establishment of an efficient technical assistance capable to implement the new techniques required as well as working friendly with the users (farmers), and
Gathering the scattered information in the region and creating tide links of cooperation not only among the scientific institutions but also between researchers and scientists in the region. Networking and establishment of national and regional networks in the appropriate approach to be followed.

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REGIONAL ACTION PROGRAMME (RAP): NETWORKING ACTIVITIES 1998-2000

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INTRODUCTION

In the Mediterranean Countries, particularly in the arid and semi-arid ones, we all recognize two opposing realities.

On one side, we know that for all practical purposes fresh water resources are finite and that most of the economically viable development of these resources has already been implemented. Thus, the potentiality to expand this resource base is marginal, in addition, water quality degradation resulting from pollution is shrinking the usable volume of fresh water.

On the other side, we are confronted with increasing population, fast urbanization and the associated expansion of economic activities, all of which require more water, putting strain on the already limited and fragile resources.

Traditionally, the response to water shortage in the Mediterranean region has been addressed trough developing more supplies. But today such approach is becoming extremely difficult. In this water crisis context, it is needed to shift from water policies based totally on water supply to new policies which rather privilege water demand.

There is no question on the central importance of demand management particularly in the agricultural sector.

Water saving in the region to satisfy increasing demand of the other user sectors and the future expansion in irrigated areas to fulfil the food gap in the region must come from agriculture knowing that more than 80% of the available water is allocated to irrigation and the water efficiently used by crops amount to 45% with losses as high as more than 50%!

In the region we need to elaborate the concept of demand management into implementation policies, programmes and actions in particular with irrigation as the main consumer, with major water losses, thus huge water saving could be realized.

This is the fundamental scope of EU/CIHEAM-MAI.B RAP Programme (1998-2002) which is mainly oriented to the sustainable use of water resources in irrigation sectors emphasizing the following major issues:

Non conventional water resources practices and management for sustainable use;

Water use efficiency;

Design, management and optimization through performance analysis of collective irrigation systems;

Participatory Irrigation Management (PIM);

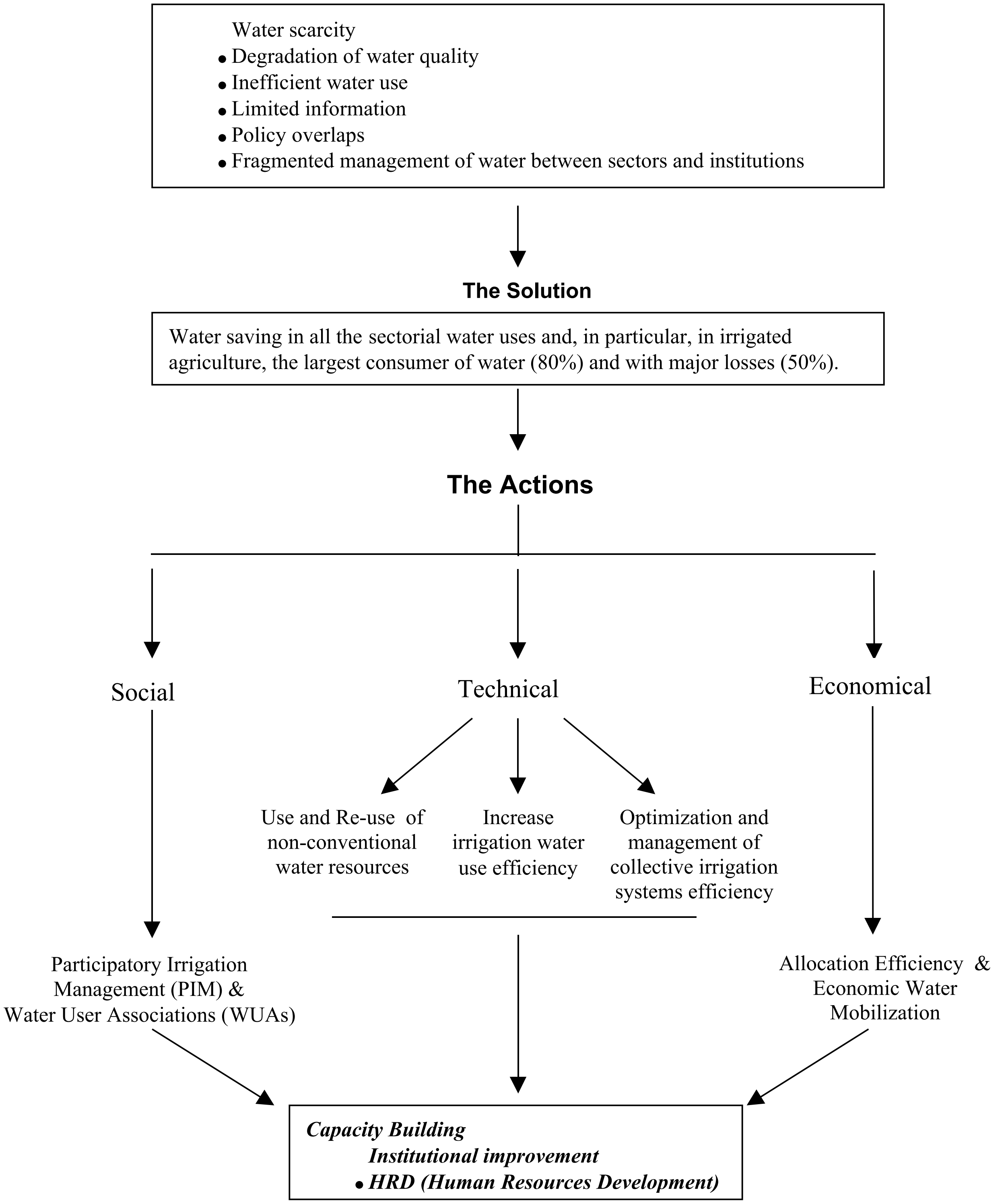
Economic aspects of water mobilization and use.

The programme objectives are to improve the institutional capacities, the development of human resources strengthening regional cooperation, the technology transfer and exchange of experiences between the Southern and Northern part of the Mediterranean through training, promotion of research, networks and communication of scientific and technical information in the field of water resources and irrigation based on the concept of "centers without walls".

Programme EU/CIHEAM-MAI.B
RAP (1998-2002)

Programme: "*Water Resources Management*" - Formulation Synthesis

Water Resources in Arid and Semi-Arid Regions:
Major Problems and Constraints



COOPERATIVE RESEARCH ACTIVITIES

SUB-PROGRAMME "NONCONVENTIONAL WATER RESOURCES MANAGEMENT"

SUB-PROGRAMME "WATER USE EFFICIENCY"

SUB-PROGRAMME "COLLECTIVE IRRIGATION SYSTEMS"

SUB-PROGRAMME

"Non-Conventional Water Resources Practices and Management for Sustainable Use"

INTRODUCTION

In the developing countries of the Mediterranean, the major challenge facing water planners and managers is that while physical availability of water is fixed, its demand will continue to increase steadily in the foreseeable future.

The limited water resources in these countries, on one hand, and the population growth with relatively high rate, on the other hand, will be the major constraint for further agricultural and socio-economic development water demand are fast approaching the limit of resources which will impose their significant effect on water sectorial use, creating notable competition and conflicts among users in the various sectors and on the irrigation and domestic sectors, in particular.

The problems aside from massive population growth rate, continuing urbanization and rapid development of the urban and water domestic supplies, water supply shortage and wastewater disposal regulations aimed at protecting environment and public health, all are pushing towards a realistic re-use of the enormous quantities of the non-conventional water resources which have not been effectively used so far.

Therefore, the use of other water resources than freshwater is now a must.

The use of such non-conventional water resources will certainly result in greater amounts of water for irrigation but of lower quality. In the long run this could seriously affect crop production, deteriorate the soil productivity as well as creating serious environmental problems.

In the situation of limited supply of good quality water, efforts should be directed towards reducing its demand, particularly in the irrigation where more than 80% of the freshwater is allocated to this sector, and as a solution, more marginal quality water should be used for irrigation substituting the good quality one. The implementation and practicability of such solution, we have to provide the decision-maker and the users a concrete and very clear answer on how agriculture can make use of non-conventional water resources in a way that is technically sound, economically viable and environmentally non-degrading. Those are the major issues our NWRM Sub-Network is focussing on.

GENERAL OBJECTIVES

Increase the potentiality and sustainability use of non-conventional, water resources in irrigation, particularly the saline and the sewage treated effluents.

Improvement of the institutional capacities and the development of human resources for the programme implementation in the region.

SPECIFIC OBJECTIVES

The establishment of new strategies for the use of non-conventional water resources (saline and treated sewage effluents) technically and scientifically based on a proper integrated approach for soil, crop and water management.

Setting the new guidelines and criteria for the re-use of the non-conventional water resources that promotes and facilitates their use on a large scale without environmental and health hazard effects.

Setting the crop salinity tolerance index for major crops in the region to attain flexibility choices of crop rotation with relatively higher economic returns.

Development of a documentation and information exchange systems through the development of data-base on the use of non-conventional water resources.

COORDINATOR

Prof. Atef Hamdy, Director of Research, CIHEAM/MAI-Bari (Italy)

PARTNERS

Algeria

Prof. A. Macklouf (Ministry of Agriculture, Alger)

Cyprus

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Egypt

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Prof. N. Ben Mechlia (INAT, Tunis)
Mrs. Akissa Bahri (Centre Recherches du Génie Rural, Tunis)

Turkey

Prof. A. Yazar (Cukurova University, Adana)
Prof. O. Tekinel (Karahmanmaras University)

Cooperative Research Activities

Under the NWRM Sub-Network the following research programmes are coordinated by the Institute and carried out in cooperation with other scientific Mediterranean Institutions members in the Sub-Network with the participation of researchers from the Mediterranean region.

ACTIVITIES 1st PHASE, 1998-2000

During this period the major research activities of the NWRM-Net can be summarised as follows:

A Saline irrigation practices and management

This programme is focussing on testing different approaches for saline water management including:
- Irrigation methods
- Irrigation scheduling (amounts and intervals)
- Leaching scheduling (amount and timing)
- Management of multi-source irrigation water of different qualities.

Several major crops in the region had been experimented (wheat, bean, tomato, sunflower, sugarbeet, potato, lentils, check-peas). The experiments were conducted in the lysimeter stations and the greenhouses in Bari Institute, and the demonstration experimental field at IAV Hassan II, Agadir. This experimental field is well equipped (tanks, pumps, monitoring equipment, etc.) and a drip irrigation system including all the accessories needed for water application control. A great part of the field equipments were provided through the logistic support.

Several members from the Sub-Network working group, professionals and experts from different Mediterranean Institutions and Universities, and several candidates from various Mediterranean countries under the M.Sc programme participated in realizing this programme.

The experimental work was mainly dictated to elucidate the following:
- plant response to salt concentration level in irrigation water to propose the one to be safely used to set the proper crop rotation;

- identifying the most critical growth stages to salinity and the management practices should be followed;
- Climatic and soil pedological conditions and their impose on the sustainability of variable crops to salinity in relation to the management practices to be adapted.
- Irrigation practices and the mode of water application where water of different qualities are available.

The main conclusions achieved under this research programme could be outlined in:

- plant response to salinity differ greatly from one crop to other and this holds true by changing varieties for the same crop.
- Crop response to salinity and its tolerance degree is mainly dependent on the degree of salt accumulation in the soil, which is highly related to soil characteristics, the prevailing climatic conditions and the irrigation systems.
- For the majority of tested crop salinity up to 3 dS/m could be used safely without significant losses in the yield.
- The salt concentration level the (Ec_i) to be used should be chosen considering not only the salt tolerance degree, but of equally importance the soil characteristics, the climatic conditions, the irrigation method and the irrigation scheduling (volumes and intervals).
- For all tested crops, generally the germination, seedling establishment, flowering and crop formation stages are very sensitive to salinity with respect to the vegetative and crop maturity ones. As the latter stages (vegetative and maturity) are relatively of longer periods with respect to the former ones and as more than 60% of irrigation water for a certain crop is delivered within the vegetative period, this will lead to the following advantages:
  - saving the freshwater and its substitution with the saline one
  - slightly reduction in the vegetative growth, less transpiration. i.e. less consumptive use and earlier flowering and maturity
  - under saline irrigation practices leaching is the key management factor. Therefore, identifying the critical growth stages is crucial in setting a proper leaching scheduling, *i.e. when to leach and what is the leaching fraction?* This will give the opportunity of using more and more salty water in irrigation even those of salt concentration level exceeding the one the plant could tolerate and achieving a satisfactory crop production hence the proper leaching management is practiced.

B Soil-water-plant interrelationships under saline irrigation practices

The research under this programme is mainly devoted to characterize the changes in plant physiological parameters, in relation to those taking place in the soil chemical properties and their impact on the water status in the plant and the yield production.

This programme is realized in cooperation with INRA-France and Wageningen University, Holland.

In the last two years (1999-2000), the I Phase of RAP Programme the activities under this programme were extended with the participation of ICARDA to evaluate the salt tolerance degree to some of the most important legumes and cereals crops in the arid Mediterranean and Middle East regions (Broad Beans, Lentils, Chick-peas, Wheat, Barly).

In the year 1999 studies were carried on six lentil varieties. In the year 2000 the different varieties of the chick-peas crop are under studies.

The wide information and the results obtained in the previous years, the time initiated the activities in the Sub-Network and those recently achieved under the RAP-Programme are now under complete analysis to set new strategies on the use of saline water in the arid countries of the Mediterranean that provide acceptable yield production economically viable and non-environmentally degrading.

This was one of the main subjects discussed during the Annual Meeting of NWRM Sub-Network held in Rabat, Morocco on October 28, 1999.

The members of NWRM fully agreed on organizing the work for analysing all the published data as well as those still under research with respect to the variable aspects (agronomic, hydraulic, economic and the prevailing environmental conditions).

The results and experience gained during the first phase of RAP Programme are all presented in several publications already issued or under print in scientific journals (see the list of publications).

C Municipal wastewater re-use

The other major component of the non-conventional water resources is the treated sewage water.

The use of this water resource in the region is nowadays a must. The reasons are not only of being as additional source to compensate the water shortage and scarcity, but, due to the advantages it provides by its use as a source for nutrients and there by reducing the excessive use of fertilizers as well as diminishing the pollution of both surface and underground water, particularly with the NO_3 ions.

In addition and above all if such water is not treated and reused in irrigation, it could result in serious environmentally problems of dangerous health hazards.

Aware of this, in the first phase of RAP Programme a part of the activities of the Sub-Network was oriented to this subject by the aim of:

- An evaluation of the wastewater treatment methods already used in the region, technically, economically in relation to the quality of the effluent.
- Setting a guidelines for re-use according to the prevailing local conditions.
- The possibilities of introducing simple technologies (gravel hydroponic system and constructed wetlands) for effluent sewage treatment in small communities and villages.

The research programme was conducted using the facilities of the municipal wastewater treatment station O.R.M.V.A. of Sousse-Massa-Benserago situated 5 km South-West of Agadir.

The research programme was focussing on: the impact of irrigation with sewage water treated by infiltration-percolation and treated by epuvalisation comparable to irrigation with freshwater enriched with fertilizers on both the quantity and quality of several horticulture crops and some flowers and ornamental cash crops to set new strategies for the use and management of treated municipal wastewater in irrigation and its adaptation in the region.

D - Supplementary irrigation of cereal crops with treated sewage water

Very promising data are already obtained indicating the high potentiality of using such source for irrigation as its use led to a better improvement of the crop production quantitatively and qualitatively. In addition, this water can meet the nutritional requirements and thereby reducing the production costs. Moreover, the use of such water irrigation providing an accurate irrigation scheduling, it is possible to avoid the risk of groundwater contamination caused by nitrates.

The results obtained in this programme are under preparation for publication.

OTHER RESEARCH PROJECTS SUPPORTING THE RAP-PROGRAMME RESEARCH ACTIVITIES

1 - EU Concerted Action Project:

“SUSTAINABLE HALOPHYTE UTILIZATION IN THE MEDITERRANEAN AND SUBTROPICAL DRY REGIONS”

The subject of the Project is of a special interest and is one of the main research activities carried out by the Institute. In addition, this subject is of vital importance for tackling the salinity problems in the Mediterranean region.

The project aims at the selection of the best species and cultivars for each region, climate as well as soil type and design for those species requiring the best irrigation system in order to minimize cost and optimize the profit gained for the general application of the new production system in each environment where it will be established.

The "Halophyte Network" was involved in this Project which was established under the co-sponsorship of the CEC as well as some research groups from relevant countries.

Countries participating:

Algeria	(I.N.R.F., Cheaga)
Brazil	(UFRPE, Recife-PE)
Egypt	(Desert Research Center, El Mataria-Cairo and Faculty of Sciences, Cairo)
Germany	(Botanical Institute, Hannove; University of Osnabruck)
Morocco	(IAV Hassan II, Agadir)
India	(Central Soil Salinity Research Institute, Karnal)
Italy	(CIHEAM/MAIBari and -Studio Sardo, Catania)
Pakistan	(University of Karachi)
Spain	(Public University of Navarra, Pamplona)
Sultanate of Oman	(Ministry of Agriculture and Fisheries)
Tunisia	(Inst. Nation. Scientif., Hamman)
U.A.E.	(Faculty of Agriculture, Al Ain)

Bari Institute is coordinating the activities with the projects in the Mediterranean region. The works started on the beginning of the year 1997.

Expectations from the CA project

Through the experimental demonstration fields realized in Morocco and in Italy-Catania and the experimental work carried by Bari Institute, major information has been possible to obtain on the sustainable use of halophytes under heavy saline conditions. In addition, the carried out research program concerning the germination and seedling establishment of different varieties and species beside the research related to the physiological parameters has increased the knowledge in different points till now not yet clear.

Our contribution will increase more and more the exchange of experience in this relevant subject and it will promote the creation of national and regional networks on the subject concerning the scarcity of available freshwater resources in arid and semiarid regions and the rapid deterioration in soil productivity due to salinity problems. Biological reclamation using Halophytes could bring such abonded soils again to its productivity.

MAI-B activity for the CA Project

Major activities were devoted to establish a well defined cooperation and coordination between Bari Institute and the Mediterranean countries participating in the Project as well as to develop a regional network for halophyte utilization under saline irrigation to be included under NWRM Network.

Workshops were organised and conducted:

- *Florence INTECOL Symposium with a Seminar on "Sustainable Halophyte Problems" (19-22 July, 1998). This Institute prepared the compilation of all CA INTECOL Seminar papers for publication in a new journal "Journal of Mediterranean Ecology";*
- an advanced short courses was organised by NWRM Sub-Network including separate sections to teach this specific subject: *the cultivation of "halophytes*" the Institute plans to include in the future saline irrigation techniques and the use of halophytes as regular parts in its scientific activities.

"*Halophytes adaptation to high salty environment* "

The programme was carried in the greenhouse of the Institute, using some of Halophyte varieties and included the following major parts:

- crop growth of different varieties irrigated with saline water of different salt
- concentrations;
- crop physiological parameters;
- salt accumulation and its distribution in the soil under successive irrigation with saline water.

Contributing in this research a specialist from Lebanon, Ms. Zeina Mezher Master Student of MAIB for Academic Year 1998/1999.

The thesis of Ms. Mezher deals with the performance of the two halophytic species Aster tripolium and Kosteletzkya virginica under saline irrigation treatments up to 50 dS/m and using different substrates. In cooperation with the University of Osnabrueck, Germany the candidate will continue her career on this subject for the Ph.D degree.

2 - EU projects:

A SYSTEM APPROACH TO WASTEWATER BIOTREATMENT FOR THE PROTECTION OF MEDITERRANEAN COASTAL AREAS ("BIOWATSYST")

Coordinator: MAI-Bari, Italy

Partners:
- Suez Canal University, Ismailia-Egypt
- CIEMAT, Spain
- NTUA, Greece
- IAV Hassan II, Rabat-Morocco and
- WERSC, University of Amman, Jordan

The principal objectives of the Project are the following:
- to monitor, prevent and remediate coastal pollution due to wastewater disposal through the use of multipurpose subsurface-flow constructed wetlands (SFW), inserting them into the productive system of rural societies and, in a more general way, into the surrounding environment;
- to gain information useful to help in the optimisation of the design and management of constructed wetlands;
- to assess the effectiveness of SFW as a low-tech, low-cost solution to domestic wastewaters treatment;
- to demonstrate the possibility of reusing treated waters for irrigation purposes and aquifer recharging;
- to conduct an economic-social-environmental analysis to evaluate the global impact of wetland construction and management.

The project is based on the construction of biodepurating systems in 5 representative places: - Egypt, Suez Canal; Spain, Madrid; Morocco, Rabat; Jordan, Amman; Greece, Athens.

Phytodepuration efficiency will be evaluated comparing physical, chemical and microbiological characters of inflowing and treated waters.

The results of system monitoring in the technical, economic and environmental aspects will be analysed to issue recommendations and guidelines and a decision support tool will be released.

The main expected outcome is a set of information and recommendations addressing operators and decision-makers, explaining and demonstrating how to take advantage of domestic wastewaters instead of polluting watercourses and seacoasts.

Further outcomes are methods for optimising the design and management of constructed wetlands.

Aspects of interest are also: the biomass production and use as an organic compost or to generate biopower; the observation of effects of treated wastewaters used for irrigation purposes and aquifer recharging; the demonstration action addressing extensionists and operators at large.

MAI-Bari Research Activities

This project provided the opportunities of many researchers to visit the depuration stations constructed in both the Southern and Northern countries involved in the programme. Exchange of experience among the researchers in this field led to optimum results in facilitating the research working programme.

Training candidates from the Mediterranean countries: in the depuration station constructed in Catania in cooperation with Bari Institute, three candidates (from Palestine, Turkey and Yemen) were fully involved in all operation steps regarding the construction of the system. The three candidates carried out their Master thesis on the spot and the research programe included the following:
- “an evolution of the system and its validity in treating the municipal wastewater to the international standards”;
- response of some horticulture crops to treated municipal water in comparison with freshwater enriched with nutrients on both quantity and quality of the production;
- permanent irrigation with treated sewage water and its impact on the physical and chemical characteristics of different soil types (clays calcareous, sandy) as well as evaluation of the pollution risks on the groundwater.

3 - Research project:

"CEREALS AND LEGUMINEOUS SALT TOLERANCE DEGREE"

The aim of the project is evaluating the salt tolerance degree of some important legumineous and cereals crops in the arid regions of the Mediterranean and Middle East.

The programme will include the crops (Broad beans, lentils, check-peas, barley, wheat).

The programme is coordinated by Bari Institute and realized in cooperation with ICARDA, Syria, INRA, France, Wageningen University, Holland.

The programme will last for 5 years. The activities started in the year 1998-1999 on six varieties of lentils already produced through the genetic-breeding techniques and evaluated according to their resistance to water stress and drought conditions. Three candidates (2 from Tunisia and 1 from Egypt) were involved in the lentils studies and obtained their M.Sc.

Three scientific papers were prepared including the scientific findings, one had been accepted in "water management journal" and is under press, and the other two papers were accepted as oral papers to be presented in Antalya, Turkey on the occasion of the International Symposium on "Techniques to Control Salinization for Horticulture Productivity", (November 7-10, 2000) which is sponsored by CIHEAM/MAI-Bari.

In the year 2000, the programme is continued and studies are carried on six varieties of check-peas with the involvement of three candidates from the Mediterranean (Egypt, Lebanon and Tunisia).

RAP PROGRAMME ACTIVITIES AND ITS IMPACT ON LOCAL, REGIONAL AND GLOBAL LEVEL

The elevated number of scientific publications, the special publications (proceedings of international seminars, workshops, round tables, short courses) and the participation on international, regional and national scientific events all led to wide dissemination of the running and developed activities carried under the Sub-Network "Non-Conventional Water Resources Management (NWRM).

Such efforts resulted in recognizing the important role CIHEAM/Bari Institute is playing in the field of non-conventional water resources in the Mediterranean and to use its experience to be applied in other arid regions around the world. This has an impact at different levels.

ON THE LOCAL LEVEL:

- **in Egypt,** the total drainage water is around 16 milliard m^3/annually. The amount already used in Agriculture till the year 1996 did not exceed 4 milliard m^3 due to the uncertainty and non-availability of the re-use strategy for both decision makers and the responsible Institutions. The tight cooperation in this field between Bari Institute and NWRC/Ministry of Water Resources and Irrigation, Egypt in setting the strategies on the re-use of drainage water resulted in increasing the re-use of drainage water in irrigation to nearly six milliard m^3/year already used for irrigation. The re-use program is advancing and it is expected with the year 2005 the drainage water will be totally recycled and re-used for irrigation. This will lead to freshwater saving around 10 milliard m^3, those will be diverted to the irrigation of around 1 million acres in the Tuska project.
- **Tunisia**, is among the countries facing a great gap in its food production and, in particular, cereals, due to severe water scarcity. The experiences of Bari Institute on the use of non-conventional water resources as supplemental irrigation to increase the cereals production under rainfed agriculture and drought conditions were applied on Tunisian realities. This programme has been realized in tight cooperation with Tunisia experts under both controlled and open field conditions. The scientific findings implemented under rainfed agriculture resulted in a notable increase of cereals yield production and, particularly, the wheat. Through such approach annual wheat production was increased by nearly 80%. Nowadays, the use of non-conventional water resources as supplemental irrigation represents an important national programme to compete drought condition and overcome the food gab in the country.
- **Morocco,** nowadays is facing severe drought conditions. Leading to nearly 80% losses in the cereals production, particularly wheat which is resulting in serious socio-economic problems. To compete the

drought, the Moroccan authorities and decision makers are now setting a national plan based on the use of non-conventional water resources as supplementary irrigation to increase the cereals production under rainfed agriculture and to face the prevailing drought conditions. In cooperation with Bari Institute, discussions are taking place to organise an international conference on “supplementary irrigation under rainfed agriculture and drought conditions: the role of non-conventional water resources. This will be a follow-up of the international conference held in Bari Institute, 1992 to be acquainted with the progress achieved in this field and to exchange the experiences between the scientists in the Mediterranean region and others all over the world.

ON THE REGIONAL LEVEL

Bari Institute is a member of the “Technical Advisory Committee” of the Mediterranean (MEDTAC) which is in direct contact with the “Global Water Partnership-TAC (GWP-TAC).

The MEDTAC was involved in preparing the Water Vision of the Mediterranean. The work published by Bari Institute concerning the water resources development and management in the Mediterranean was taken as bases for the Water Vision presented in the 2nd World Water Forum, The Hague-Holland (November 17-22, 2000).

The part of the Vision - concerning the non-conventional water resource and how it can be integrally managed with freshwater - was prepared in tide cooperation with Bari Institute.

In the last meeting of MEDTAC with the participation of GWP/TAC (Athens, May 2000), Bari Institute was asked to prepare a working paper on the Action Plan needed for water resources development and management in the region to be discussed in Athens in November 2000 to set the water projects and programs for the region.

- Euro-Mediterranean Cooperation

The Institute was invited, as observer- in the Ministerial Conference on Water Resources of the Mediterranean to discuss policies and programmes to be implemented in the region.

The subject wastewater re-use and recycling achieved a primary priority. The presentation of Bari Institute in this field was essential, and, the sequence, European Commission has asked a representative of Bari Institute to attend the meeting on the 7th of June 2000 to discuss on the proposals to draw up a regional cooperation programme based on the Action Plan endorsed at Turin Conference.

- Bari Institute is coordinating the following two EU-Projects:

1. “SUSTAINABLE HALOPHYTE UTILIZATION IN THE MEDITERRANEAN AND SUBTROPICAL DRY REGIONS”;
2. “A SYSTEM APPROACH TO WASTEWATER BIOTREATMENT FOR THE PROTECTION OF MEDITERRANEAN COASTAL AREAS (BIOWATSYST)”;

both are highly related to the RAP Programme activities on Non-conventional water resources.

Such programmes are realized by both Northern and Southern Mediterranean Institutions.

ON THE INTERNATIONAL LEVEL

The World Water Council decided to have its Regional Office for the Mediterranean region at Bari Institute. This ultimately confirms the important role Bari Institute is playing in the water resources development and management in the Mediterranean.

In the 2nd World Water Forum held in the Hague, Holland (March 17-22, 2000) with the participation of nearly 4500 scientists all over the world, the organizing and scientific committee of the World Water Council (WWC) asked Bari Institute to organize a special session on “Non-conventional water resources practices and management in arid regions” representing the activities of the NWRM Sub-Network including the research programme, scientific findings and proposed strategies for the re-use and recycling could be implemented.

The special session was held on 19 March, 2000 where NWRM activities were presented in details by the members of the sub-network. Attended the special session more than 300 scientists from several international and national institutions working in this field. In this event more than 1000 copies of special session proceedings was distributed.

The event in itself was a real success in bringing the activities of the NWRM from the regional level to the global one, in increasing the area of the dissemination of the information through distributing more than one thousand copies of the proceedings, the elevated number of scientists attending the session, the fruitful discussions backed with each presentation and the great interest showed by many scientists to be updated with the further progress in Sub-Network activities.

SUB-PROGRAMME

"Water Use Efficiency"

INTRODUCTION

The Regional Action Plan (RAP) on *Water Resource Management* was developed on three major considerations:

Water scarcity is one of the major limiting factors of agricultural, economic and social development in the arid and semi-arid regions of the Mediterranean

An increasing number of developing Countries of the Mediterranean are approaching full utilization of their available water resources

The quantity of fresh water resources available to agriculture is diminishing while lower quality water is increasing

The agricultural sector is the principal consumer of water resources in the Mediterranean Region (about 80%), half of which is lost due to inefficiencies throughout the whole traveling path, going from its source (reservoir or rainfall) to the root-zone of the cropped field. Furthermore, the trade of the water transpired by the crop in exchange for the carbon assimilated can be made more efficient if eco-physiological analysis are introduced along with the hydrological ones of water transport and field application. An overview of the whole water use efficiency framework is shown in Fig. 1.

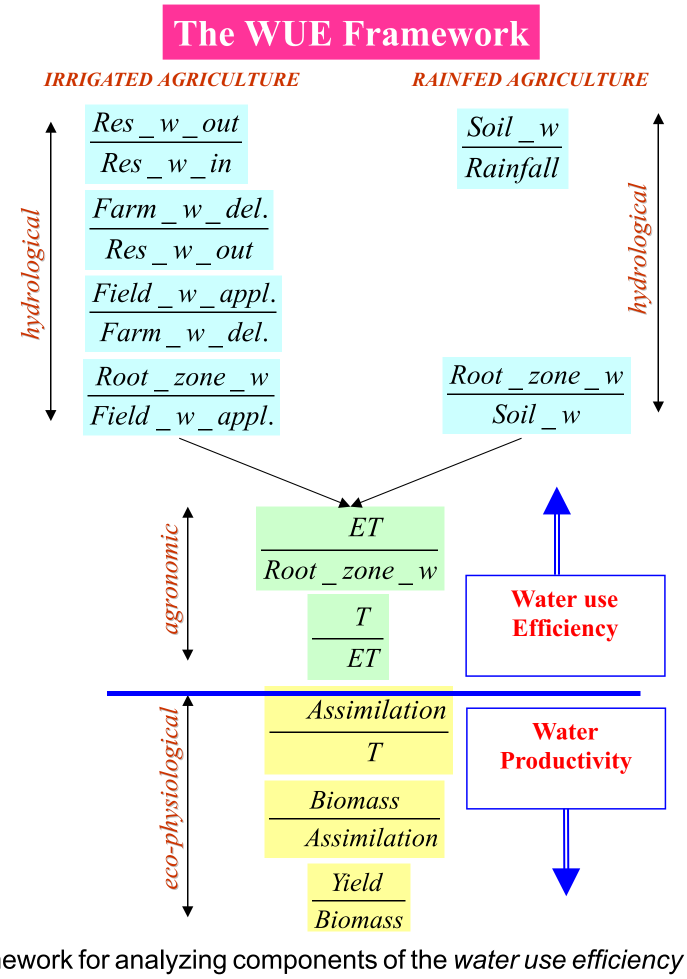

Fig. 1. Suggested framework for analyzing components of the *water use efficiency* and *water productivity* in agricultural crop production. The overall path "traveled" by water is split into different segments where appropriate analysis can be implemented.

Appropriate treatments of the whole water use efficiency domain (including the water productivity of crops) require large amount of information about different aspects of the crop-environment system and the human capacity to organize and elaborate the available data and interpret properly the results in order to support effectively decision-making processes.

Expansion of the new information technologies such as geographic information systems (GIS), terrain analysis tools, remote sensing and modeling techniques along with the networked PC and powerful workstations has offered improved strategies and tools to enhance the ability to extract quickly and efficiently insight knowledge from the information stored. However, the rapid evolution of the technological component of the system has not still been followed by the adequate development of the human resources having corresponding background and being able to use efficiently the new information tools.

Consequently, this sub-program on *Water Use Efficiency* aims to surmount the gap still existing between the two major components of the information system: Information Technology & Human Resources; where the first is an invaluable instrument to reinforce (support) the capacity of the second, and where the second is the ideological spearhead able to manage and speculate the information derived from the first.

The present sub-program has the following objectives:

GENERAL OBJECTIVES

Improvement of the water use efficiency in the Mediterranean Region in both rainfed and irrigated agriculture, i.e. to reduce the quantity of water used in agriculture while maintaining or increasing the crop production and saving environmental balance

SPECIFIC OBJECTIVES

Cooperative Research setting up the Information Technology System able to measure the impact of various scenarios regarding to the cropping pattern, management activities and agricultural policies in terms of crop water requirements, expected (projected) crop production and environmental hazards. Specific actions are needed to:

a) produce an Information Manual, containing all the variables and parameters necessary for the complete characterization of agricultural crops of interest in the Mediterranean Region;
b) build a crop productivity model which uses the databases developed in the Information Manual;
c) create a User Interface providing the link between the model and the alfa-numerical database of Geographic Information System for spatial analysis of information

Training of the qualified personnel able to efficiently use and manage such tool and to collect, develop, elaborate and interpret the information stored and derived by the system.

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COOPERATIVE RESEARCH ACTIVITIES

The cooperative research activities were carried out in order to satisfy the following requirements.

1. Crop Information Manual.

Crop data and parameters were collected and organized from different field experiments in the Mediterranean to build a special database (the Crop Information Manual). The major field crops to be included in the Manual are: wheat, barley, chickpea, sorghum, corn, cotton, sunflower, sugarbeet and tomato. Additional field crops will be included as reliable sources of information will be available. The structure of the Manual for the field crops is functional to the crop productivity model to be implemented for the WUE investigation of the different cropping pattern scenarios. A different structure was followed for the tree-crop Manual since these cannot be modeled mechanistically in the same way the field crops are. Two major tree crops are included: Olive and Pistachio. Possibility of extension to other tree crops might be considered (e.g., figs, palm date) depending on the resource availability.

The Crop Information Manual is under preparation and is not yet completed.

A first initiative has been taken for Pistachio, implementing an experimental work on the orchards of the Gaziantep Pistachio Research Institute (GAP Region of Turkey) to investigate on the water relation and water response of this particular species. The relevance of this subject has drawn the attention of different institutions (GAP administration, Ministry of Agriculture, ªanliurfa, Çukurova and Karamanmaras Universities).

A second specific initiative has been taken for the advective problem of dry areas which strongly affect the crop water requirement estimates. An experimental work has been carried out in Egypt, using local high precision lysimeters, for the investigation of the evapotranspiration modification induced by Regional Advection.

Master and Ph.D. students have been involved, along with junior scientists, to run the previous activities.

2. Crop Productivity Model

A WUE objective oriented crop model is being implemented to evaluate the productivity of water, water consumption and efficiency of different cropping systems. The model is based on mechanistic relations of the growth and productivity processes, in agreement with the latest knowledge on the subject. Furthermore, it relies on algorithmic formulations derived in part from the most known software present in the literature and adapted to the specific need of the WUE sub-program. The peculiarities of this model are clarity, simplicity, flexibility, transparency and reliability.

This model has already acquired a certain impact on the research community. It was required, in fact, for the estimation of the “potential productivity” of the Apulia Region (Southern Italy). Moreover, economists find it easier to handle than other specialized software. This model, in fact, will be used in some of the projects carried out by the Mediterranean Agronomic Institute of Montpellier (IAMM). In addition, it will be used during the academic year 2000/2001 for a *Professional Master* in “Water Management” where technical and economical aspects are considered jointly. The two institutions involved in this professional Master are IAM-Bari and IAM-Montpellier. This action is in line with the suggestions of the “Technical Working Group” aiming to more integration between the RAP-IAMB and the RAP-IAMM. A certain degree of integration of the RAP activities is being attempted also between IAM-Bari and IAM-Zaragoza since the crop model is suitable also for rainfed agriculture.

The horizontal crossover of the RAP actions is also established between sub-programs. In fact, the crop model of the WUE sub-program is going to be used by at least one of the other two sub-programs (UWRM and CIS).

The demand of Masters and Ph.D. students is increasing toward the application of the Information Technology for water use, economics and scenarios evaluation.

3. Link between Model & GIS

A specific version of the crop productivity model has been implemented to address the link with geographical Information Systems (GIS). In this way, a Region of the Mediterranean can be mapped on GIS according to its peculiar characteristics of climate and soil. On the GIS, different cropping pattern scenarios can be simulated and the crop productivity model runs automatically throughout the Region to estimate the productivity and the corresponding water use for subsequent comparisons.

The advantage of having the link between model and GIS lies on the ability to evaluate the scenarios in a very straightforward, simple and fast way, using existing GIS tools already available in the different institutions.

To apply the model and the GIS-Link to local Regions of the Mediterranean, some pilot areas have been chosen and are being prepared for scenario simulation. The ones in progress of implementations are: the Cap Bon area of North-East Tunisia; the GAP Region of Southern-East Turkey; the Province of Foggia in the Apulia Region of Italy (also used as pilot area in the CIS sub-program). Additional areas will be implemented depending on the resources availability.

4. 2^nd Phase Program (2000-2002)

During the next two year, the WUE sub-program will conclude all these tasks by continuing to work on the completion of the *Crop Information Manual*, the *Crop Productivity Model* and the *Link* between *Model and GIS*. All documents related to these three products will be made available according to the original program. Output samples of scenario simulations will be reported as well.

For the GIS component, a particular attention will be paid to land evaluation and capability criteria, making use of Remote Sensing approaches for tree crops applications.

During the second phase of the RAP Program, it is expected that the partners of the WUE sub-program could apply for a coordinated cooperative research to be carried out on their own country to further exploit the necessary information for an extended WUE investigation.

TRAINING

To establish a common background on the various aspect of water use efficiency (WUE), an advanced short course on "*Water Use Efficiency of Crops*" was organized in Settat (Morocco) between 6 and 19 September, 1999, in cooperation with the Aridoculture Center CRRAINRA of Settat.

A second advanced short course (*"Water Saving in Irrigated Agriculture"*), focusing mainly on the hydrological aspects of water use efficiency, was held in Cairo (Egypt) 2-16 April 2000, as an integration of the two sub-programs NWRM & WUE.

The WUE course of Settat was the natural evolution of a series of advanced short courses and/or workshops, organized in a previous EU/CIHEAM program, to set the basics for understanding the processes involved in the soil-plant-atmosphere continuum and consequently in WUE.

The impact of this course reflected at the national level of Morocco, since most of the Moroccan participants were involved in the "National Water Use Efficiency Laboratory" (established after the WUE Network was present in the country from a few years). Furthermore, ICARDA wanted to organize another WUE course for the Near-East countries, following the framework developed by the course in Settat. After the course, FAO asked to write a report on the opportunities offered by the Biotechnology to improve Water Productivity in Agriculture.

A monograph on the various aspects of WUE is expected to be published in the future as a reference book on this subject.

Most of the work carried out by the partners of the cooperative research network linked to the WUE sub-program have been published, while others are in progress for being published.

CLOSING REMARKS

Few considerations are probably relevant in closing this report.

The RAP program between EU and CIHEAM (1998-2002) is a continuation of the activities started with the previous EU program (1993-1997) and that will continue coherently in the future, also after the completion of the ongoing program.

The sub-program on WUE and its related activities have been appreciated by the country members of CIHEAM for two major reasons:

I. the efficiency in water use and the water productivity of crops is considered of extreme relevance to tackle the problem of water scarcity in arid and semi-arid Regions of the Mediterranean

II to be in a market economy more open and competitive in a context of globalization requires ability for innovation of production systems. The "changes" to be possibly implemented need to be investigated in terms of resource requirements, economy and environmental impacts, in order to ensure a certain degree of sustainability and probability of success for such changes. Then, appropriate tools for decision-making process where water productivity of crops of different scenarios can be evaluated in a relatively simple way is of great help in such decision process.

The demand for participating to the program has increased and some visitor scientists applied to spend sabbatical periods at IAM-Bari to acquire experience and further insight on the subject.

Furthermore, the GIS work and the Networking approach of IAMB have attracted interests to extend the actions on water resources also toward the soil resources. In fact, the European Soil Bureau supported an International Workshop (held at IAMB the 4-7 Dec. '99) for the "Establishment of a Euro-Mediterranean Network of Soil Information". This new Network, formed by all the Mediterranean Countries, aims to establish an effective task force to tackle the erosion and desertification problems in the Region.

The soil and water resources are essential in a context of "food security" and they should be considered integratively.

The Soil Network is preparing the 1st pedological map of the whole Mediterranean and Europe with the same standard of the Soil European Bureau, to be presented at the "7th International Meeting on Soils with Mediterranean Type of Climate", to be held (always at IAMB) in September 2001.

In other terms, this program is not confined to itself but it is seen as an opportunity to add durable values to the overall training, research and cooperation that CIHEAM is running within the Mediterranean Region, considering it as an Euro-Mediterranean open space for development.

Sub-Programme

"Collective Irrigation Systems"

INTRODUCTION

Large distribution irrigation systems have played an important role in the distribution of a scarce resource that otherwise would also be accessible to few but also allow for a sound water resource management by avoiding the uncontrolled withdrawals from the source (groundwater, rivers, etc).

However, traditional distribution systems have all a common shortcoming: water must be distributed by some rotation criteria that guarantees equal rights to all beneficiaries. The inevitable consequence is that crops cannot receive the water when needed and reduced yields are unavoidable. However this compromise was necessary to spread the benefits of a scarce resource.

Among the distribution irrigation systems, the pressurized ones have been developed during the last decades with considerable advantages with respect to open canals. In fact, they guarantee better services to the users and higher distribution efficiency. Greater surface may be irrigated by using similar quantity of water. They allow overcoming the topographic constraints and made easier the establishment of water fees based on volume of water consumed because, in these systems, it is easy to measure the water volume delivered by farmers. Consequently, important quantity of water may be saved since farmers tend to maximize the net income by making an economical balance between costs and incomes. Thus, because the volume of water represents an important cost, farmers tend to conduct soundly their irrigation. Furthermore, operation, maintenance and management activities are more technical but in a way easier to control and maintain a good service.

Since farmers are the ones who take risks in their business, they should have water with as much flexibility as possible, i.e., they should have water on-demand.

By definition, in irrigation systems operating on-demand farmers decide when and how much water to take from their hydrants, connected to the distribution network, without informing the system manager. Usually, this type of delivery schedule is more common in pressurized irrigation systems in which the control devices are more reliable than in open canal systems where it is also applied.

The on-demand delivery schedule offers a greater potential than other types of irrigation schedules and gives a great flexibility to farmers that can manage water in the best way and according to their needs.

Of course, a number of preliminary conditions have to be guarantee for on-demand irrigation. The first one is an adequate water tariff based on the volume effectively withdrawn by farmers, preferably with increasing rates for increasing water volumes. The delivery devices (hydrants) have to be equipped with flow meter, flow limiter, pressure control and gate valve. The design has to be adequate for conveying the demand discharge during the peak period by guaranteeing the minimum pressure at the hydrants for conducting the on-farm irrigation in an appropriate way.

In fact, one of the most important uncertainties the designer has to face for designing an on-demand irrigation system is the calculation of the discharges flowing into the network. Because of the freedom allows to farmers in conducting their irrigation, it is not possible to know, a-priori, the number and the position of the hydrants in simultaneous operation. Therefore, a hydrant may result satisfied, in terms of minimum required pressure and/or discharge, when it operates within a configuration and may be not satisfied when it operates in another one, depending on its position and on the position of the other hydrants of the configuration.

Therefore, both designers and managers should have adequate knowledge on the hydraulic behavior of the system when the conditions of functioning change respect to what has been assumed..

Improving the design and the performance of irrigation systems operating on-demand requires, thus, the consideration of the flow regimes during the design process. It implies to define new criteria to design those systems which, usually, are designed for only one single peak flow regime. Complementary models for the analysis and the performance criteria need to be formulated in order to support both the design of new irrigation systems and the analysis of existing ones. In fact the first should be able to operate satisfactory within a wide range of possible demand scenarios, while, for existing irrigation systems, the models for the analysis may help managers in understanding why and where failures occur. In this way, rehabilitation and/or modernization of the system may be carried out in an appropriate way.

Expansion of the new information technologies such as geographic information systems (GISs), analysis tools, remote sensing and modeling techniques, along with the networking PC and powerful workstations has offered improved modern strategies and tools to enhance the ability to extract quickly and efficiently insight knowledge from the information stored. However, the rapid evolution of the technological component of such a system has not been followed by the adequate development of the human resources having corresponding background and being able to use efficiently the new information tools.

Consequently, this sub-program on *Collective Irrigation Systems* has been formulated aiming at establishing the still lacking equilibrium between these two components of the system: **Information Technology & Human Resources**, where the first is an invaluable instrument to reinforce (support) the capacity of the second and where the second is the ideological spearhead able to manage and speculate the information derived from the first. Furthermore, this project intends to provide durability and diffusion of the basic knowledge in the field of irrigated and rainfed agriculture and in such a way to improve the rational use of water in the Mediterranean Countries.

GENERAL OBJECTIVES

Contributing to a better understanding of the performance of collective irrigation systems in the Mediterranean region in order to improve the rational use of water resources.

SPECIFIC OBJECTIVES

Training of qualified personnel able to efficiently use and manage the information technology system, to develop and interpret the information stored and produced by the system.

Cooperative research setting up an Information Technology System able to evaluate the impact of various cropping pattern and management scenarios on the hydraulic performance of collective irrigation systems.

The system shall include:

- A database on the physical and cultural characteristics of the pilot irrigation systems in the Mediterranean regions.
- An user-friendly software for the assessment of physical features of networks stored in the database;
- An user-friendly software for the performance analysis of irrigation systems;
- An user-friendly software for the generation of demand hydrographs;
- An information manual.

Through such Information Technology System, new criteria for rehabilitation of actual collective systems may be achieved, new management rules (i.e.: delivery schedules, water price, etc) may be set up and interesting suggestion for improving the technologies of delivery equipment and pumping station may arise.

In order to produce reliable information on actual irrigation systems, the data collection activity still remain an important tool and it has to be continued in the different countries involved in the CIS_Network. Of course, the training of the qualified personnel able to efficiently use and manage such tool and to collect, develop, elaborate and interpret the information stored and derived by the system, is a major component of the project. An important contribution is expected also by the Master students.

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COOPERATIVE RESEARCH ACTIVITIES

Actions were taken to collect and organize field data and parameters to build a database to be used in the model for the analysis of collective irrigation systems.

Several missions in Italy and in the partner countries have been organized in order to carry out local database work and to discuss the on-going activities.
Initial Step of the Digital Data-Base on the physical characteristic of the pilot area in Italy
Master and Ph.D. students have been involved, along with junior scientists, to run the activity.
Initial development step of the software package for the analysis of collective irrigation systems
Senior scientists have been involved to run this activity. Master students are involved for using and calibrating the software.

Logistic Support

Multi-parameter data-logger for recording demand hydrograph data on irrigation systems in Morocco and Tunisia

Seminars & Workshops

Thanking the CIS_Net activity, the FAO asked to organize a Regional Workshop on "Valorisation de l'eau d'irrigation dans les grands périmètres du Maghreb". It was held in Ksar El Kabir, Loukkos (Morocco) from 18 - 23 October 1999
The CIS_Net annual meeting was organized in Malta from 3 to 6 November 1999
A Workshop on "Nouvelles technologies de l'information et de la communication", was held at IRESA - Tunis Tunisia from 8 to 13 November 1999

TRAINING

To establish a common background on the various integrated aspect of Collective Irrigation Systems, two advance short courses were organized:
Advanced Short Course on "Modelisation, Techniques Informatiques et SIG pour la Gestion de l'Eau et des Reseaux Hydrauliques" held in Tunis (Tunisia) from 3 to 14 May 1999.
Advanced Short Course on "New Technologies Development for Irrigation Systems Management" held in Beirut (Lebanon) from 8 to 19 May 2000.

The impact of the first course reflected at the national level of Tunisia. The Tunisian Ministry of Agriculture asked to present a project to the Italian Cooperation on "Management and Rehabilitation tools for improving management of on-demand pressurized irrigation systems". The project was prepared and approved on January 2000.

The impact of the second course reflected at the national level of Lebanon. The Director of the Litany River Authority (an important Irrigation Agency in Lebanon) asked to present a proposal to the Italian Cooperation for equipping a pilot area with advanced irrigation system.

Mobility program: 2 M.Sc. students are developing their work within the framework of CIS_Net, by using the mobility program:

- Salah Bey Lagoun (from Algeria) in Italy, in cooperation with the CNR-Water Research Institute
- Naima Bouhamida (from Morocco) in Morocco, in cooperation with the Ministry of Agriculture - AGR.

Several scientific works regarding the activities of the Sub-Program were already published and some others are in preparation.

2ND PHASE PROGRAM (2000 - 2002)

During the next two years the CIS_Net sub-program will conclude all these tasks by continuing to work on the completion of the Information Technology System. All documents related to this product will be made available according to the original program.

The following activities may be planned:

Training

Advanced Short Course on “Information technologies and Distance Learning in Water Management”, to be held in Tunis (Tunisia), May 2001.
Advanced Short Course on “ Integrated modeling approach for improving management of irrigation systems”, to be held in Malta, May 2002
Mobility program: two M.Sc. students per year will develop their work within the mobility program.

Cooperative Research Network

Continuation of collection and organization of the field data and parameters to build a data-base (the demand hydrograph Information Manual) to be used in the model for the analysis of collective irrigation systems
Continuation of the development of the Digital Data-Base on the physical characteristic of the pilot area
Continuation of the development of the software package for the analysis of collective irrigation systems

Logistic Support

The workstation for I&CT development in Morocco (MDAPM AGR) and Algeria (Ministry of Agriculture)

Seminars & Workshops

CIS_Network annual meeting (Lebanon, October 2000)
Regional Workshop, on “Multimedia techniques to build up a distance learning course on water management”, to be held in Tunis (Tunisia), November, 2000
Seven bilateral meetings for assessing the progress of the on-going activities and running local experimental determinations needed for the Digital Data-Base

Orientation Note

a) Attempt to develop a synergy between the three themes of the RAP-IAMB. Some actions in this direction is to better integrate the training courses, to use the crop model developed in the theme 2 with the optimization model of theme 3 and, possibly, including the use of unconventional water resources (theme 1) as input for water. Everything should be integrated with the I&CT program
b) the actions indicated by the *Logical Framework* should continue to be supported coherently.
c) In terms of *Logistic Support*, the proposed orientation is (i) to set-up an experiment on “Distance Learning” by implementing the existing prototype in each country partner; (ii) to continue the installation of Internet Utilities, hardware and software, for improving the Information and Communication Technologies (ICT) of the RAP partners, so that a real Mediterranean Virtual Campus can be established; (iii) to continue the training activities in support of Mediterranean Institutions both at user and web master levels.

RAP-Networking, Water Saving in Irrigated Agriculture.
WASIA Project presentation:

Non-Conventional Water Resources Management - Network

SUSTAINABILITY AND OPTIMISATION OF TREATMENTS AND REUSE OF WASTEWATER IN AGRICULTURE: CASE OF MOROCCO

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SUMMURY

Wastewater reuse represents a potentially important additional source of water in arid and semi-arid regions. The interest in the reuse of treated wastewater has increased significantly in southern part of morocco due to water deficit (over 260 millions m^3 per year) and increase demand for water supply. Several local experiments have shown the benefit of using treated wastewater on plant growth and yield (Ouarzane, 1996; Aissi, 1997; Skouri, 1998; Lahkim, 1999; Majidi, 2000). However, the high nitrogen content of treated wastewater represents a treat to ground water contamination under irrigation and sandy soils, because mobile contaminate such as nitrates are more easily leached. To reduce nitrate loading to groundwater and controlling this pollution requires an ability to measure and predict pollution loading by specific wastewater treatment technology and agro-management, including identification of timing and application method to provide nutrients rates necessary to achieve realistic crop yield and prevent pollutents' loss to the environment.

Nutrient management is a pollution prevention achieved by developing a nutrient budget for the crop, applying nutrient at the proper time, applying the amount of nutrient necessary to produce a crop and considering the environmental hazard of the site. The response to the need to control leaching of nutrients and contamination of soil and water recommended several steps to reduce the risks of nitrogen pollution practices as well as reducing cost of supplied water. Within this framework, we are testing different water regime as well as alternation between saline water and treated wastewater to optimize nitrogen application and reduce the risk of groundwater nitrate pollution. As well as to determine the feasibility of supplemental irrigation to stabilize the bread wheat yield.

The conclusions resulting from these studies demonstrate the height value of the reuse of treated wastewater when appropriate practices are adopted, in fact:

1- Treated wastewater resulted in similar to better growth and yield as well as the same quality of crop irrigated with reclaimed waste water in comparison to the control.
2- The use of drip irrigation and plastic mulch eliminated the risk of coliforms contamination of the harvested products.
3- The nitrogen mass balance for the tested crops receiving treated wastewater indicates the high risk of nitrate ground water table. In fact the texture, the high infiltration rate and the high nitrate concentration in the treated effluent contribute to high nitrate leaching potential the amount of nitrogen lost to the underground water are 346 and 343 kg of N/ha respectively for eggplant and chrysanthemum, considering all the components related to nitrogen budget.

Additional experiments for selected crops showed that water application of 100% ETM during the two first stages characterized by low water requirement and 120% ETM during the last stage of the crop growth reduce the nitrate leaching by 67% and increased the soil salinity by only 25%.
The studies on cereals crops demonstrate that supplemental irrigation stabilizes bread wheat yield under arid condition of morocco. There is an increase of grain yield of wheat crop from 9.5 qx /ha to 32 qx/hat, when the amount of water increase from 100 mm to 300 mm. Plants growing under rainfed condition yielded almost zero production.

Our findings demonstrate that flowering stage is the most critical growth stage, in fact, the units that received the highest amounts of water at flowering stage produce the largest yield (48.1q/ha with dose 363 mm and 34.9 q/ha with dose 230 mm).

In other investigation, when denitrification process and tertiary treated wastewater is applied (using reed bed), the quantities of NO_3 and P levels were low and did not meet the plant nutrition requirement with dose (200mm), and induced soil nitrate reduction.

INTRODUCTION

Since the sixties, Morocco has emphasis all his effort on maximizing the capture of the country's surface water and encouraging for their optimal use in irrigated agriculture. In Morocco, there are approximately 7.7 millions of arable lands of which one million ha are actually irrigated and the rest is under rainfed irrigation. High cash crops are the major crops cultivated under irrigation and wheat dominant the crops grown under rainfed conditions. Wheat production in arid regions of morocco is very dependent on rainfall. Frequent droughts took place during the spring that corresponds to flowering or grain filling stage depending on the planting date. Rational use of irrigation water, by adopting adequate drip irrigation for high value cash crops and the use of supplemental irrigation is widely recommended to stabilize and to improve crop yield. However with the scarcity of high quality water resources, the use of marginal waters (saline water and treated wastewater) is not only a necessity, but also an inevitable option to alleviate the water crisis in these regions.

Due to the pronounced water deficit, Agadir region is using sand infiltration system to treat its wastewater to be reused in agriculture and landscaping. This technology generates high nitrate concentration in the effluent (more than 500 mg/l). This indicates the high risk of nitrate leaching and nitrogen pollution of the ground water. This risk is amplified by the soil type (sandy soils) and the hydro-geologic analysis of this studied region. Therefore a pilot project on wastewater treatment was implemented at the commune of Drarga using recycling sand filter, denitrification process, and reed bed as tertiary treatment. The acceptability of wastewater to replace conventional water resources is highly dependent whether the health risks and the environmental impacts (salinity, nitrate pollution) are within acceptable levels. The needs for improving wastewater-use efficiency (WUE) in agricultural production and sustainable reuse of treated wastewater are clearly urgent. Our objectives is to optimize the use of wastewater for maximum crop yield or profit, but taking into account the cost of the irrigation water and minimizing the risks for soil salinity and deep percolation of nitrate. Several experiments were undertaken during the last four years to develop irrigation techniques compatible with sustainable agriculture practices:

For vegetables and flower crops our objectives were to:

(i) Master the water-nitrogen interactions by increasing the water efficiency and reducing the nitrate leaching by testing different rates of water.
(ii) Evaluate the water and the nitrogen use by different crops taking into account their nitrogen and water requirement.
(iii) Evaluate the potential risk of ground water pollution and salt accumulation for the different treatments.

For wheat we adopted supplemental irrigation order to:

(i) Determine the optimum water depth under supplementary irrigation practice.
(ii) Evaluate the effects of supplementary irrigation on the crop development, flowering, and grain yield.
(iii) Determine the impacts of applying treated effluent on the soil characteristics and the plant nutrition.

Tab. 1. Physicochemical characteristics of the irrigation treated wastewater used in our experiments

Characteristics	sand infiltration (Bensergao)	sand infiltration + denitrification+ reed bed (Drarga)
CE dS/m	3	2.61
pH	7.41	7.6
NO_3^- ppm	651	49
NH_4^+ ppm	1,8	18
K^+ ppm	46,8	20.28
PO_4^{3-} ppm	42.2	2.4
Cl- ppm	603	515
Ca^{++} ppm	169	219
Na^+ ppm	228	176
Mg^{++} ppm	90	62
CO_3^{--} ppm	0	8.5
HCO_3^{-} ppm	-	662
SAR	-	2.69
MES mg/l	10	5
Coliformes (Nbr/100ml)	<1000	<600
Streptocoques (Nbr/100ml)	<1000	-
Œufs d'helminthes (Nbr/l)	0	0

First year experiments:

Using drip irrigation, and 120%ETM regime we compared three type of irrigation water (sand infiltration treated wastewater, epuvalisation treated wastewater, well water to which we added nutrients).we also compared two varieties of eggplants and geranium.

For cereal's crops (maize, durum wheat, bread wheat, barley) we applied increasing regime of irrigation water (100, 110, 120%ETM) and compared two type of water (sand filter treated wastewater, well water to which we added nutrients). Also we had a control treatment for which plants were irrigated at the germination stage and for the rest of the cycle they were under rainfed conditions.

Second year experiments:

Using drip irrigation, several irrigation regime were applied on chrysanthemum (60, 80, 100, 120%ETM) and on zucchini (100,120%ETM) and we also compared treated wastewater to well water to which we added nutrients.

For wheat crop we applied increasing dose of treated wastewater (100, 200, 300, 400 mm) using micro-sprinklers.

Third year experiments

Using drip irrigation system, three irrigation practices were applied; (i) treated wastewater rich in nitrate nitrogen (651 mg/l), (ii) saline well water to which we added nutrients according to crop requirements, (iii) alternating well water with treated wastewater based on the nitrogen requirements of chrysanthemum and pepper crop. During the first growing stage of these two crops, we used well water since needs for nitrogen is very limited, and during the vegetative growth and fruit development we switch to treated wastewater. The combination of these three treatments with two water regimes (100% ETM and 120% ETM) resulted in six treatments randomly distribute in a Latin scare design. Six lyzimeters of $1m^2$ corresponding to each treatment were installed to collect leachate in order to monitor water and nitrogen balance during the crop cycle. Soil samples were analyzed for nitrogen contents before planting and at the end of the harvest. Total yield for four month growing cycle was recorded for each treatment.

For wheat crop we compared five irrigation doses (250, 275, 300, 350, 400 mm) to rainfed treatments

Fourth year experiments

Using drip irrigation system, two water regime (100% ETM, and 120% ETM) were applied; and two vegetable crops (green beans, tomato) were evaluated for their growth and yield responses).

Four lyzimeters of $2m^2$ corresponding to the treatment 120%were installed to collect leachate in order to monitor water and nitrogen balance during the crop cycle. The plant response evaluation, in terms of mineral content, dry matter, quality of the fruits, and total nitrogen leached from the soil solution was collected in the lyzimeters. Salts accumulation were also monitored during the whole crops cycle by mesearing the saturated paste electrical conductivity of the soil under the two water.

Soil samples were analyzed for nitrogen contents before planting and at the end of the harvest and total yield for seven months growing cycle was recorded for each treatment.

Wheat experiment was undertaken using the same treated wastewater and applied two doses of irrigation water (200, 350 mm) throughout all the crop growth stages. The entire field has received the same amount of water, which was equal to 100 mm in the vegetative stage (germination + tillering),

Starting from the flowering stage the irrigation amount is (D1-100 mm) and (D2-250 mm), was allocated according to the schedule (S1, S2, S3) between the flowering stage (F) and the grain filling stage (G) as following:
S1: 50% at (F) and 50% at (G)
S2: 70% at (F) and 30% at (G)
S3: 30% at (F) and 70% at (G)

The control plants received also the same amount of water (100mm) up to the flowering stage, after which no irrigation was added, and the plants water requirements depended on the rainfall. The experiment design adopted for our experiment was a split plot with six repetitions. The cultivars of the bread wheat used in our experiment was *Marchouch*

In this trail, we used the mini-sprinkler irrigation system which known as *micro jet sprinkler*. Its discharge ranges between 40-50 l/h, according to the water pressure, and each sprinkler covers (1 m^2).

The objectives of all these studies were to find the answers to two questions: (i) which irrigation management is optimal, considering both crop production and reduction of nitrates leaching, in the relation to the need for increasing water use efficiency? (ii) Does the use of different depth of irrigation lead to conciliate between nitrogen pollution and salt build up in the soil? (iii) Does denitrification process reduces nitrate loads?

RESULTS

Appropriate technology

There are four projects in Morocco considering the reuse of wastewater in conceiving the STEP: Ouarzazate (lagoon) Ben sergao (infiltration-Percolation), Benslimane (aerated lagoon) and Drarga (infiltration-percolation). Table 2a below represents some identification elements concerning the main projects of treatment and reuse of wastewaters in Morocco. The table includes only studies subjected to a regular follow-up by multidisciplinary teams.

Table 2a. Projects of wastewater treatment and reuse in Morocco

Plant	**Ouarzazate**	**Ben Sergao**	**Ben Slimane**	**Drarga**
Processing System	Lagoon	Infiltration Percolation	Aerated Lagons	recirculating sand filters
Implementation	ORMVAO FAO-OMS-PNUD IAVHII	DGCL RAMSA	ONEP/ MILD Canadian Contribution Municipality Ben Slimane	Project PREM/ USAID Department of Environment Commune of Drarga ERAC-Sud
Date of launch	1989	1990	1997	2000
Processing capacity	430 m³/d (5 l/s)	750 m^3/d	5.600 m^3/d	1.000 m³/d
Connected Population (Eq-hab.)	4 300	15 000	37 000	10 000

Concerning the treatment of wastewaters, Table 2b sums up the results of the treatment performances of some experimented processing systems.

Table 2b: Sewage performances: Reduction percentage

Plant	Ouarzazate		Ben Sergao	Drarga	Ben Slimane	Marrakech	Bouznika
Processing System	Lagoon	High Output Lagoon	Infiltration - percolation		Aerated Lagoon	Optional Lagoon	Lagoon
Period of Stay (Days)	25	21.9	-	-	30 – 40	30	-
DBO_5 (mg/l)	81.7	65.3	98	98.5	78	97	75
DCO (mg/l)	72	65.4	92	96	79	76	71
MES (mg/l)	28	-	100	96.6	-	69	76
NTK (mg/l)	31.5	48	85	96.8	75	71	14
Pto t(mg/l)	48.5	54	36	95.9	41	85	-
CF /100ml	99.9	99.9	99.9	99.9	100	99.4	99.9
O. Helminthes/L	100	100	100	100	100	100	100

Source: ONEP-FAO (2001)

Agro-management studies

In most cases of arid and semi-arid areas of the world, the shortage of water is increasing the interest for the recycling of treated wastewater in agriculture. Our research gives a clear picture on the use of unconventional water to get higher water use efficiency without decrease in yield.

As matter of fact, yields were higher for plants irrigated with treated wastewater (table 3). The increase of yield for plants receiving 20% more water is mainly due to more supply of nitrogen and lower salinity in the roots zone. The water use efficiency was significantly different between treated wastewater and saline well water. Water use efficiency was the highest for the plants receiving treated wastewater at 120%ETM.

Table 3. Response of several crops to treated wastewater irrigation

Treatments	Chrysanthemum	Zucchini	Egg plant	Maize	Bread wheat	Hard wheat
	Flower/plt	(Kg/plt)	(Kg/m^2)	Qx/ha	Qx/ha	Qx/ha
Control *	69	1.29	3.17	12.43	5.107	0
Treated wastewater	80	2.18	3.41	12.62	48.69	31.83

* In the case of vegetable and flower control correspond to well water with added fertilizers and for cereals control correspond to rainfed conditions.

The alternation of saline water with treated wastewater increased the water use efficiency and reduces by 50% the total nitrogen lost under treatment irrigated with treated wastewater. It appears that changes in irrigation management, as demonstrated in these studies reduce the download flux of nitrogen to the ground water, resulting in lower nitrates concentration compared to plants irrigated during the whole cycle with treated wastewater. Water and nutrients must be supplied in correspondence with their uptake to prevent the occurrence of nutrients deficiencies, salinization or pollution. As treated wastewater nutrient concentration is constant, it appears from our results that alternating saline water with treated wastewater reduce considerably nitrogen leaching and increase nitrogen efficiency.

The economic analysis of the reuse of treated wastewater allows farmers to reduce the cost of the fertilizers inputs (table 4). This could be a great incentive for the promotion on recycling treated wastewater in agriculture.

Table 4. Economic gains from treated wastewater (Euro/ha)

species	Geranium	Durum wheat	Bread wheat	Eggplant	Maize
Fertilizers inputs gains (Euro/ha)	456	780	680	776	350

The nitrogen mass balance for the tested crops receiving treated wastewater indicates the high risk of nitrate ground water table. In fact the texture, the high infiltration rate and the high nitrate concentration in the treated effluent contribute to high nitrate leaching potential the amount of nitrogen lost to the underground water are 346 and 343 kg of N/ha respectively for eggplant and chrysanthemum, considering all the components related to nitrogen budget.

Regarding the water efficiency, the results show two mean tendencies:
The amount of water corresponding to 120% ETM induced high nitrogen leaching and reduced salt accumulation in the root zone. Eventhough, the obtained yield was significantly increased for this water regime.

The application of an equal amount of the crop requirement induces salt accumulation and reduces the nitrogen leaching and yields. Additional experiments for selected crops showed that water application of 100% ETM during the two first stages characterized by low water requirement and 120% ETM during the last stage of the crop growth reduce the nitrate leaching by 67% and increased the soil salinity by only 25%.

Salt accumulation

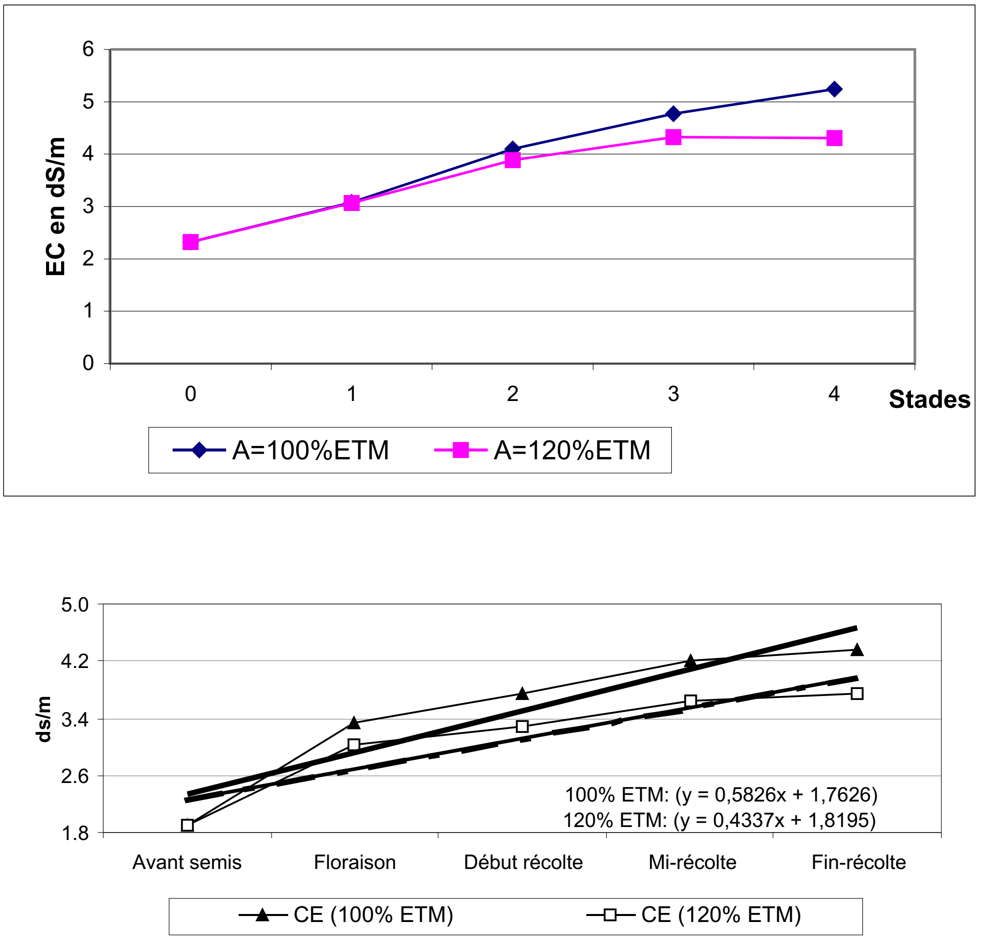

Fig 1. Evolution of the soil conductivity during the tomato (a) and green beans (b) crop cycle.

The studies on cereals crops demonstrate that supplemental irrigation stabilizes bread wheat yield under arid condition of morocco. There is an increase of grain yield of wheat crop from 9.5 qx /ha to 32 qx/hat, when the amount of water increase from 100 mm to 300 mm (Table 5). Plants growing under rainfed condition yielded almost zero production.

Table5. Effect of treated wastewater irrigation depth on wheat yield and its components.

Amount of water	tillers/m^2	grains/tiller	Weight of 1000 grains	Grain yield (g/m^2)	yield (Qx/ha)	Straw yield (Qx/ha)
100 mm	312	12	25	90	9.4	25.8
200 mm	328	16	22	120	11.5	32.7
300 mm	478	18	37	320	31.8	61.6
400 mm	371	26	17	160	16.4	43.5

Our findings demonstrate that flowering stage is the most critical growth stage, in fact, the units that received the highest amounts of water at flowering stage produce the largest yield (48.1q/ha with dose 363 mm and 34.9 q/ha with dose 230 mm).

One of the important observations at this trial is that the units that receive less than 50 mm at flowering stage have a critical impact on its grain yield. Furthermore, the units that received the highest amounts of water at flowering stage produce the highest number of spikes per m^2.

This high yield obtained using treated wastewater as supplementary irrigation source, compared with adjacent rainfed wheat field, which received 107 mm yielded almost zero tonnage. This result indicates the high value of the treated wastewater reuse as supplementary irrigation. If water is the limiting factor, and land is available, it appears more effective to use lower dose on large acreage.
In fact, if the same amount of water (363 mm) which produced the highest yield, is applied at the rate of (230 mm), this will cover 1.58 ha which will produce 55.1 q/ha (based on the yield produced at a rate of 230 mm), and the WUE will increases from 132.4 to 151.8 g grain /m^3.

The other components that must be taken into consideration are the concentration of sodium and chloride, which are presented in high concentration in treated wastewater, as the accumulation of these salts lead to salinity problem on the long run. For example the soil chloride concentration before sowing was 0.28 g/kg, at the end of trial it became between 0.6-0.8 g/kg; the sodium was 0.3 g/kg it became between 0.5-0.6g/kg.

In other investigation, tertiary treated wastewater is applied (using reed bed), so the quantities of NO_3 and P levels were low and did not meet the plant nutrition requirement with dose (200mm), and induced soil nitrate reduction. Therefore tertiary wastewater treatment could meet the environmental goals, but didn't match the crop nutrition requirement.
The high purification level of treated wastewater, and the installation of disc-filter upstream in the field, protects the mini-sprinklers system from clogging, but the disc-filter has to be washed frequently after each three applications.

4. NITRATE LEACHING

Treated waste water used in our experiment is very rich in nitrate nitrogen (Table 6), eventhough the treatment plant used a denitrification process and reed beds as a tertiary treatment. The soil permeability of our soil is very high which presents a risk for ground water nitrate pollution and limits the reuse of treated wastewater unless best management practices are used to reduce nitrogen loading.

Tableau 6a. Quantities of leached nitrate during each stage of tomato (kg/ha)

	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**	**Total**
$N\text{-}NO_3^-$	2,56	1,41	2,66	5,16	**11,87**

Table 6. Quantities of leached nitrate during each stage of green beans (kg/ha)

Stage	Floral initiation	Flowering	Initial harvest	Final harvest	Total
Quantities of leached nitrate (kg/ha)	**13,4**	**13**	**9**	**3,1**	**38,5**

The average results for the quantities of leached nitrogen nitrate during each stage of the different cropping system are presented in table 8a and 8b. The results show that there's a significant difference between the irrigation management options and the cropping system.

For the green beans the quantity of nitrogen leached in treatments irrigated with treated wastewater for 120%ETM regime varied from the initial to the last one. The last two stages contributed to 65% of the total amounts of nitrate nitrogen leached during the whole cycle of green beans (table 8b). This is the result of induced less salt accumulation in the soil and reduced the level of nitrate. These conditions allowed better symbiotic nitrogen fixation for the green beans plants irrigated with 120% ETM regime and not use the nitrate supplied by the treated wastewater irrigation. All these conditions favored the high amounts of nitrate leached during the last two stage of the crop. The water regime 100% ETM supplied the amount of water equal to the plant requirement; therefore the nitrate leaching was significantly reduced. Alternating these two regime reduce the nitrogen loading to the groundwater by 60%. This practice allows satisfying the nitrogen requirements of the crop during the early stage by using 100%ETM water regime when nitrogen requirement of the plant are very low and then irrigate plant with 120% ETM during the vegetative and the fruit development stages with treated wastewater.

For tomato crop the leached nitrates are evaluated to 11, 9 kg/ha, and represent 31,2% of the treated wastewater irrigation supply. These losses are relatively low compared to the ones cited by Benhoummane.B (2001) which represent 60% the supply and amounts to 126,8 kg/ha. Also Mojtahid.A (2001) has found 66,9% nitrate losses, which represent 74,4 kg/ha. This indicates that in our case the use of treated wastewater to irrigate tomato does not represent a nitrate pollution risk. Also the quantities leached in the average farms in the region are around 42 kg/ha which represent almost four times the amounts leached in our trial. We noticed that 50% 0f the total leached nitrate was lost during the 4th stage. This mainly due to the high water demand during this stage which forced us to add more irrigation water to satisfy the high water demand of tomato crop.

5. SOIL FERTILITY

Table 7 shows the major nutrients (N, P, and K) variation in the soil from initial to the final cropping cycle of green beans. It appear from this table the nitrate and potassium have been considerably lixiviated under 120% ETM treatment compared to phosphorus and the treatment receiving just the plant water requirement. The high nutrient plant uptake under 120%ETM regime did reduce the level of nitrate and potassium in the soil. This mainly due to the low concentration of these elements in the treated wastewater irrigation and could not satisfy the plant requirement, therefore the plant had to satisfy its need by pumping on the soil fertility.

Table 7a. Soil's major nutrients Variation under green beans cropping system

Elements	Water Regime	Before seeding	After harvest
NO_3^- (mg/kg)	100%ETM	115	50
	120%ETM	115	34
NH_4^+ (mg/kg)	100%ETM	14	11
	120%ETM	14	10
P_2O_5 (mg/kg)	100%ETM	121	97
	120%ETM	121	94
K_2O (mg/kg)	100%ETM	171	128
	120%ETM	171	121

In the case of tomato crop we noticed a considerable decrease of potassium and phosphorus, since it reached about 50%. There was less decrease for the nitrogen, which was reduced by 26% for the nitrate and 13% for the ammonium. This indicate that the use of reds bed as a tertiary treatment and the denitrification basin reduced tremendously the concentration level of nitrate, potassium, and phosphorus in the final effluent, which reduced the fertility value of the treated wastewater.

Using 2410 $m^{3\ per}$ hectare for wheat production can save 30-35% of the nitrogen fertilizer, 10% of P fertilizer, and 70-82% of K fertilizer, of the whole plant exported nutrients and increase the farmer income.

Table 7b. Soil's major nutrients Variation under tomato cropping system (kg/ha)

	$N\text{-}NO_3^-$		$N\text{-}NH_4^+$		P		K	
	T1	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
initial soil fertility	70,56	70,56	25,92	25,92	84,38	84,38	403,78	403,78
After harvest	67,10	61,06	20,30	19,09	45,50	42,62	253,44	227,52
soil stock Variation	**-3,46**	**-9,50**	**-5,62**	**-6,83**	**-38,88**	**-41,76**	**-150,34**	**-176,26**

T1: treatment 100% ETM, **T2**: treatment 120% ETM

Water nutrition contribution

Since the wastewater contains nutrients, an evaluation of the contribution of irrigation water in the total nutrition requirement is determined and presented in table (8).

Table 8. the irrigation water nutrition supply

Treatment	Water dose (mm) Wastewater	Nutrient kg/ha			
		$N\text{-}NO_3$	$N\text{-}NH_4$	P	K
D1	108	12	1.5	1.1	50.7
D2	241.7	26.8	3.4	2.6	113.2

As it is presented in table (9), the treated wastewater contributes more or less to the plant-exported nutrients.

Table 9. Treated wastewater contribution to Wheat nutrients uptakes (in % of total the nutrient uptake)

Treatment	Nutrients %		
	N	P	K
D1S1	20.2	7.3	43.9
D1S2	16.2	5.3	36.5
D1S3	26	9.2	57.6
D2S1	30.8	10.4	75.8
D2S2	34.6	9.7	82.3
D2S3	32.2	9.8	71.9

Soil fertility

The difference between the soil nutrients content in the initial stage (before sowing) and the end of crop season indicates that there is a slight depression in $N\text{-}NO_3$ (negative value) in most treatments except D2S1and D2S2, an increase in $N\text{-}NH_4$ values, a high depression in P values, and an increase in K values as a result of the Potassium fertilizer application.

Water Use Efficiency (WUE)

Water use efficiency based on the yield (g/m^2) per water applied (l/m^2) has been calculated, as presented in table (10) the highest WUE obtained by the treatment S2 and the lowest by S3 in both doses D1&D2.

Table 10. water use efficiency for each irrigation treatment

Treatment	Water applied (l/m^{2})	Yield (g/m^2)	WUE (g/l)
D1S1	230	270.1	1.18
D1S2	230	349.4	**1.53**
D1S3	230	171.7	0.75
D2S1	363.3	413.7	1.14
D2S2	360.3	480.9	1.32
D2S3	363.3	402.1	1.11

It is important to remind that the average WUE of rainfed producing wheat dry areas of WANA (West Asia and North Africa) is about 0.35 g/l, the pronounce difference between this value and that obtained from our trial (1.53 g/l) indicates the importance of supplementary irrigation schedule using wastewater as irrigation source.

8. ECONOMIC ASPECT

Using treated wastewater as irrigation source (water and fertilizer) can reduce the production cost and in turn increases the farmer net income.

8.1. Water contribution

Wastewater price is less than fresh water, so this difference constitutes increment in farm net return. Table (11) presents the gain can be saved by using wastewater.

Table 11. Treated wastewater gain as water source

Dose (m^3/ha)	Cost of fresh water (DH)	Cost of wastewater (DH)	The income gain (DH)
D1 1080	756	540	216
D1 2417	1691	1208.5	482.5

Fresh water cost: 0.7DH/m^3, Wastewater cost: 0.5DH/ m^3

Fertilizer contribution

The nutritional value of wastewater is important to the agricultural economy in developing countries, where fertilizer cost is a major constraint to improve production of irrigation agriculture. Table (12) shows the money that could be saved by using treated wastewater.

Table 12. treated wastewater gain as nutrient source

Irrigation dose Mm	Commercial fertilizer equivalent to treated wastewater fertilizer supply kg/ha			Total cost DH
	Ammonium Nitrate	Potassium Sulfate	Phosphoric acid	
D1: 108	164.3	105.4	4.9	609
D2: 241.7	367.5	235.9	14.7	1363

Ammonium nitrate (33.5%) ; 1.8 DH/kg,Potassium sulfate (48%); 2.7 DH/kg, Phosphoric acid (54%); 5.8 DH/kg
1Euro = 10 DH

In table (13), an attempt to determine the economic benefit of the reuse of treated wastewater irrigation for wheat production under the different treatments.

Table 13. Determination of the income for each treatment

Treatment	Wastewater cost (DH)	Yield q/ha	Income (Dh)	Net return (DH)
D1S1	540	27.1	8130	7590
D1S2	540	34.9	10470	9930
D1S3	540	17.2	5160	4620
D2S1	1208.5	41.4	12420	11211.5
D2S2	1208.5	**48.1**	14430	**13221.5**
D2S3	1208.5	40.2	12060	10851.5

Wastewater cost: 0.5DH/ m^3, Wheat price: 300 DH/q

CONCLUSIONS

This study was a part of comprehensive project aimed to develop wastewater best management practices for irrigation of vegetable crops, flowers, and cereal's crops grown commonly by the farmers in the Agadir region. These studies show clearly the feasibility of the reuse of treated wastewater, if certain management practices are applied. To approach this challenge will require reaching different user groups. I believe that the farmer's cooperatives and water user associations are the main clientele. We suggest developing a demonstration farm which will serve as a demonstration plots to show the farmers how to attain optimum yield and quality with minimum leaching of NO3-N below the root zone.

Other targets will be political leadership at the regional and national level, and influential people, for whom a sensitization program should established, through the organization of seminars and workshops. The results established in these studies should be presented and discussed.

The assessment of leading experiments in terms of processing and re-using waste water remains mitigated. With assistance from international organizations, Morocco launched several projects with significant results. The failure of certain processing projects because of the inadequacy of the process to the socio-economic context of the concerned regions made it possible to better understand the problem of waste water.

In spite of the acquired experience, used water processing projects achieve only a timid progress. The principal obstacle remains the financing, the awareness of the public authorities and the lack of a national policy in the field of management of the waste water with the purpose to protect water resources.

Currently, certain stations reprocess used water by maintaining the treatment performances defined in their system. The follow-up of the physicochemical and microbiological parameters is regularly assured by scientific supervision teams. Treated waste water is currently re-used in agriculture only on an experimental basis or is limited in certain cases to the farmers on grounds located near the station when this water is evacuated in nature as it is the case of the rural commune of Drarga.

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WASTEWATER RECYCLING AND REUSE IN MEDITERRANEAN REGION AS A POTENTIAL RESOURCE FOR WATER SAVING

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ABSTRACT

Water resources scarcity, accessibility, and environmental degradation are the major challenges facing most of the Mediterranean region and especially the southern and eastern Mediterranean countries. Treated and re-used sewage water is becoming a common source for additional water in some water scarce regions and many countries have included wastewater re-use in their water planning. Policies have been formulated but few have had the capacity to implement them in their water management practices in terms of actions to deal with water pollution control and waste disposal. In arid and semi-arid countries, particularly the developing ones, the full utilization and re-use of sewage water is still far from our final goal, i.e. to be used as a water source, in spite of the vital role it could play in reducing the high pressure imposed on the limited available freshwater. Health and environmental problems are the major obstacles restricting the sustainable and safe re-use and recycle of wastewater which requires concerted efforts supported by regional and international organizations, if real change and beneficial results are to be realized in the near future.

Keywords: Wastewater re-uses, water management, water saving,

INTRODUCTION

Expansion of urban population and increased coverage of domestic water supplies and sewage network will give rise to greater quantities of municipal wastewater which can become a new water source, particularly for irrigation. The water recycling and re-use provide a unique and a viable opportunity to increase traditional water supply. Water reuse can help to close the loop between water supply and wastewater disposal. The successful development of this reliable water resource depends upon close examination and synthesis of elements from infrastructure and facilities planning, wastewater treatment plant sitting, treatment process reliability, economic and financial analysis, water utility management, and public acceptance.

Mediterranean regions are characterized by severe water imbalance uneven rainfall, and at the same time, increased demands for irrigation and domestic water supply have been occurred in recent decades as results of expending urban population and tourist industry. Although water is recycled in the global hydrologic cycle for millenniums; much smaller-scale planned local water recycling and reuse have become increasingly important for two reasons in the Mediterranean regions. Firstly, properly treated municipal wastewater often is a significant water resource that can be used for a number of beneficial purposes; such as agricultural and landscape irrigation. Secondly, discharge of sewage effluent into surface effluent into surface water is becoming increasingly difficult and expensive as treatment requirements become more stringent to protect receiving waters such as rivers, estuaries, and beaches.

Consequently, the re-use of municipal wastewater will require more complex management practices and stringent monitoring procedures than when good-quality water is used. Treatment and re-use of sewage waters is becoming a common source for additional water in some water scarce regions. Re-use of sewage waters, when properly managed, has the benefit of reducing environmental degradation.

For many of those arid and semi-arid countries, re-use of wastewater may contribute more future water availability than any other technological means of increasing water supplies. Treated wastewater can be used effectively for irrigation, industrial purposes and groundwater recharge and for protection against salt intrusion in groundwater aquifers. Furthermore, the wastewater treatment and possible use of sewage effluents is a health and environmental necessity to the civil society, especially in urban areas. Therefore, for those countries, the use of appropriate technologies for the development of alternative sources of water is, probably, the single most adequate approach for solving the problem of water shortage, together with the improvements in efficiency of water use and adequate control to reduce water consumption. Our water management policy should be fundamentally directed to support that "no higher quality, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade". This is what we are challenging for and we have to find the key-recommendations and solutions for action.

POTENTIAL OF SAVING BY USING TREATED WASTEWATER

Wastewater treatment provides opportunities to increase the use of wastewater in agriculture (GWP8Med, 2000). The percentage of population served with water supply and sanitation varies from one country to another. The table 1 below indicates that the annual water use in domestic and industrial sectors could reach 83 BMC. Assuming 80% of wastewater will be collected and treated, the annual collected wastewater could reach 66.7 BMC. The existing wastewater reuse is estimated at 0.75 BMC in the Mediterranean countries (FAO, 1997). The potential treated wastewater for reuse can therefore be estimated at 66 BMC/year in the Mediterranean region. Based on the water demand of year 2025, and assuming that this water could be satisfied, the saving using treated wastewater could reach 70 BMC / year. The cost to achieve this saving is estimated to 55 billions euros which include the need to fill the gap in water supply and sanitation coverage for 25 million people without access to water and to treat the wastewater effluents.

Table 1. Annual domestic and industrial water use and potential treated wastewater for reuse

	Potential Total Irrigation Savings	Potential Total Domestic Savings	Potential Total industrial/Commercial Savings	Potential Treated Wastewater for use	Total Potential Water Savings
	M m3/year	M m3/year	M m3/year	M m3/year	M m3/year
Syria	1,360.0	174.1	3.5	135.9	1,673.5
Lebanon	95.0	99.7	1.9	286.3	482.9
Jordan	73.8	71.0	0.4	89.7	234.9
Egypt	4,773.0	1,079.4	55.5	5,108.1	11,016.0
Libya	400.2	161.9	1.2	248.0	811.2
Tunisia	270.6	91..5	1.2	201.1	564.3
Algeria	270.0	368.3	8.4	1,138.6	1,785.4
Morocco	1,016.1	186.5	4.1	553.9	1,760.6
Albania	99.4	129.3	0.0	221.4	450.1
Croatia	0.0	121.7	4.8	506.9	633.3
Cyprus	15.6	16.1	0.1	20.1	51.8
France	488.0	1,947.9	371.1	26,776.5	29,583.5
Greece	569.4	359.0	2.6	779.2	1,710.3
Italy	2,537.6	2,136.9	197.5	16,135.3	21,007.4
Malta	0.7	15.5	0.0	25.3	41.4
Spain	2,415.4	1,472.1	79.9	7,567.3	11,534.7
Turkey	2591.5	1,818.8	48.8	6,173.9	10,633.0
Total	**16,976**	**10,250**	**781**	**65,968**	**93,974**

WASTEWATER AS AN ADDITIONAL WATER RESOURCE

Benefits

There are several benefits of treated wastewater reuse. First, it preserves the high quality, expensive fresh water for the highest value purposesprimarily for drinking. The cost of secondary-level treatment for domestic wastewater in MENA, an average of $US 0.5/m3, is the cheaper, in most cases much cheaper, than developing new supplies in the region (WB, 2000). Second, collecting and treating wastewater protects existing sources of valuable fresh water, the environment in general, and public health. In fact, wastewater treatment and reuse (WWTR), not only protects valuable fresh water resources, but it can supplement them, through aquifer recharge. If the true, enormous, benefits of environmental and public health protection were correctly factored into economic analyses, wastewater collection, treatment and reuse would be one of the highest priorities for scarce public and development funds. Third, if managed properly, treated wastewater can sometimes be a superior source for agriculture, than some fresh water sources. It is a constant water source, and nitrogen and phosphorus in the wastewater may result in higher yields than freshwater irrigation, without additional fertilizer application (Papadopoulos, 2000). Research projects in Tunisia have demonstrated that treated effluent had superior non-microbiological chemical characteristics than groundwater, for irrigation. Mainly, the treated wastewater has lower salinity levels (WB, 2000, pg.8).

Case-Studies

Countries in the region which practice wastewater treatment and reuse include Spain, France, Cyprus, Malta, Tunisia, Israeli, Italy, Greece, Portugal, and Egypt. However, only Israel, Cyprus and Tunisia, and to a certain extent, Jordan, already practice wastewater treatment and reuse as an integral component of their water management and environmental protection strategies.

In Tunisia, treated effluents (250 m^3/day) are used to irrigate about 4500 ha of orchards (citrus, grapes, olives, peaches, pears, apples, and pomegranate), fodder, cotton, cereals, golf courses and lawns (Abu-Zeid, 1998).The agricultural sector is the main user of treated wastewater. Mobilisation of treated wastewater, and transfer or discharge are an integral part of the national hydraulic equipment program and are the responsibility of the State, like all related projects. The advantage of this water resource is that it is always available and can meet pressing needs for irrigation water. Indeed use of wastewater saved citrus fruit when the resources dried up (over-exploited groundwater) in the regions of Soukra (600 inhabitants) and Oued Souhil (360 inhabitants) since 1960 and contributed among other things to the improvement of strategic crop production (fodder and cereals) in new areas.

Technical and economic criteria enabled the irrigation of more than 6600 ha mobilising 30% of discharged effluent. The average effective utilisation rate of treated wastewater is 20%. The volume consumed differs greatly from one area to another, according to climatic conditions (11 to 21 Million m^3 per year). At present, treated wastewater is an available source of water for farmers, but on the one hand, it is not suitable for crops that are economically profitable, and on the other hand it poses some health risks. The best levels of utilisation are found in arboriculture areas, in areas with a tradition of irrigation and in semi arid areas.

With a projected volume of 215 million m^3 by the year 2006, the reuse potential of this water will be about 20,000 hectares that is 5% of the areas that can be irrigated, if we assume intensive inter-seasonal storage and a massive introduction of water saving systems that would increase the mobilisation rate to 45%. It is expected that additional treatment of treated wastewater will improve the rate of use in irrigated areas (ONAS 2001).

Agricultural reuse however will not see marked improvement, unless restrictions are lifted on pilot wastewater treatment plants with complementary treatment processes. This can only be decided when the stations are functioning with acceptable reliability. This will take a few years of experience. Nonetheless, in all cases, and regardless of the treatment method, technical and organizational measures should be introduced in order to systematically warn those managing the reuse of any breakdowns that may occur in the wastewater treatment plants and to avoid the flow of treated wastewater into the distribution network.

In Jordan, Treated wastewater generated at nineteen existing wastewater treatment plants is an important water resources component. About 72 MCM per year (2000) of treated wastewater are effectively discharged into the watercourses or used for irrigation, 76% is generated from the biggest waste stabilization pond Al-Samra treatment plant serving a population of 2 million (approximately 70% the total served population) in 2000. By the year 2020, when the population is projected to be about 9.9 million, about 240 MCM per year of wastewater are expected to be generated. All of the treated wastewater collected from the As-Samra wastewater treated plant is blended with fresh water from the King Talal reservoir and used for unrestricted irrigation downstream in the Jordan Valley.

In Israel reuse up to 1982 amounted to about 25% of the wastewater generated. Since that time several large projects lead to a large increase in water reuse. In 1987 some 230 reclaimed water projects produced about 0.27×10^6 m^3/day of reclaimed water from a population of over 4 million people (Argarnan, 1989). About 92% of the wastewater was collected by municipal sewers and of this 72% was reused for irrigation 42%) or groundwater recharge (30%). Reuse constitutes approximately 10% of the water in Israel but by 2010 it is projected that reuse will account about 20%, with about 33% of the total water resource allocated to agricultural irrigation.

In Israel of the various advanced treatment options used in Israel, sewage treatment systems, employing conventional biological treatment, followed by a long detention reservoir, as a system of choice, provides in the mean time a superior conventional method of treatment for wastewater and reuse for arid and semi-arid regions. This practice is generally recognized at the moment as an economically feasible strategy for developing a crucial water source for irrigation replacing freshwater to be reallocated for urban/domestic use, while also having public health advantages. About eighty percent of Israel's treated wastewater is reused in irrigation. Despite all efforts in practice and research however, the associated health and environmental risks and the implications of the increase in the quantities of wastewater effluents in the human environment are not fully understood. Furthermore, the inclusion of sewage effluents as part of “water irrigation rights” and the associated institutional and pricing adjustments need to be analyzed as well as the modifications in the agricultural production systems. Extensive engineering and academic research is being conducted in an attempt to elaborate the consequences and effects of large scale and expanded use of treated effluents of varying degree of quality on the human and natural environment, in general, and the soil/water/crop relationship, in particular. Subsurface trickle irrigation in large field scale was tried and no yield benefits or deficits were found as compared to surface trickle irrigation. However the E.coli pathogens in the surface soil was the same as background samples suggesting a safer method of irrigation though not always the maximum yields are obtained.

In Cyprus wastewater generated from the main cities is collected and following tertiary treatment is used for irrigation. It is expected that the irrigated agriculture will be expended by 8-10% and an equivalent amount of water will be conserved for other sectors (Papadopoulos. 1995)

In Italy, in the areas near the treatment plants of the towns Castiglione, Cesena, Cesenatico, Cervia and Gatteo an intensive programme of reuse of treated wastewaters has been carried out. Wastewater irrigation now covers an area of over 4000 ha and very interesting results both in terms of the effects on the soil and on the irrigated crops are shown. The first survey of Italian treatment plants estimated the total treated effluent flow at 2 400 Mm3 /yr of usable water. This gives an estimate of the potential resource available for reuse.

The reuse of treated wastewater in Spain is already a reality in several sever regions of the country for four main applications: golf course irrigation, agriculture irrigation, groundwater recharge and river flow augmentation. In Tenerife, the treated water reused in irrigation amount to 17 00 m^3/day. These waters are stored in two reservoirs of a capacity of 250 00 m^3 and 50 000 m^3 respectively in San Lorenzo and Sen Isidro. The main crops irrigated are banana, vineyards, tomatoes, and cut flowers.

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In Portugal, treated wastewater is a valuable potential resource for irrigation and should soon reach 580 Mm3 /yr, which is approximately twice as much as today. Even without storage, this amount could be enough to cover about 10% of the water needs for irrigation in a dry year. Roughly, between 35 000 and 100 000 ha, depending on storage capacity could be irrigated with recycled water.

In Morocco, the reuse of raw wastewaters has become a current and old practice. They are reused in agriculture in several parts the country. These practices are mainly localized to the periphery of some big continental cities where agricultural lands are locate in the downstream of effluent discharge, and also in small parts around the wastes of the treatment networks. The climatic constraints had pushed farmers to irrigate their crops with raw wastewater when water resources are not available.

During the last years, the reuse of wastewaters has also developed around some suburbs recently provided with a treatment network. A total of 7000 ha is directly irrigated with raw wastewaters discharged by towns, i.e. about 70 million m^3 of wastewater is used every year in agriculture with no application of the sanitary precaution (HWO standards for example). This second use concerns a diversity of cultivation types (fodder, cereals, forest threes…).

The irrigation of vegetable crops with raw wastewaters is forbidden in Morocco, but this banning is not respected, which makes the consumer of agricultural products and the farmer face risks of bacteria or parasite contaminations. In general, the volume of wastewaters that have been recycled does not represent more than 0.5% of the water used in Agriculture.

This situation tends to be generalized in all the suburbs that are provided with a treatment system where wastewaters are discharged. Following an investigation carried out within the framework of NSLC (1998), a total of 70 areas using wastewaters are spread out in the territory. This practice is not free of dangerous consequences on environment; for example:

1- Difficulty and high cost of the processing and the production of potable water.

2- Many section of water courses in the country present a largely weak quantity of dissolved oxygen, and even a deficit in oxygen when these discharges are important, which causes massive fish mortality, and;

3- Many dam volumes present marks of eutrophication, as a consequence of the important phosphor and nitrogen wastes.

Since early nineties, many multidisciplinary projects concerning the treatment and reuse of wastewater in irrigation have been launched in Morocco. The aim was to answer the major agronomic, health, and environmental concerns. The results of these researches have made the local collectivities and the regional agriculture services benefit from reliable data necessary to conceive and to size the treatment plants of wastewaters adapted to the local contexts and to disseminate the best practices for reusing treated wastewaters in agriculture.

In Egypt an ambitious programme is running for municipal wastewater treatment that will provide by the year 2010 nearly 3 billions m^3 /yr of treated wastewater as an additional water source to be used in agriculture (Abu-Zeid , 1992).

Most nations in the region are already importing virtual water, in the form of food, and will likely have to increase specific imports, such as cereal crops. Despite this, many countries wish to increase fresh water supplies to domestic, and industrial usages, and at the same time, expand irrigated agriculture. For example, Tunisia wishes to increase the area of irrigated agriculture by at least 30,000 hectares (ha), and Egypt, by 880,000 ha. How can these seemingly contradictory objectives be reconciled? The answer is water demand management more efficient water use within all sectors. One specific component is to increasingly reuse domestic wastewater, for industry, for some municipal purposes, such as flushing toilets and irrigating green spaces, but above all, for agriculture, to offset the fresh water being taken out of this sector.

WASTEWATER REUSE CONSIDERATIONS

Wastewater reuse applications

In the planning and implementation of wastewater reclamation and reuse, the reuse application (see Table 2) will usually govern the wastewater treatment needed, and the degree of reliability required for the treatment processes and operations. Because wastewater reclamation entails the provision of a continuous supply of water of consistent quality, the reliability of the existing or proposed treatment processes and operations must be evaluated in the planning stage (Tchobanoglous and Burton, 1991). Specific reuse categories and treatment technologies that may be applicable will depend on the location and type of wastewater management employed (e.g., centralized versus decentralized, as discussed subsequently). Worldwide, the most common use of reclaimed wastewater has been for agricultural irrigation. Recently, groundwater recharge and potable reuse have received considerable attention in the United States. The repurification project in San Diego, CA, in which it is proposed to blend repurified wastewater with local runoff and imported water in a local water supply storage reservoir, is an example of such a project (Montgomery/Watson and NBS Lowry, 1994.)

Table 2. Categories of municipal wastewater reuse and potential issues/constraints

Wastewater reuse categories	Issues/constraints
Agricultural irrigation Crop irrigation COMMERCIAL NURSERIES **Landscape irrigation** Parks School yards Freeway medians Golf courses Cemeteries Greenbelts Residential	(1) Surface and groundwater Pollution if not managed properly, (2) Marketability of crops and public acceptance, (3) effect of water quality, particularly salts, on soils and crops, (4) public health concerns related to pathogens (bacteria, viruses, and parasites), (5) use for control of area including buffer zone, (6) may result in high user costs.
Industrial recycling and reuse Cooling water Boiler feed Process water Heavy construction	(1) Constituents in reclaimed wastewater related to scaling, corrosion, biological growth, and fouling, (2) public health concerns, Particularly aerosol transmission of pathogens in cooling water.
Groundwater recharge Groundwater replenishment Salt water intrusion control Subsidence control	(1) Organic chemicals in reclaimed wastewater and their toxicological effects, (2) total dissolved solids, nitrates, and pathogens in reclaimed wastewater.
Recreational/environmental uses Lakes and ponds Marsh enhancement Stream flow augmentation Fisheries Snowmaking	(1) Health concerns of bacteria and viruses, (2) eutrophication due to nitrogen (N) and phosphorus (P) in receiving water, (3) toxicity to aquatic life.
No potable urban uses Fire protection Air conditioning Toilet flushing	(1) Public health concerns on pathogens transmitted by aerosols, (2) effects of water quality on scaling, corrosion, biological growth, and fouling, (3) cross-connection.
Potable reuse Blending in water supply Pipe to pipe water supply	(1) Constituents in reclaimed wastewater, especially trace reservoir organic chemicals and their toxicological effects, (2) aesthetics and public acceptance, (3) health concerns about pathogen transmission, particularly viruses

Source: Tchobnoglous and Burton, 1991

Wastewater treatment technology

Technology, particularly in terms of performance and available wastewater treatment options, cannot be expected to find a solution to each problem. Wastewater systems are generally capital-intensive and require expensive, specialized operators. Therefore, before selecting and investing in wastewater treatment technology, an analysis of cost effectiveness needs to be made and compared with all conceivable alternatives.

The selection of technologies should be environmentally sustainable, appropriate to the local conditions, acceptable to the users, and affordable to those who have to pay for them. In developing countries, western technology can be a more expensive and less reliable way to control pollution from human domestic and industrial wastes. Simple solutions that are easily replicated, that allow further up-grading with subsequent development and that can be operated and maintained by the local community, are often considered the most appropriate and cost effective. The choice of a technology will depend to the type of reuse. The selection of reuse option should be made on a rational basis. Reclaimed water is a valuable but a limited water resource; so investment costs should be proportionnel to the value of the resource. Also, reuse site must be located as close as possible to the wastewater treatment and storage facilities.

In the developing countries usually characterized by high population density and notable shortfall in available water resources, the proper waste water technology to be adopted under the prevailing local conditions is one of the critical issues which should be well defined. Technologies available are many and well known, but any choice should rely on those not entailing excessive costs and providing the best environmental practice and option.

Indeed, the selection of the best available technology is not an easy process: it requires comparative technical assessment of the different treatment processes which have been recently and successfully applied for prolonged periods of time, at full scale. However, this is not sufficient, the selection should be carried out in view of well-established criteria comprising: average, or typical efficiency and performance of the technology; reliability of the technology; institutional manageability, financial sustainability; application in re-use scheme and regulation determinants. Furthermore, for technology selection, other parameters have to be carefully considered: wastewater characteristics, the treatment objectives as translated into desired effluent quality which is mainly related to the expected use of the receiving water-bodies.

Wastewater quality and health issues

Irrigating with untreated wastewater poses serious public health risks, as sewage is a major source of excreted *pathogens* - the bacteria, viruses, protozoa- and the helminthes (worms) that cause gastro-intestinal infections in human beings.

Wastewater may also contain highly poisonous chemical toxins from industrial sources as well as hazardous material from hospital waste. Relevant groups of chemical contaminants are heavy metals, hormone active substances (HAS) and antibiotics. The risks associated with these substances may, in the long run, turn out to constitute a greater threat to public health and be more difficult to deal with than the risks from excreted pathogens. Unregulated and continuous irrigation with sewage water may also lead to problems such as soil structure deterioration (soil clogging), salinization and phytotoxicity.

These risks are not limited to 'official' wastewater but often also apply to rivers and other open water sources, as indicated by figures gathered by Westcott: 45% of 110 rivers tested carried faecal coliform levels higher than the WHO standard for unrestricted irrigation (FAO, unpublished, cited in Birley).

The ideal solution is to ensure full treatment of the wastewater to meet WHO guidelines prior to use, even though the appropriateness of these guidelines are still under discussion. However, in practice most cities in low income countries are not able to treat more than a modest percentage of the wastewater produced in the city, due to low financial, technical and/or managerial capacity. The rapid and unplanned growth of cities with multiple and dispersed wastewater sources makes the management more complex. In many cities a large part of the wastewater is disposed of untreated to rivers and seas, with all related environmental consequences and health risks. The perspectives regarding the increase in wastewater treatment capacity in these cities are bleak. It may safely be assumed that urban and peri-urban farmers increasingly will use wastewater for irrigation, irrespective of the municipal regulations and quality standards for irrigation water.

Only a few large cities in developing countries and newly industrializing countries have adequate sewer systems and treatment plants, which is not the case for the majority of developing countries. In any case, usually, only a small portion of the wastewater is treated and purified even when it is channeled through a sewer system. Existing sewage treatment plants rarely operate satisfactorily and, in most cases, wastewater discharges exceed legal and/or hygienically acceptable maxima.

This does not necessarily lie in the treatment plants themselves, but in the frequent lack of adequately trained technicians capable of technically operating such treatment plants.

The discharge of untreated wastewater and/or minimally treated municipal ones in water sources has resulted in a substantial economic damage and has posed serious health hazards to the inhabitants, particularly in the developing countries. In many countries, various diseases are particularly prevalent and the consequential costs for the health care system are considerable.

Considerable sums have been spent on water and wastewater treatment in both the developing and developed regions of the world to substantially reduce waterborne diseases and meet commonly accepted environmental and ecological objectives. Yet, statistics indicate that in spite of such enormous investments in water quality improvement and protection, in the less developed countries, nearly 2 billion people are suffering from the lack of clean drinking water and sanitation facilities.

This is now the case in many mega-cities where the drinking water supplies from rivers or local groundwater sources are no longer sufficient, mostly because of their poor quality.

As a matter of fact, water quality problems are certainly not restricted to urban areas. The lack of sanitation facilities and the too often associated unsafe drinking waters remain among the principal causes of disease and death, especially in rural areas. Specific measures to counteract water-related threats are often needed, but, lack of investments and inadequate local management often lower their effectiveness.

Institutional manageability

Wastewater reuse is characterized by the involvement of several departments and agencies, either governmental or private or both. In the southern part of the Mediterranean countries, few governmental agencies are adequately equipped for wastewater management. In order to plan, design, construct, operate and maintain treatment plants, appropriate technical and managerial expertise must be present. This could require the availability of a substantial number of engineers, access to a local network of research for scientific support and problem solving, access to good quality laboratories and monitoring system and experience in management and cost recovery. In addition, all technologies, included the simple ones, require devoted and experienced operators and technicians who must be generated through extensive education and training.

For adequate operation and minimization of administrative conflicts, a tight coordination should be well defined among the Ministries involved such as those of Agriculture, Health, Water Resources, Finance, Economy, Planning, Environmental Protection and Rural Development. The basic responsibilities of such inter-ministerial committees could be outlined in:

developing a coherent national policy for wastewater use and monitoring of its implementation;

defining the division of responsibilities between the respective Ministries and agencies involved and the arrangements for collaboration between them;

appraising proposed re-use schemes, particularly from the point of view of public health and environmental protection;

overseeing the promotion and enforcement of national legislation and codes of practice;

developing a national staff development policy for the sector;

Financial considerations

The lower the financial costs, the more is attractive the technology. However, even a low cost option may not be financially sustainable because this is determined by the true availability of funds provided by the polluter. In the case of domestic sanitation, the people must be willing and able to cover at least the operation and maintenance cost of the total expenses. The ultimate goal should be full cost recovery although, initially, this may need special financing schemes, such as cross subsidization, revolving funds and phased investment programmes.

In this regard, adopting an adequate policy for the pricing of water is of fundamental importance in the sustainability of wastewater re-use systems.

The incremental cost basis, which allocates only the marginal costs associated with re-use, seems to be a fair criteria for adoption in developing countries.

Subsidizing re-use system may be necessary at the early stages of system implementation, particularly when the associated costs are very large. This would avoid any discouragement to users arising from the permitted use of the treated wastewater.

However, setting an appropriate mechanism for wastewater tariff is a very complex issue. Direct benefits of wastewater use are relatively easy to evaluate, whereas, the indirect effects are “non monetary issues” and, unfortunately, they are not taken into account when performing economic appraisals of projects involving wastewater use. However, the environmental enhancement provided by wastewater use, particularly in terms of preservation of water resources, improvement of the health status of poor populations in developing countries, the possibilities of providing a substitute for freshwater in water scarce areas, and the incentives provided for the construction of urban sewage works, are extremely relevant. They are also sufficiently important to make the cost benefit analysis purely subsidiary when taking a decision on the implementation of wastewater re-use systems, particularly in developing and rapidly industrializing countries.

Monitoring and Evaluation

Monitoring and evaluation of wastewater use programmes and projects is a very critical issue, hence, both are the fundamental bases for setting the proper wastewater use and management strategies. Ignoring monitoring evaluation parameters and/or performing monitoring not regularly and correctly could result in serious negative impacts on health, water quality and environmental and ecological sustainability.

Unfortunately, in many countries that are already using or start using treated wastewater as an additional water source, the monitoring and evaluation programme aspects are not well developed, are loose and irregular. This is mainly due to the weak institutions, the shortage of trained personnel capable of carrying the job, lack of monitoring equipment and the relatively high cost required for monitoring processes.

In the developing countries, two types of monitoring are needed: the first, process control monitoring to provide data to support the operation and optimization of the system in order to achieve successful project performance; the second, compliance monitoring to meet regulatory requirements and not to be performed by the same agency in charge of process control monitoring.

In the developing countries, to avoid failure in wastewater use and attain the desired success, the monitoring programme should be cost effective, and should provide adequate coverage of the system. Equally so, it must be reliable and timely in order to provide operators and decision making officials with correct and up-to-date information that allows the application of prompt remedial measures during critical situations.

Public awareness and participation

This is the bottleneck governing the wastewater use and its perspective progress. To achieve general acceptance of re-use schemes, it is of fundamental importance to have active public involvement from the planning phase through the full implementation process.

Some observations regarding social acceptance are pertinent. For instance, there may be deep-rooted socio-cultural barriers to wastewater re-use. However, to overcome such an obstacle, major efforts are to be carried out by the responsible agencies.

Responsible agencies have an important role to play in providing the concerned public with a clear understanding of the quality of the treated wastewater and how it is to be used; confidence in the local management of the public utilities and in the application of locally accepted technology, assurance that the re-use application being considered will involve minimal health risks and minimal detrimental effects on the environment.

In this regard, the continuous exchange of information between authorities and public representatives ensures that the adoption of specific water re-use programme will fulfill real user needs and generally recognized community goals for health, safety, ecological concerns programme, cost, etc.

In this way, initial reservations are likely to be overcome over a short period. Simultaneously, some progressive users could be persuaded to re-use wastewater as supplementary source for irrigation. Their success would go a long way in persuading the initial doubters to re-use the wastewater available.

MAJOR NEEDS FOR RECYCLING AND REUSE OF WASTEWATER

Applying realistic standards and regulations

An important element in the sustainable use of wastewater is the formulation of realistic standards and regulations. However, the standards must be achievable and the regulations enforceable.

Unrealistic standards and non-enforceable regulations may do more harm than having no standards and regulations because they create an attitude of indifference towards rules and regulations in general, both among polluters and administrators. In arid and semi-arid countries where wastewater is recognized additional water source standards, guidelines and regulations in the majority of developing countries do not consider the re-use aspect as an integrated part of the treatment process; they are only intended to control and protect the quality of water bodies where the reclaimed water is discharged. In reality, in the arid regions of the Near-East, North-Africa and Southern-Europe, not all countries have developed guidelines and regulations for reclaimed water use. For those countries, standards and regulations for the re-use should be tailored to match the level of economic and administrative capacity and capability standards should cope with the local prevailing conditions and should be gradually tightened as progress is achieved in general development and in the economic and technical capability of the involved institutions and of the private sector as well.

Formulation of national policies and strategies

It is now widely recognized that wastewater re-use constitutes an important and integral component of the comprehensive water management programs of the majority of countries, more so in the water scarce ones.

This implies that these countries should have national policies and strategies relating to wastewater management in general and wastewater re-use for agriculture, in particular, in order to guide programmes, projects and investments relating to wastewater collection, treatment, re-use and disposal in a sustainable manner.

This requires the establishment of a clear policy with regard to wastewater management.

This policy should be compatible with a number of related sectoral or sub-sectoral policies such as national water management and irrigation policy, national health, sanitation and sewage policy, national agricultural policy and national environmental protection policy.

Such policy should give guidance on the following issues:
the current and future contribution of treated wastewater to the total national water budget;
criteria required to achieve maximum benefit of wastewater-reuse for the different water sectoral uses;
Modalities for strengthening the national capacity building in this sector.

Such policy should be accompanied by an appropriate national strategy for wastewater reuse characterized by the following features:
spelling out ways and means of implementing policy directives;
defining the nature and mechanisms of inter-institutional collaboration, allocation of funds, establishment of pilot wastewater reuse demonstration sites of good management practices and phasing the implementation of wastewater programmes;
fostering the share of responsibilities between involved ministries, agencies and authorities, and the way to link and integrate the activities among them, individually and in combination;
Identifying an economically feasible, safe and socially acceptable set of standards, regulations and codes of practices for sustainable use.

Ideally, policies of wastewater reuse and strategies for its implementation should be part of water resources planning at the national level. At the local level, individual reuse projects should be part of the overall river basin planning effort.

Institutional, Legal and Political aspects of wastewater reuse

Safe water treatment, disposal and reuse are the responsibility of different organizations such as authorities, cooperatives and communities operating under the jurisdiction of the ministries of agriculture, water resources and others. The responsibilities of these organizations must be considered and reconciled.

To tackle the range of institutional levels involved and to allocate responsibilities in both treatment and reuse stages, several actions are needed, including:

1. A well-defined policy and strategy for the comprehensive management and reuse of treated wastewater is a precondition to success.
2. Many different stakeholders are involved, so roles and responsibilities (who does what) need to be clearly defined, along with mechanism to ensure the active co-ordination of the various institutions.

3. Inadequate legislation often hinders the effective reuse of treated wastewater. Integrated legal arrangements can be of great value, along with provisions for active enforcement of all laws and egulations, without exception.
4. A comprehensive plan of action for reusing treated wastewater, with clearly assigned roles, needs to be complemented by periodic reviews and follow-up. Adequate funding is essential.
5. Capacity building is required to analyze staff needs and provide suitable training.
6. More participatory approaches are needed, including raising the awareness of the general public (whose cultural and religious perceptions sometimes regard treated wastewater as impure). Irrigators also need to be involved in the planning and utilization of this resource.
7. More co-ordination is needed between donors and national institutions involved in wastewater reuse.

To reinforce and help consolidate improved arrangements in countries with many ministries involved, the possible formation of a " higher council " to create policy and strategies should be considered. This body could oversee implementation and obtain necessary funding. Where many different laws complicate wastewater reuse, consideration could be given to consolidated legislation that would cover all aspects of water resources planning, management and utilisation.

Awareness raising, education, and best practices

Targeted health education is the most realistic, practical and cost effective measure to reduce health risks associated with wastewater use in agriculture. The following categories should be addressed:

Policymakers: convince them that the use of wastewater is a reality that has to be accepted; provide them with data on the food security, income generating capacity, health and nutrients aspects of wastewater use in agriculture; show trade-offs of costs and benefits of wastewater treatment and reuse in agriculture, co-management of water provision, sanitation, treatment and reuse, and strategies for handling wastewater from the source to the users.
Farmers: provide information through interactive learning methods on health risks associated with wastewater use, information and technical assistance on proper crop selection in relation to wastewater quality, irrigation techniques, protective clothing (boots), personal hygiene, washing crops before marketing, group organization for on field sanitation and washing facilities; preventing damage to soils and ground water

- Consumers: Inform them on proper washing; cooking or blanching of vegetables; and sufficient cooking time for fish raised with wastewater; necessity of paying for treatment of household wastewater as they are the generators.

Tradesman: use of clean water for freshening products (vegetables) on the market; ways for minimizing contamination risks during transport and processing.
Local authorities: to help them understand the implications of wastewater use and the role they can play in minimizing the risks.
The NGO's and media may have to play a vital role in this exercise, if authorities are slow to take the lead.

Best practices should include:

Crop selection and certification of produce (labeling)

Variations in absorption of certain chemicals by crops, makes crop selection a suitable strategy, in the absence of market forces, which discourage crop restriction.
Offering financial incentives i.e. labeling clean products, which will fetch higher prices, is also a possibility provided customers are willing to pay more and certification programs, which are costly processes, can be set up.

Improving irrigation practices

Irrigation techniques, which wet only the roots and not the leafy part of vegetables, were suggested as good practice for minimizing risk of contamination. Bed and furrow irrigation, drip systems and any other technique applying water close to the root systems was suggested. There is a further advantage in that there will be less infiltration into groundwater. Rotating wastewater application over fields if this is possible is another means to limit over-fertilization and pollution of groundwater. Avoiding irrigation with wastewater in the two weeks before harvest can minimize the risk from pathogen contamination of leafy vegetables, but this necessitates a fresh water source accessible to farmers, which is rarely possible in these peri-urban situations.

CONCLUDING REMARKS AND RECOMMENDATIONS

Domestic WWTR is one tool to address the food and water insecurity facing many countries in the Mediterranean. In coming years, in most Mediterranean countries, valuable fresh water will have to be preserved solely for drinking, very high value industrial purposes, and for high value fresh vegetables and salad crops consumed raw. Where feasible, most other crops in arid countries will have to be grown increasingly, and eventually solely, with treated wastewater. The economic, social and environmental benefits of such an approach are clear. To help the gradual and coherent introduction of such a policy, which protects the environment and public health, governments shall have to adapt an Integrated Water Management approach, facilitate public participation, disseminate existing knowledge, and generate new knowledge, and monitor and enforce standards.

One of the prerequisites for any cure is an adequate information base. This includes inventorying water stocks, on one hand, and ascertaining the demand at local and regional level, in quantitative and qualitative terms within the framework of national water strategy, on the other one. Economic, social and environmental concerns must all be taken into account in accordance with the goal of sustainability.

It is important to strengthen the capacity of national and local hydrological research institutes to improve their links to environmental research as well as to institutes in the field of economic and social science, particularly in the field of urban studies and planning. The transfer of knowledge to local government decision-makers must be improved.

Local governments must focus their policies on treating municipal wastewater to eliminate the rapid degradation in both surface and groundwater quality. In this regard, simple methods of wastewater treatment are to be recommended as realistic solutions; equally so, governments have to operate as well to strengthen the capacity of both institutions and users.

Efforts concerning domestic sewage must center on promoting and further developing low cost, easy-to-handle and, in general, regionally developed technologies with a low degree of complexity. Special weight must be placed on minimizing the energy needs for these technologies.

The failure of governance at local government level should be counteracted by improving the efficiency of public administration at the local level. The measures required include the building of responsibilities, combining management and financing functions, improving environmental legislation and monitoring, dismounting bureaucratic, decentralizing tasks to the lowest levels possible, increasing the transparency of government activities as well as enhancing the skills of the public administration employees.

Enhancing and improving cooperation between local governments and the informal sector which is far below the level required. The informal sector should be exploited to a greater extent and integrated with decentralized public administration to find more rapid, appropriate and flexible solutions to the existing and raising problems. In this regard, the involvement of the NGOs has to be strengthened in the management of infrastructural institutions and the mobilization of public participation and individual responsibility within the framework of urban supply and wastewater treatment and use projects.

Existing water charges must be changed so that they reflect scarcities and increase the reliability of supply. Most of the water tariff systems in both developed and developing countries do not reflect the economic and environmental scarcity of water. To be environmentally and economically viable, water tariff systems should ensure that the costs of collecting, treating and using water are recovered. Low income users should be able to reduce the amount they have to pay through active participation in systems of water collection, water supply and wastewater disposal and treatment.

The demand of major polluters or large consumers should be controlled using the instrument of marginal cost tariffs. Taxing consumption in this way is a financial incentive to water sustainability.

Where many different laws complicate wastewater reuse, consideration could be given to consolidated legislation that would cover all aspects of water resources planning, management and utilisation.

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WASTEWATER TREATMENT TECHNOLOGY ADAPTED TO SMALL AND MEDIUM COMMUNITY IN THE MEDITERRANEAN REGION

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PROJECT SUMMARY

Wastewater reuse represents a potentially important additional source of water in arid and semi-arid regions. The interest in the reuse of treated wastewater has increased significantly in southern part of morocco due to water deficit (over 260 millions m^3 per year) and increase demand for water supply.

The Municipality of Drarga is located in a semi-arid region near the coast in southwest Morocco. At the initiation of the project, the wastewater generated in the town was discharged untreated leading to the development of a large cesspool, where it percolated into the soil or evaporated. As part of the Water Resources Sustainability (WRS) project jointly funded by the United States Agency for International Development (USAID) and the Moroccan Ministry of the Environment, a wastewater treatment facility and water reuse system have been developed. At capacity, the wastewater treatment facility will serve an estimated 17,600 people in the Municipality of Drarga.

Based on the experience of Ben Sergao, irrigation with water that was treated by the infiltration-percolation system brings on the ground a quantity of nitrogen nitric that largely exceeds the needs for the agricultures and consequently generates nitrates in underground water. This is likely, in the long run, to considerably deteriorate the quality of water resources. This concern is even more significant in areas with sandy ground where the transfer of nitrogen towards the water sources is fast. To reduce nitrate loading to groundwater and controlling this pollution requires an ability to reduce the concentration of nitrate in the treated influent. In this respect WRS project added a denitrification basin to the treatments process in the Drarga plan by recalculating the effluent getting out from the sand filter, and used reed beds as a tertiary treatment. The objective of our study is to analyze the performance of the treatment process in terms of organic pollution reduction and nitrogen removal. The results indicate that treated effluent could be used with no restriction for irrigated agriculture based on WHO regulation. Also the addition of a denitrification basin reduced nitrate level by more than 80%. The use of reed beds allowed a polishing of both the bacteriological, organic, and nitrogen level in the treated effluent.

The wastewater treatment facility includes influent screening, grit removal, anaerobic lagoons, denitrification lagoons, and flow holding basins. The effluent from the wastewater treatment facility will be passed through recirculating sand filters and reed beds (man-made constructed wetlands) to further reduce solids, organics, pathogens, and nitrogen to the performance of the plant allowed us to produce an effluent that meet the World Health Organization (WHO) standards for unrestricted agricultural irrigation water. No chemicals or complex mechanical equipment are required in the treatment process. The effluent from the wastewater treatment facility will be stored on-site in lined basins and pumped to local farms for use as irrigation water. Crops grown in the local area include alfalfa, clover, corn, wheat, corn, and vegetables. The wastewater treatment facility will receive income from the sale of the irrigation water, the sale of reeds, and the sale of composted sludge. The Commune of Drarga that operates the water distribution system for the town will operate the wastewater treatment and reuse facility as well.

INTRODUCTION

Most countries in the Mediterranean region are arid or semi-arid. They have low rainfall, mostly seasonal and with erratic distribution. Moreover, due to the rapid development of urban and rural domestic water supplies, conventional water resources have been seriously depleted and waste water reclamation and irrigation gained increasing role in the planning and development of additional water supplies.

The WRS Project (Water Resources Sustainability) is intended to improve water resources management by completing three demonstration pilot projects. The WRS Project supports the efforts of the Moroccan Ministry of the Environment and its partners to protect water resources in Morocco and fulfills Strategic Objective No.2 of USAID/Morocco, which is "to improve the management of water resources in the agricultural, urban, and industrial sectors." WRS Project has decided to take a very pragmatic approach that involves completing three pilot demonstration projects, including treatment and reuse of domestic wastewater in the Agadir region. The other two projects are the recovery of chrome discharged by tanneries in *Dokkarat* in Fez and reduction of soil erosion in the *Oued Nakhla* watershed in the Rif.

SITE SELECTION AND COMMUNITY INVOLVEMENT

The town of Drarga was selected as the most appropriate location for the WRS pilot project on the treatment and reuse of domestic wastewater. Of the four districts in the Agadir province that are not included in the Master Plan for Sewage Management of Grand Agadir (Drarga, L'qliâa, Ouled Dahou, and Temsia), only the town of Drarga, in the rural district of Drarga, was equipped with an existing sewerage system (but not a sewage treatment plant). Moreover, the town of Drarga is close to nearby agricultural areas that could be economically irrigated by the treated wastewater.

Fig. 1. Map of Morocco

The Municipality of Drarga is a rapidly expanding town with an efficient central planning organization. Two large housing developments financed by ERAC-Sud are under construction within the district limits. The entire town has been electrified, and a water distribution system serves most of the town. In addition, the town has a sewage collection system that covers about 80% of the town's population. The water and sewage services are provided by the Municipality of Drarga.

Current discharges of untreated wastewater in the town of Drarga pollute ground water, emit unpleasant odors, and are a threat to public health. Wastewater from the town of Drarga is drained through four drainage or outfall sewers coming from (1) Iguidar and Ikiou; (2) Drarga Centre, eastern part; (3) Drarga Centre, western part; and (4) Talat Izem. Those outfall sewers take the wastewater directly to undeveloped areas, which in some cases are only a few meters from residential areas (outfall sewers 3 and 4). The wastewater accumulates in ponds (particularly for discharge points 1 and 2), and a part of it infiltrates into the ground. These ponds promote the development of parasites and insects and give off unpleasant odors. In addition, nitrogen in the wastewater was identified as a contributor to the high nitrate concentrations in the local groundwater (although agriculture is the primary contributor).

As the first step in the project development, potential sites for the treatment plant were identified and compared. The main evaluation criteria for the selection of the site were as follows:

1. Distance between the site and the population center (impact of odors)
2. Ownership of the site (private or public land)
3. Access to the site
4. Conveyance to the site of untreated wastewater
5. Topography and geology of the site
6. Risks of flooding
7. Risks of polluting groundwater
8. Proximity to users of treated wastewater
9. Room for future expansion

Based on these criteria, four potential sites were established and evaluated. The most favorable site was selected and acquired by the municipality.

Development of Design Criteria

Average wastewater flow rates at the four existing sewage outfalls in the Municipality of Drarga were measured in May 1997. This flow data was compared to the current number of customers connected to the existing sewage system to determine an average wastewater generation rate per capita. In addition, the following additional parameters were examined: the connection rate of customers to the existing municipal water and sewage systems, the average drinking water consumption for customers connected and unconnected to the municipal system, the average ratio of water consumption to sewage flow for customers connected to both systems, and the historical changes in per-capita water usage in the municipality. Based on this data and population growth estimates for the municipality, the required design capacity for the wastewater treatment facility was developed for a 20-year period. These estimates assume that the existing municipal water and sewage system will continue to expand until all residents of the municipality are connected. The estimates also assume that per capita water consumption (and thus sewage generation) in the municipality will continue to increase from a current rate of 46 L/capita/day to a projected rate of 65 L/capita/day in the year 2020 as the area modernizes and expands.

Table 2. Population and Influent Flow

	YEAR 2000	YEAR 2010	YEAR 2020
Population (Estimated)	7,300	11,300	17,600
Percent of Population Connected to Sewer System	80 %	90 %	100 %
Design Average Wastewater Flow per Capita (1)	41.6 L/d	59.7 L/d	67.3 L/d
Design Wastewater Flow Rate (Average Daily Flow)	243 m^3/d	607 m^3/d	1,184 m^3/d
Peak Hour Flow Rate (2)	437 m^3/d	1,090 m^3/d	2,130 m^3/d

Notes :(1) Average wastewater flow rate estimates include 10% safety margin.
(2) Peak hour flow rate based on an observed diurnal peak hour factor of 1.8.

Wastewater sampling was conducted in February 1998 to collect additional data on the composition and diurnal flow variation of the domestic wastewater generated in the Municipality. This data was used to establish the design influent sewage characterization upon which the facility design is based on. The design assumes that the *concentrations* of contaminants in the influent sewage will decrease in the future with the modernization of the municipality. This will occur because although the per capita water consumption rate is anticipated to increase in the future, the overall waste generation rate per person will remain relatively constant.

Table 3. Influent Sewage Characterization (Design Concentrations)

YEAR	TSS (MG/L)	COD (MG/L)	BOD_5 (MG/L)	TKN (MG/L)	TP (MG/L)
Current	1070	2350	1220	210	30
2000	886	1946	1010	174	25
2010	656	1441	748	129	18
2020	530	1164	604	104	15

The treated effluent water quality design standards for the facility were developed based on local water quality goals as well as WHO and UN-FAO standards. Of primary importance was the limitation of nitrate concentration in the reuse water, because although the presence of some nitrogen in the irrigation water will act as a beneficial nutrient for crop growth, any excess water seeping into the ground will eventually enter the groundwater supply aquifer for the area. Nitrate contamination of groundwater is a significant problem in this area, with 26% of the local wells analyzed exceeding the recommended nitrate limit for drinking water of 50 mg/L and an additional 40% of the wells having nitrate concentrations between 25 and 50 mg/L. A goal of 30 mg/L effluent nitrate-nitrogen concentration was developed based on UN-FAO guidelines and the limitations in treatment performance expected with the selected low-technology treatment process. Also important was to limit the concentration of pathogens in the reuse water. For this purpose, the 1989 WHO standards for unrestricted irrigation of edible crops (less than 1,000 fecal coliforms per 100 mL and less than 1 intestinal nematode egg per liter) were selected to provide maximum protection against disease transfer. Four primary performance indicators were selected for ease in monitoring the performance of the treatment process.

In addition to effluent reuse for agricultural irrigation, another goal of the project was to include reed beds for the growth of giant reeds for sale as a commercial product. Also, sludge dewatering facilities were requested so that sludge produced at the facility could be co-composted with municipal solid waste and used as an organic soil amendment.

WASTEWATER TREATMENT PROCESS DESCRIPTION

The demonstration treatment facility is situated in the southwest corner of the Municipality on land formerly used for agriculture. The site is bordered on the west by the Oued Irhzer El Arba, a dry river which drains into the Oued Souss and on the east by the right-of-way for a future rail line which is planned for the region in the year 2050. The selected site has about 5.6 hectares of land area available for construction and is relatively flat. As discussed earlier, the goal of the project was to design a plant capable of reaching the target concentrations shown in Table 4. Although the treatment plant was designed to meet the year 2020 wastewater flow, during the initial stage of the project, only the facilities necessary to meet the year 2010 design flow are being constructed. Two supplementary projects were also required to implement the wastewater treatment process; construction of flood protection improvements along the Oued Irhzer El Arba (which is subject to seasonal flooding) and extension of the existing sewer system from the four current outfall points to the treatment plant site. A step-by-step description of the treatment plant components follows.

Table 4. Target Effluent Concentrations for Performance Indicators

YEAR	BOD_5 (MG/L)	NO_3-N (1) (MG/L)	TN (1) (MG/L)	FECAL COLIFORMS (MPN/100 ML)
2000	< 30	< 30	< 38	< 1000
2010	< 30	< 30	< 38	< 1000
2020	< 30	< 30	< 38	< 1000

Notes: 1. Targeted nitrogen concentrations in RSF effluent. Effluent nitrogen concentration from Reed Beds will vary with the amount of evapotranpiration.

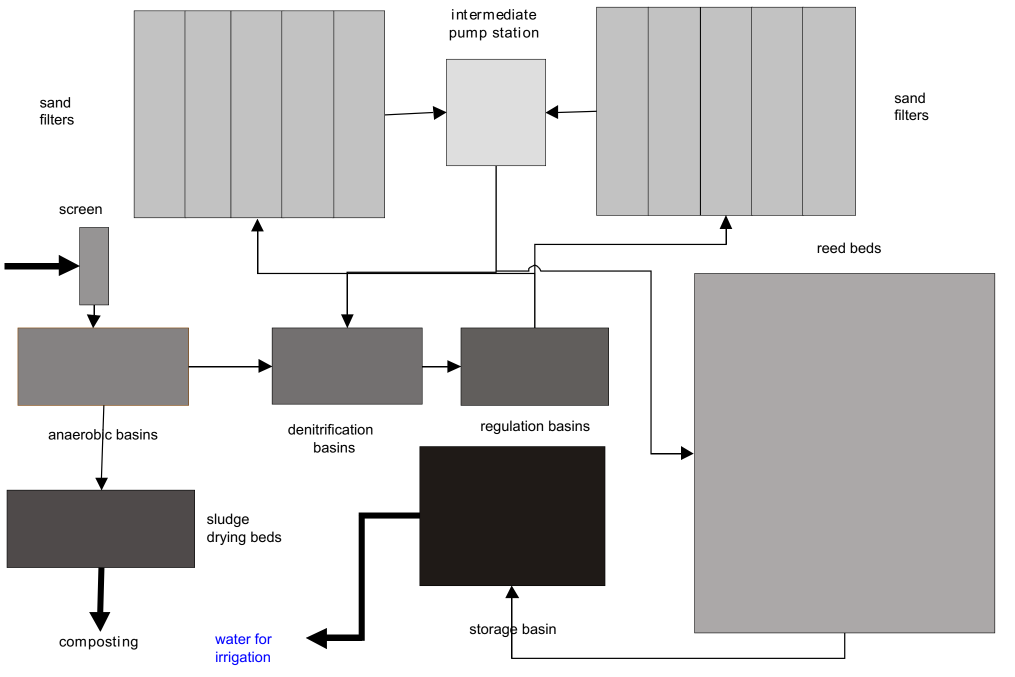


Fig. 4. Site Plan of Drarga Wastewater Treatment Plant

Bypass Chamber

The bypass chamber is the first structure in the wastewater treatment plant. Normally, all of the wastewater flow generated by the Municipality will be treated at the plant. However, during heavy rain events, a large quantity of rainwater may enter the collection sewer system through inflow and infiltration. This rainwater will dilute the strength of the sewage, but it will also increase the quantity of sewage above what the treatment plant is capable of handling. During such periods, the treatment plant will continue to function at full hydraulic capacity, while any additional flow will bypass to the intermediate pump station from where the combined raw sewage and recirculating sand filter effluent will be pumped into the Oued Irhzer El Arba. It is anticipated that this situation will occur very infrequently, and when it does the Oued Irhzer El Arba will be flowing with water which will further dilute the bypassed sewage.

Screening

The first step of the treatment process is to remove large floating and suspended solids, rags, rocks, debris, and other large objects from the influent wastewater. These objects will be captured in the manually cleaned influent bar screen located immediately downstream of the bypass chamber. Influent screening is important because large solids and rags could potentially clog downstream pumps, pipes, and valves if not removed at this time.

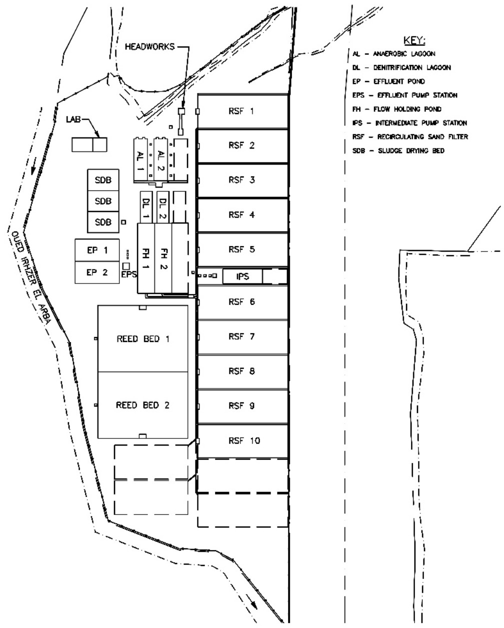
Grit Removal

The next step of the treatment process is grit removal, which occurs in two parallel grit removal chambers. Dense solids such as sand or bone fragments will settle to the bottom of this chamber, from which they must be shoveled out by hand. A proportional weir at the end of each chamber maintains a constant flow velocity through the chamber. This constant velocity ensures that biodegradable organic solids, which are typically less dense than grit, will not settle inadvertently in the grit removal chamber.

Flow Distribution

There are three flow distribution boxes in the plant: Flow Distribution Box No. 1, Flow Distribution Box No. 2, and the Nitrate Recycle Flow Distribution Box. These boxes are used to spilt the wastewater flow evenly between all process tanks on line by flow over equal length sharp-crested weirs set at the same height.

In addition, the Nitrate Recycle Flow Distribution Box allows the RSF effluent pumped from the intermediate pump station to be distributed proportionally between the denitrification lagoons and the reed beds. By using stop plates to cover some of these weirs, the operators can achieve a 3:1, 2.4:1, 1.8:1, 1.2:1, or 0.6:1 ratio of nitrate recycle to plant influent. The design nitrate recycle ratio is 2.4 for the year 2010 design and 1.8 for the year 2020 design. The ratio is lower for the future design condition because the nitrogen concentration in the plant influent is expected to decrease with modernization of the area (see Development of Design Criteria, above).



Anaerobic Lagoons

The purpose of the anaerobic lagoons is to remove COD present in the influent wastewater through anaerobic biological decomposition. At the same time, suspended solids present in the influent wastewater and the bacteria that grow as a result of the anaerobic activity will settle to the bottom of the lagoon. There are two anaerobic lagoons in the year 2010 design. A third lagoon will be added in the future expansion to the year 2020 design flow. Each lagoon has a volume of 918 m^3 and the units combine to provide a 3.0 day hydraulic detention time (HRT) for the year 2010 design flow, and a 2.3 day HRT for the year 2020 design flow. The anaerobic biological decomposition process generates methane gas and carbon dioxide as a byproduct. Floating covers over the lagoon capture this gas. Collection piping carries the gas to a 16 kW engine generator, which converts the energy in the methane gas into electricity. The electricity can be used to power the operator's house, laboratory, and selected pumps. Submersible sludge pumps in the bottom of the lagoon can be used to pump the sludge out of the lagoon onto the sludge drying beds for dewatering.

Denitrification Lagoons

The purpose of the denitrification lagoons is to remove oxidized nitrogen (nitrate and nitrite) by the biological process of denitrification. This process is carried out by heterotrophic bacteria operating in an anoxic environment. The bacteria require a carbon source to carry out the denitrification process. The carbon source in this application is the COD present in the anaerobic lagoon effluent wastewater. Additional COD can be supplied by directly bypassing a portion of the influent wastewater from Flow Distribution Box No. 1 around the anaerobic lagoons. The effluent from the anaerobic lagoons contains most of the nitrogen present in the form of TKN. Therefore, a portion of the effluent from the RSFs (in which the nitrification process has converted ammonia into oxidized nitrogen) must be recycled back to the denitrification lagoons. This is accomplished by the Nitrate Recycle Flow Distribution Box. Like the anaerobic lagoons, the denitrification lagoons contain submersible sludge pumps that can be used to pump settled solids out of the lagoons and onto a sludge drying bed for dewatering. There are two denitrification lagoons in the year 2010 design. A third lagoon will be added in the future expansion to the year 2020 design flow. Each lagoon has a volume of 736 m^3 and the units combine to provide a 2.4 day nominal HRT for the year 2010 design flow, and a 1.9 day nominal HRT for the year 2020 design flow.

Flow Holding Basin

The purpose of the flow holding basin is to store the effluent from the denitrification lagoons until it is time to dose the next sand filter. The sand filters are dosed three time per day, so the combined volume of the flow holding basins are equal to one-third of the total volume of influent flow and nitrate recycle flow for one day. At pre-set intervals during the day, the operators will manually open the sluice gate at the end of the flow holding basin, releasing the contents of the basin to the RSFs. There will be relatively few solids present in the flow leaving the denitrification lagoons, but some additional solids may settle out in the flow holding basins and can be removed periodically by draining the foot of the basin into the recycle pump station. There are two flow holding basins in the year 2010 design. A third basin will be added in the future expansion to the year 2020 design flow. Each basin has a volume of 360 m^3.

Recirculating Sand Filters

The primary purpose of the recirculating sand filters (RSFs) is nitrification (the biological process by which ammonia is converted to nitrate by autotrophic bacteria under aerobic conditions). Additional reduction of BOD and some degree of denitrification will also take place in the RSFs. The denitrification is possible in portions of the RSF which do not receive adequate oxygen. The primary source of oxygen in the RSFs is diffusion of oxygen into the upper layers of the sand from the air. This effect is enhanced by frequent “tilling” of the sand on the surface. The tilling process involves turning the top few centimeters of sand to expose the bacteria growing on the sand grains to the surface air. The tilling process also breaks up the hard pan of solids and algae that tends to build up on the RSF surface over time. Some oxygen will also enter the bottom of the RSF through the open underdrains. There are ten RSFs built for the Year 2010 design flow. An addition four RSFs will be constructed for the year 2020 design flow. Two RSFs will be dosed at a time for the Year 2010 design, and three at a time for the Year 2020 design. Each RSF has a surface area of 1560 m^2 and at the design dosing rate of 360 m^3 per sand filter, the hydraulic loading will be 230 mm per dose. Each RSF is dosed once every five dosing periods. There are three dosing periods each day. In each dosing periods, the slide gate at the end of both flow holding basins is opened, sending a rush of stored wastewater onto the surface of two of the RSFs. The flow of wastewater onto the RSF surface is faster than the liquid can percolate through the sand, so the liquid ponds on top of the sand surface. The ponding results in an even depth of wastewater over the entire RSF surface, which in turn, ensures an even distribution of flow across all parts of the RSF. Over the next several hours, the ponded water percolates through the sand particles, where attached bacteria carry out the nitrification process. The close packing of the sand grains also filters out solids. In addition, studies at Ben Sergao have indicated that significant pathogen reduction occurs across the sand filters, both from filtration and from natural die-off of bacteria, which is largely a function of time and temperature.

Intermediate Pump Station

The effluent from the RSFs drains into the intermediate pump station. The maximum water level in the intermediate pump station must be kept below the bottom of the RSFs to allow the RSFs to drain completely. Due to the great depth below the ground surface at this point, submersible wastewater pumps are used to lift the wastewater back up to the surface level. These pumps serve a dual purpose, as they also return a portion of the RSF effluent back to the front end of the denitrification lagoons to serve as a source of nitrates for the denitrification process. The intermediate pump station has a large volume so that it can act as a flow equalization point. Even though liquid exits the RSFs at an inconsistent rate (due to the periodic loading method), the RSF effluent flow will be equalized in the intermediate pump station and (when properly adjusted) the pumps will operate at a constant rate throughout the 24-hour period.

Reed Beds

There are two reed beds, each about 2,900 m^2 in area. These membrane lined beds, which are subsurface irrigated with a constant water depth of 1.0 m, will be planted with local varieties of fast-growing giant reeds (qchqlich and aghanin) in alternating rows. The primary purpose of the reed beds is to grow reeds that will be harvested periodically and sold as a source of income for the plant. The reed beds will also remove some nitrogen and other nutrients from the wastewater by uptake into the plants and by biological nutrient removal. This nitrogen removal, however, will be partially off-set during many parts of the year by the loss of water through the basins due to evapotranspiration. Thus, although the nitrogen load (in kg/d) will decrease across the reed beds, the change of nitrogen concentration across the reed beds is highly dependent on the percentage of water loss across the reed beds. The concentration can increase or decrease.

Effluent Storage Ponds and Pump Station

There are two effluent storage ponds, each with a volume of 1,014 m^3. The effluent flow storage ponds store treated effluent from the plant until it is needed by the local farmers. The effluent pump station pumps treated plant effluent from the effluent flow storage ponds to the farmer's fields for use as irrigation water. A flowmeter is used to measure the quantity of irrigation water delivered to the farmers. Irrigation water will be distributed among the eligible farmers through a piping distribution network. Valves will be installed at each farm parcel and controlled under the authority of a “gouadier” (according to the traditional rules of the region). Major crops to be developed include alfalfa, clover, corn, bananas, zucchini, pumpkin, cabbage, potato, and onion. Water may be allocated for cereal crops, such as wheat, during certain crucial growing periods (such as the ripening period). The reuse water will provide a significant source of nutrients (nitrogen, phosphorus, and potassium) to the irrigated crops without excessive contribution of nitrates to the groundwater. Excess water which is not required by the farmers will overflow the storage ponds and into the adjacent Oued Irhzer El Arba.

Sludge Drying Beds

The purpose of the sludge drying beds is to dewater sludge produced in the anaerobic lagoons and the denitrification lagoons. The liquid sludge is pumped from the bottom of the lagoons by submersible pumps and onto the surface of the sludge drying beds. The liquid portion of the sludge will evaporate into the atmosphere or drain through the sand in the drying beds into the underdrain below. The underdrain is piped back to the anaerobic lagoon effluent channel. The dried sludge must be removed with a small loader and disposed of or used for co-composting with municipal solid waste. The on-site municipal solid waste/wastewater sludge co-composting project is currently under design through a separately funded project.

There are five sources of nitrogen removal in this treatment system.
Nitrogen contained in sludge removed from the anaerobic lagoons.
Nitrogen contained in sludge removed from the denitrification lagoons.
Nitrates (from the RSF effluent) recycled in the nitrate recycle flow and denitrified in the denitrification lagoon.
Ammonia nitrified (converted to nitrates) in the RSFs and immediately denitrified in anoxic regions of the same filter.
Nitrogen contained in the harvested reeds.

At the same time, the nitrogen *concentration* through the treatment system is increased by water losses from the system through evaporation, transpiration, and plant uptake. The overall result is an anticipated reduction in the total nitrogen across the facility of 70% (in the year 2010) and 63% (in the year 2020).

Performance of the plant in reducing water pollution

Test conducted at the plant during the period of 2000- 2002 show that the facility was meeting the targets set for reducing water pollution in Drarga. Table 5 below shows the levels after the establishment of the treatment plant. The quantity of treated wastewater generated from the plant was about 400 m^3 per day.

Table 5. Drarga wastewater treatment plant performance

	Raw waste water		After anaerobic lagoon		After sand filter		After reed bed		Reduction %	
Parameters	Saison		Saison		Saison		Saison		Saison	
	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm
N-NH4 mg/l	182	170	177	165	0.8	0.6	0.6	0.5	99.6	99.7
N-NO3 mg/l	0.05	0.10	0.08	0.11	48	59	38	45		
NTK mg/l	297	317	121	118	18	12	15	10	95	96.8
DBO5 mg/l	709	625	332	256	12	10	14	9	98	98.5
DCO mg/l	1345	1033	584	417	71	56	69	56	94.8	94.5
CF/100 ml	$6.4\ 10^6$	$1.6\ 10^7$	$6.1\ 10^5$	$6.7\ 10^5$	$2.0\ 10^3$	790	170	500	99.99	99.99
Helminthes/l	4	5	3	4	0	0	0	0	100	100
Conductivity dS/m	2.8	2.4	2.9	2.5	2.8	2.7	2.4	2.2		

WATER SAVING

The water wastewater fulfills the requirements of world health organization without restriction. The WRS project increased farmers' awareness on the use of treated wastewater for crop irrigation by developing demonstration plots using drip irrigation. The results of the demonstration plots convinced the farmers of the benefits of using treated water for irrigation. Crops that are irrigated with treated influents in the demonstration plots includes cereals (wheat, maize) , vegetables (tomatoes and zucchini), and forage crops (alfalfa, ray grasses).

In 2001, the commune of Drarga started operating the treatment plant and provided treated wastewater to a few farmers to irrigate fields in the irrigated perimeters of 6 Ha around construction site of the plant. Currently, farmers grow forage crops, particularly alfalfa, clover, maize, and others vegetables crops.

The farmers irrigating with treated water are benefiting in two ways. First, they have access to guaranteed amount of low priced water. In addition, they can economize on buying fertilizers since the treated wastewater already contains nutrients elements needed by the crops.

Table 6 summarizes the economic saving of water and fertilizers for each crop. The total economic saving ranges from 222 euro per ha up to 514 euro per ha respectively for zucchini and for maize.

Table 6. Economic saving of water and fertilizers for crops irrigated with treated wastewater

Crop	Water savings (DH/ha)	Fertilizer Savings (DH/ha)	Total Savings (DH/ha)
Wheat	750	1492	2242
Maize	1588	3614	5140
Alfalfa	774	1539	2313
Zucchini	677	1545	222
Tomato	1553	3542	5059

COST RCOVERY

The Drarga wastewater treatment and reuse project was conceived with cost recovery features in mind. In Morocco, nearly 70% of wastewater treatment plants are not functioning due to luck of spears parts and poor cost recovery. The Drarga project includes several cost recovery features. The plant it self generates a number of products that have the marked value:

Treated wastewater is sold to farmers for irrigation;
Reeds from the reed beds are harvested and sold twice a year;
Residual sludge from the anaerobic basins are pumped, dried, and combined with organic wastes from Drarga to produce compost;
The methane gas from the anaerobic basins is recovered and converted to energy to run pumps at the plant, thereby reducing electricity costs.

In addition to the products from the plant, the commune is committed to raise revenues to pay for the operations, maintenance, and replacement costs of the plant. These revenues include:

An increase of 1 Dirham ($0.10) per cubic meter to the water and sewage tariff;
An increase of 1,500 Dirham ($150) to the one time sewage connection charge for new connections.

These revenues, combined with revenues from the plant are deposited into a special account that is independent of the commune's account is further divided into two sub accounts: (1) an operations account for current expenses, and (2) an extension and renewal account the future expansion of the wastewater treatment plant.

The project provided the commune Drarga with a spreadsheet model to manage all financial aspects of the plant.

The WRS team assisted the commune in the implementation of the cost recovery mechanisms for the Drarga plant. Activities implemented include the following:

Opened a special account to manage the costs and revenues of the Drarga plant;
Installed a new billing system for water and sewage at the plant using a computer equipments and software package that will enable the commune of Drarga to track expenses and revenues of the wastewater treatment plant;
Organized an association of treated wastewater users, who will purchase the treated water from the commune and therefore contribute to the payment of part of the operation and maintenance expenses of the plant.

CONCLUSION

The Drarga WWTP will serve as a model for other communities along the Oued Souss river, in other parts of Morocco, and arid and semi-arid areas throughout the world that are considering investing in appropriate wastewater treatment technologies.

The primary requirements for an appropriate technology are that the treatment system must be affordable to construct operable by available staff, and reliable in performance. Without external operation and maintenance provided by the central government, the system must be as passive as possible, requiring a minimum of mechanical equipment and technically skilled manpower. The simple alternative called a recirculating sand filter requires only one pump.

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SUSTAINABLE USE OF HIGHLY SALINE WATER FOR IRRIGATION OF CROPS UNDER ARID AND SEMI-ARID CONDITIONS: NEW STRATEGIES

Corn yield response to saline irrigation water applied with a trickle system under Mediterranean climatic conditions

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ABSTRACT

A field experiment was carried out to evaluate the corn yield, yield loss, and water use efficiency in relation to the salt concentration level of irrigation water applied with a trickle system in the Mediterranean Region of Turkey. Saline irrigation water with electrical conductivities of 3.0, 6.0, 9.0, and 12.0 dS/m along with canal water of 0.5 dS/m was used. In addition, three treatments were included in the study by applying 10% leaching fraction to 0.5, 6.0, and 12.0 dS/m treatments after flowering. Results indicated no significant difference in corn grain yields among the treatments studied as indicated by the variance analysis. Highest yield averaging 8875 kg ha^{-1} was obtained from the treatment plots irrigated with canal water. Generally, profile salt concentration increased with increasing salinity of irrigation water used. Higher salt concentration in the top layer was due to higher evaporation rate from the wetted surface. The general salt distribution profile under saline irrigation water treatments followed the typical water distribution pattern under trickle irrigation (bulb shape) with maximum ECe occurring at the soil surface. Applying a leaching fraction of 10% after flowering did not affect the profile salt distribution significantly in treatments. There were no significant differences in dry matter production levels, water use efficiency (WUE), 1000-grain weight, and harvest index (HI) among the salinity treatments. This study concluded that saline irrigation water may be used for irrigating corn crop when applied with trickle system under the Mediterranean climatic conditions.

Key words: Saline water, corn, trickle irrigation, water management

INTRODUCTION

The decreasing availability of fresh water for agriculture use, while the need for production of food and fuel from plants is increasing, has become a major concern to many countries in the region. Under such condition of fresh water scarcity, agriculture is forced to use more and more waters of poorer quality such as the saline water in the region. Fortunately, there are abundant sources of those water sources that could be used successfully in irrigation, but they are still marginally used in the arid and semi arid countries of the Mediterranean region. Water availability for irrigation in the region could be enhanced through proper use and management of saline water and the recycling of treated sewage water (Hamdy, 2002).

Saline water is a potential source for irrigation. Recent research developments on plant breeding and selection, soil crop and water management, irrigation and drainage technologies enhanced and facilitated the use of saline water for irrigating crops with minimum adverse effects on the soil productivity and environment. From the point of irrigation, the use of marginal quality waters will require careful planning, more complex management practices and stringent monitoring procedures than when good quality water is used (Rhoades, 1977; Hamdy, 1997).

There is usually no single method to achieve safe use of saline water in irrigation. Many different approaches and practices can be combined into satisfactory saline water irrigation systems; the appropriate combination depends upon economic, climatic, social, as well as edaphic and hydrogeologic situations (Rhoades et al., 1992).

In general, crops tolerate salinity up to a threshold level above which, the yields decrease approximately linearly as salt concentrations increase.[5] Using proposed linear response model, the maximum allowable salinity without yield decrease per unit increase in salinity beyond the threshold may be obtained. High crop productivity with salt-affected irrigation waters and soils can be attained if management practices are appropriate and environmental conditions are favorable. From around the world, numerous examples of successful results under saline conditions can be cited (Maas and Hoffman, 1977; Moore and Hefner, 1977).

Reuse of drainage water for crop production is a common practice in downstream section of the Lower Seyhan Irrigation Project (LSP) area in the Mediterranean region of Turkey. Therefore, effective salinity control measures must be implemented for sustainable irrigated agriculture, which requires safe use of saline, low quality irrigation and drainage waters for crop production (Tekinel et al., 1989).

Corn, cotton, and wheat are the major crops grown in the LSP. It should be noted that corn is classified as a moderately sensitive crop to soil salinity, which should be considered in the scheme of crop production.

Yazar and Yarpuzlu (1997) conducted a five-year study in the Lower Seyhan Irrigation Scheme in Turkey from 1991 to 1995 in order to evaluate the response of cotton and wheat grown in rotation on a clay soil to drainage water applications with four different leaching fractions (varying from 0.15 to 0.60) as well as salinity build-up in the soil profile. Effect of winter rainfall on salt balance of the soil profile was also investigated in this study. The results revealed that drainage water can be used for irrigating wheat and cotton crops in the Lower Seyhan Project in Turkey without resulting in salinity build up in the soil profile as long as an efficient drainage system is provided.

The main objectives of this study are (1) to investigate new ways of using saline water for corn production under semi-arid conditions; (2) to characterize the plant growth parameters of investigated variety as a function of irrigation with saline water at different salt concentration levels; (3) to evaluate the yield production and yield loss in relation to the salt concentration levels of irrigation water; (4) to determine the WUE under saline water conditions, which is a key parameter in a water saving program.

Materials and Methods

The experiment was conducted at the Research Station of the Irrigation and Agricultural Structures Department of the Cukurova University in Adana, Turkey during 2001 corn growing season. The station has latitude of 36°59'N, a longitude of 35°18'E, and is at 375 m above mean sea level. The soil of the experimental site is classified as Mutlu soil series (*Palexerollic Chromoxeret*) with clay texture throughout the soil profile. Available water holding capacity of the soil is 256.2 mm in the 120 cm soil profile. Mean bulk density varies from 1.19 to 1.25 g/cm^3. Average soil salinity (ECe=0.32 dS/m) at planting time is well below the salinity threshold level for reducing corn (ECe=1.7 dS/m) yield. Corn is classified as moderately sensitive to soil salinity (Maas, 1986). Typical Mediterranean climate prevails in the experimental site. Average annual rainfall is 630 mm, of which 65 % falls during the winter months.

Corn variety “Pioneer 3163” was planted on 19 April 2001 at a row spacing of 70 cm with a seeding density of 8 seeds per square meter. The experimental plot was fertilized with compound fertilizer of 15-15-15 a rate of 105 kg/ha N, P_2O_5, and K_2O at planting. Prior to second irrigation, all plots received 115 kg N per hectare on June 5 in the form of urea. A pre-emergence herbicide was applied prior to sowing and weeds appearing later were controlled by hand-weeding and hoeing.

Irrigation was applied by drip system and scheduled at weekly intervals using cumulative evaporation during the irrigation interval from the Class A pan located at the experimental station. Drip irrigation systems were installed on the surface of the plots after the plant establishment. In the experiment, two drip irrigation systems were used simultaneously, one for the canal water and one for the saline water. Both systems were operated at 100 kPa throughout the study. The control unit of the drip irrigation system for saline water consisted of a pump, gravel filter, disk filter, flow meter, control valves and pressure gauges. Drip irrigation system for the fresh water including a disk filter, flow meter, and a pressure gauge was directly connected to a pressurized hydrant at the experimental site.

There were 8 different treatments in the study. Saline irrigation water with electrical conductivities (ECw) of 3.0, 6.0, 9.0, and 12.0 dS/m (prepared using various dilutions of sea water with salinity of 54 dS/m in the pool with irrigation canal water with salinity of 0.5 dS/m) along with canal water. In addition, three treatments were included in the study by applying a 10% leaching fraction (LF) to treatments of 0.5, 6.0, and 12.0 dS/m after flowering (silking). Thus, a total of 8 treatments were studied. Namely, 0.5, 3.0, 6.0, 9.0, and 12.0 dS/m; 0.5+10%, 6.0+10%, and 12.0+10% LF after flowering stage. The experiment was a randomized block design with three replications giving a total of 24 plots. The experimental plot dimensions were 10 m in length, and 2.8 m (four plant rows) in width.

There were two quadruple (four) drip laterals laid in the center of two adjacent crop rows in each treatment plot. When all four laterals were connected to the saline water manifold, the treatment received saline water of 12.0 dS/m; if all four laterals were connected to canal water line, the treatment irrigated with water of 0.5 dS/m was established. When three laterals were connected to saline line, and one lateral was connected to fresh line, then a salinity treatment of 9.0 dS/m was established. When two laterals were connected to saline line, and two laterals were connected to fresh water line, then a salinity level of 6.0 dS/m was created. For the 10% leaching fraction, additional laterals were connected to the manifolds. In this study, in-line drip emitters with a flow rate of 4.0 L/h and, spaced 75 cm apart were used on laterals of 16 mm in diameter.

The amount of water applied to each treatment plot was based on cumulative evaporation from Class A pan within the irrigation interval of 7 days. Both drip systems were operated simultaneously during each irrigation event. The amount of water applied to treatment plots were monitored with flow meters. Rainfall and the other meteorological parameters were recorded at the research station.

Measurements

Plant growth stages

The plant growth stages were observed weekly throughout the study. For this purpose, three plants in each replicate were randomly selected representing all the characteristics of its treatment. Occurrences of different growth stages were monitored on these plants. Plant height measurements were also carried out on these selected plants and average plant height was calculated for each treatment.

Dry matter and leaf area index

The development of the above-ground portion of the crop was monitored by destructive sampling during the season. Plant samples were taken by cutting all plants in 1.0 m length of a row in each plot at two-week intervals. Leaf area of the samples was measured with an optical plant area meter. After leaf area measurements, all leaves and stems were dried in the oven at 68°C until constant weight was achieved.

Soil water

Soil water in each experimental plot was monitored with a neutron probe as well as by gravimetric sampling at 0-20, 20-40, 40-60, 60-80, 80-100 cm depths every week prior to each irrigation. An access tube was installed in each treatment plot to a depth of 150 cm. A calibration equation developed for the experimental site was used to calculate the soil water in the profile prior to irrigation.

Soil salinity

At planting, and at flowering stage all treatment plots were soil sampled at depth intervals of 0-10 cm, 10-20 cm, 20-40 cm, 40-60, 60-80, 80-100 cm using an auger. The electrical conductivity of the soil samples was measured on saturation extracts with an EC meter.

Crop water use (evapotranspiration)

Crop water consumption of the corn was calculated through use of water balance equation:

$$ET \quad I \quad P \quad S \quad D \qquad (1)$$

where ET is evapotranspiration (mm), I irrigation (mm), P precipitation (mm), D deep percolation (i.e., drainage, mm) and S is change of soil water storage in a given time period t (days) within plant rooting zone. The amount of water above the field capacity was considered as deep percolation in this study.

Water use efficiency (WUE)

Water use efficiency was computed as the ratio of yield to water use. Irrigation water use efficiency was determined as the ratio of wheat or corn grain yield for a particular treatment to the applied water for that treatment.

Harvest and harvest index (HI)

Corn plants were harvested by hand cutting all the plants in two rows each 6 m long at the ground level. Corn grain yield and biomass yield at harvest were determined for each treatment. Grain yield was adjusted to 15.5 % moisture content. In addition, 1000-seed weight was also evaluated.

RESULTS AND DISCUSSIONS

The seasonal amount of irrigation water applied, water use, biomass and grain yield, 1000-grain weight, water use efficiency and irrigation water use efficiency, and harvest index data are given in table 1. For good plant establishment, 35 mm of fresh water was applied equally to all treatment plots by means of a sprinkler system. The first treatment irrigation was applied on May 29, and soil water deficit was replenished to the field capacity. All irrigation treatments were terminated on July 31, thus, a total of 9 irrigation applications were made. The amount of water applied in each irrigation varied from 28 to 100 mm. All treatments received the same amount of irrigation water until the flowering stage. After flowering, 10 % leaching fractions was utilized in treatments of 0.5, 6.0, and 12.0 dS/m. Thus, the treatments without leaching received a total of 561.4 mm; treatments with 10% LF received 576.8 mm of irrigation water. Seasonal plant water use varied from 688.3 mm in treatment of 12 dS/m to 750.2 mm in the treatment plots irrigated with canal water. As the salinity of the irrigation water increased plant water uptake decreased slightly. Water use values were 746.4, 690.5, and 684.5 mm for treatments of 3.0 dS/m, 6.0 dS/m, and 9.0 dS/m, respectively. Cumulative evapotranspiration of corn crop under different treatments is shown in figure 1. As shown in figure 1, cumulative evapotranspiration of corn crop under different treatments were very similar. The effect of water salinity on plant water uptake with drip irrigation was slightly different. Water uptake was reduced approximately 8 percent in treatments with salinities higher than 6.0 dS/m as compared to plots irrigated with canal water.

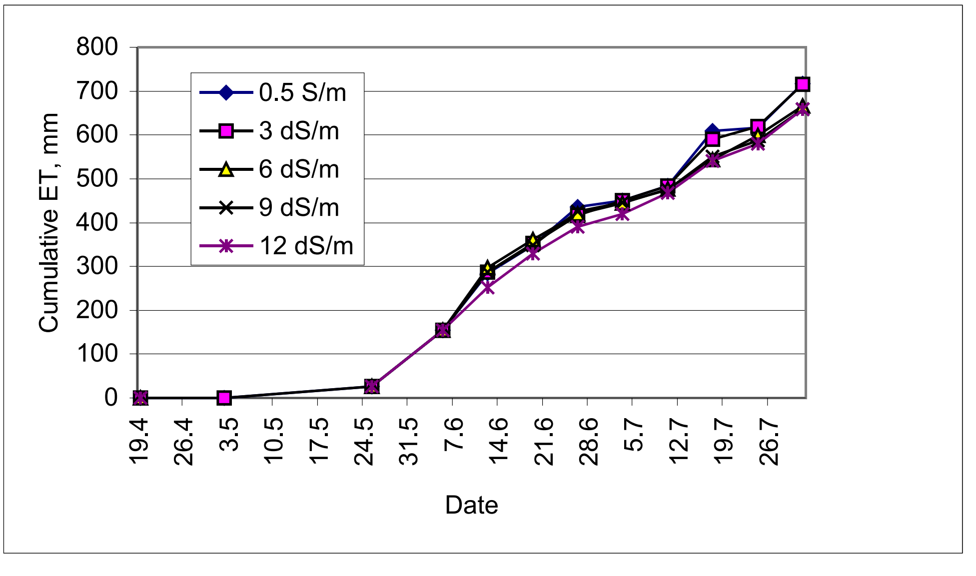

Fig 1. Cumulative evapotranspiration in the different treatments

Average corn grain yields obtained from different treatments are given in table 1, and variance analysis of the grain yield data is given in table 2. There was no significant difference in corn grain yields among the treatments studied as indicated by the variance analysis ($P<0.2197$). Highest yield averaging 8875 kg/ha was obtained from the treatment plots irrigated with canal water. The effect of irrigation water salinities on corn grain yield was similar in all treatments. Increasing irrigation water salinity increased salt concentration and osmotic potential in the root zone. However, due to nature of trickle irrigation, frequent water applications maintained the soil water content in the root zone in the first 50% of the available water, thus reducing the effect of osmotic potential on water uptake.

Corn is moderately sensitive to soil salinity. The degree to which productivity (as measured by grain or silage yield) is affected by soil salinity termed corn's salt tolerance. For corn grown on either mineral or organic soils, no grain yield reduction is expected if electrical conductivity of soil water is less than 3.7 dS/m or 2400 ppm of total dissolved salts in the soil water (Willardson et al., 1985). Maas (1986) gives salt tolerance of corn as 1.7 dS/m.

Sometimes crops are exposed to conditions differing significantly from those for which salt tolerance data were obtained. Several factors, including soil, crop, and environmental conditions interact with salinity to cause a different yield response (Rhoades, 1984).

There were no significant differences in dry matter production levels between salinity treatments. Dry matter yields varied from 1.707 kg/m^2 in treatment 12 dS/m+10% to 2.270 kg/m^2 in treatment 3.0 dS/m.

There was a trend of decreasing dry matter production with increasing water salinity. The development of the aboveground portion of the crop was monitored for each treatment at two-week intervals until harvest, and the results are shown in Figure 2. Development of leaf area index for different treatments is shown in Figure 3. As shown in this figure, corn crop irrigated with canal water resulted in highest LAI. Saline irrigation water treatments resulted in similar LAIs but smaller than that of the fresh water.

As shown in table 1, there were no significant differences in WUE, IWUE, 1000-grain weight, and HI among the treatments studied. Highest WUE value was found in the treatment of 12.0 dS/m as 1.22 kg/m^3. The lowest WUE value was observed in the treatment of 6.0 dS/m as 1.05 kg/m^3. The highest IWUE value was estimated in the treatment of 0.5 dS/m as 1.58 kg/m^3 and the lowest was found in the treatment of 12.0 dS/m+10% LF as 1.23 kg/m^3. 1000-grain weight values ranged from 273.5 g to 293.5 g among the treatments. Generally, treatments resulted in similar values for the abovementioned parameters.

Table 1. Biomass, grain yields, 1000-grain weight, WUE, IWUE, HI in different treatments

Treatments	0.5 dS/m	3.0 dS/m	6.0 dS/m	9.0 dS/m	12.0 dS/m	0.5 dS/m +10% LF	6.0 dS/m +10%LF	12.0 dS/m +10% LF
Biomass, kg/m^2	2.059	2.27	2.027	2.103	1.798	2.164	1.905	1.707
Grain Yield, kg/ha	8875	8295	7267	7533	8164	7377	8222	7087
1000-Grain, g	282.6	290.6	293.5	273.5	277.6	282.2	287.2	273.6
ET, mm	750	746	690	684	668	750	690	668
I, mm	561	561	561	561	561	577	577	577
WUE, kg/m^3	1.18	1.11	1.05	1.10	1.22	0.98	1.19	1.06
IWUE, kg/m^3	1.58	1.48	1.29	1.34	1.45	1.28	1.43	1.23
HI	0.23	0.27	0.28	0.28	0.22	0.29	0.23	0.24

Table 2. Analysis of variance table for corn yield values from different treatments

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	4828981.266	2414490.633	3.2654	0.0686
Factor A	7	8195179.298	1170739.900	1.5833	0.2197
Error	14	10351741.389	739410.099		
Total	23	23375901.953			

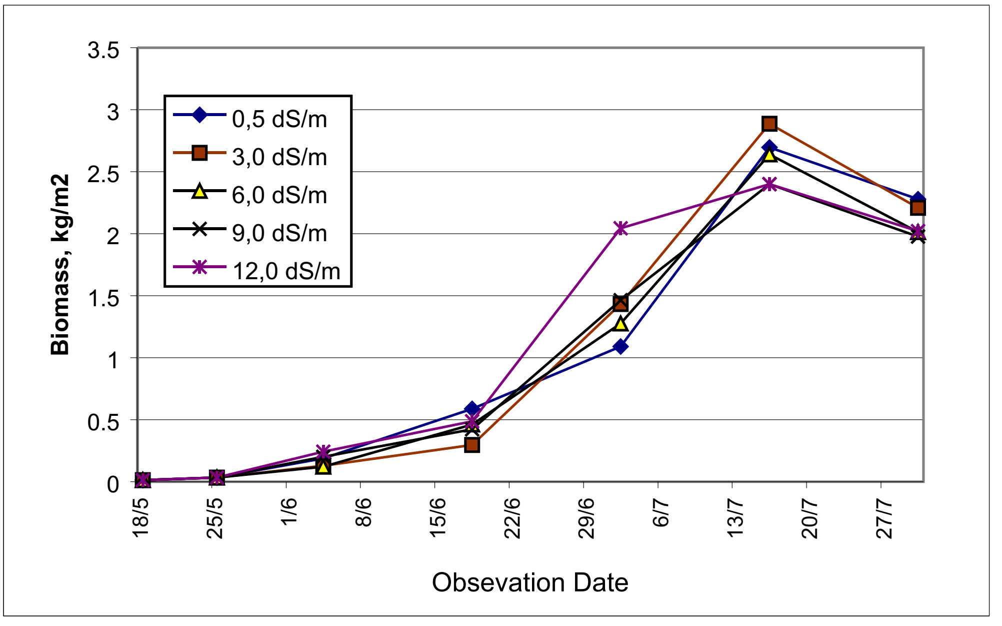

Fig. 2. Dry matter yield in the different treatments.

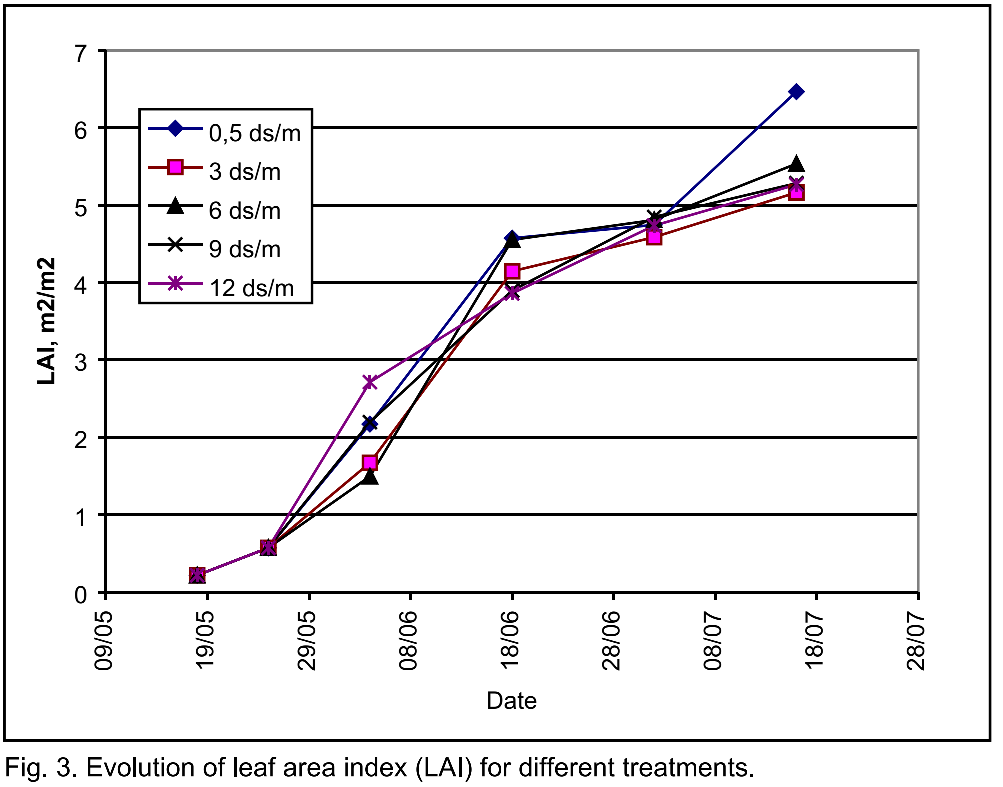

Fig. 3. Evolution of leaf area index (LAI) for different treatments.

Soil salinity

Soil salinity at planting varied from 0.295 dS/m at 100-120 cm soil layer to 0.310 dS/m at 10-20 cm soil layer. SAR values ranged from 0.27 to 0.55 at the time of planting. Before the salinity treatments were imposed, there were no significant differences in soil salinity or soil sodicity levels between the treatments. Soil salt distribution and concentration along the soil profile at planting, flowering, and harvest in different saline irrigation water treatments is shown in figures 4 and 5. The high salt concentration at the surface layer is due to high evaporation rate from the wetted areas and the nature of the soil water distribution associated with drip irrigation system.

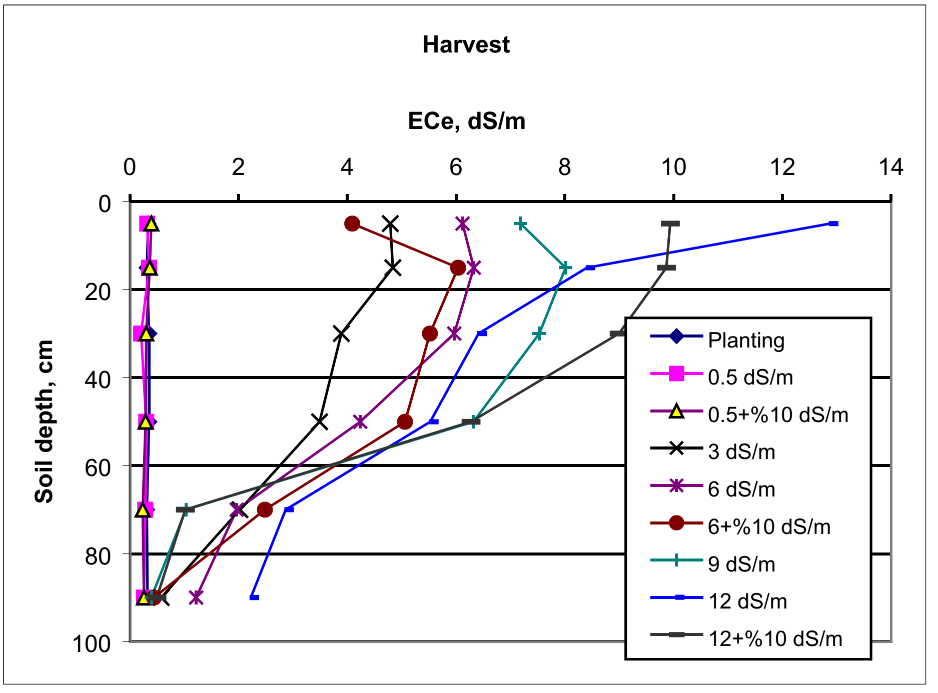

Fig. 4. Soil salinity profile at planting and at harvest in the different treatments

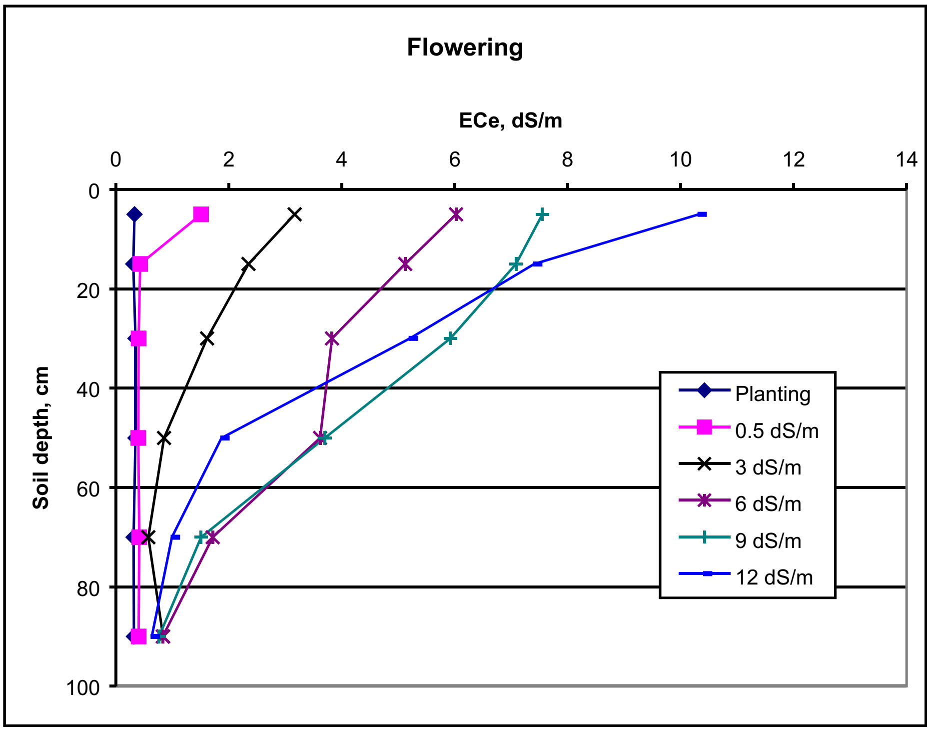

Fig. 5. Soil salinity profile at planting and at flowering in the different treatments

The general salt profile at saline irrigation water treatments followed the typical water distribution pattern under trickle irrigation (bulb shape) with maximum ECe occurring at the soil surface. In the control treatment (irrigation with canal water) maximum ECe was 1.5 dS/m at the surface layer at flowering stage. At harvest, profile salinity content decreased in all depths and salinity values were similar to those at planting time. A rainfall of 35 mm received before harvest leached the salts from the surface layer. Applying a leaching fraction of 10% after flowering did not affect the profile salt distribution significantly in treatment 0.5 dS/m+10% LF.

In treatment of 3.0 dS/m, ECe increased to a maximum of 3.0 dS/m at flowering and 5.0 dS/m at harvest in the 0-10 cm depth, and then gradually decreased with increasing depth following the wetting pattern of trickle irrigation. Soil salinity increased from planting to harvest period in all depths. In treatments of 6.0 dS/m and 6.0 dS/m+10% leaching, very similar salt distribution patterns to 3.0 dS/m treatment were observed. Maximum ECe occurred in the top 10 cm of the soil profile with a value of 6.4 dS/m at harvest. Profile salt content again increased towards the end of season as expected. Lowest salt content was measured in the soil layer of 80-100 cm. Applying a leaching fraction of 10% after flowering did not affect the profile salt distribution significantly in treatment 6.0 dS/m+10% LF as compared to 6.0 dS/m treatment except in the top soil layer in which salt content was 4.0 dS/m at harvest. In treatment of 9.0 dS/m, salt concentration distribution followed the same pattern as in the other treatments. Highest ECe of 8.0 dS/m was measured in the surface soil layer and then salt content decreased with increasing depth in the profile. Salt distribution at flowering and harvest had similar pattern. A rainfall of 35 mm received just prior to harvest reduced salt content in the top layer slightly. In treatments of 12.0 dS/m and 12.0 dS/m+10% leaching, resulted in the highest salt concentration throughout the soil profile as expected. The maximum ECe of 13 dS/m was measured in the surface soil layer in treatment plots irrigated with water of 12.0 dS/m. Salt content gradually decreased with increasing soil depth. Leaching reduced salt content throughout the profile in treatment 12.0 dS/m+10% as compared to 12.0 dS/m.

Generally, profile salt concentration increased with increasing salinity of irrigation water. Higher salt concentration in the top layer is due to high evaporation rate from the wetted surface.

When the concentration of sodium becomes excessive in proportion to calcium plus magnesium, the soil is said to be sodic (Maas and Hoffman, 1977). The sodium adsorption ratio (SAR) of irrigation water is a good indicator of the sodium status that will occur in the soil. Permissible value of SAR is a function of salinity. High salinity levels reduce swelling and aggregate breakdown (dispersion), promoting water penetration. SAR values were low at planting time ranging from 0.27 to 0.49 in different soil layers. SAR values increased drastically with the salinity content of irrigation water applied. In the treatment plots irrigated with canal water, SAR values remained low except SAR of the top layer. At harvest, SAR values were similar to those at planting. Maximum value of SAR was estimated in the treatment of 12.0 dS/m as 27.92. In other treatments, SAR values were in between values at planting and those in the 12 dS/m treatment plots.

Conclusions

There was no significant difference in corn grain yields among the treatments studied as indicated by the variance analysis. Highest yield averaging 8875 $kgha^{-1}$ was obtained from the treatment plots irrigated with canal water. Increasing irrigation water salinity increased salt concentration and osmotic potential in the root zone. However, due to nature of trickle irrigation, frequent water applications maintained the soil water content in the root zone in the first 50% of the available water thus reduced the effect of osmotic potential on water uptake.

There were no significant differences in dry matter production levels between salinity treatments. Dry matter yields varied from 1.707 kgm^{-2} in treatment of 12 dS/m+10% LF to 2.270 kgm^{-2} in treatment 3.0 dSm^{-1}.

Generally, profile salt concentration increased with increasing salinity of irrigation water used. Higher salt concentration in the top layer is due to high evaporation rate from the wetted surface. Soil salinity reached and exceeded the threshold level of 1.7 dS/m in the saline water treatments. However, due to frequent watering high water content in the profile was maintained, thus in turn reduced the effect of osmotic potential on water uptake as well as plant growth.

The general salt profile at saline irrigation water treatments followed the typical water distribution pattern under trickle irrigation (bulb shape) with maximum ECe observed at the soil surface. In the control treatment (irrigation with canal water) maximum ECe was 1.5 dSm^{-1} at the surface layer at flowering stage. At harvest, profile salinity content decreased in all depths and salinity values were similar to those at planting time. Rainfall of 35 mm received before harvest leached the salts from the surface layer. Applying a leaching fraction of 10% after flowering did not affect the profile salt distribution significantly in treatment 0.5 dS/m+10% LF.

SAR values increased drastically with the salinity content of irrigation water applied. In treatment plots irrigated with canal water, SAR values remained low except SAR of the top layer. At harvest, SAR values were similar to those at planting. Maximum value of SAR was estimated in the 12.0 dS/m treatment as 27.92. In other treatments, SAR values were in between values at planting and in the 12 dS/m treatment plots.

The study demonstrated that saline water can be used for irrigating corn crop in the Mediterranean region of Turkey when applied with trickle irrigation system.

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SUSTAINABLE USE OF HIGHLY SALINE WATER FOR IRRIGATION OF CROPS UNDER ARID AND SEMI-ARID CONDITIONS: NEW STRATEGIES

Wheat Yield Response to Irrigation With Saline Water Under the Mediterranean Climatic Conditions in Turkey

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Abstract

The response of wheat (*Triticum aestivum* L.) to different salinity levels of irrigation water under the Mediterranean climatic conditions was investigated in a field study at the experimental station of Cukurova University in Adana, Turkey during the 2001-2002 growing season. Saline waters with electrical conductivity values of 0.5 (fresh water), 3.0, 6.0, 9.0, and 12.0 dS/m were used for irrigation of wheat. The average grain yields ranged from 5940 to 6484 kg /ha in different treatments. Variance analysis of the grain yield data showed that the effect of salinity levels of irrigation water used in the study on grain yields was not significantly different. Average dry-matter yields varied from 1154 to 1349 g/m^2 from the different treatments at harvest time. However, treatments resulted in similar biomass yields. Since wheat was irrigated only twice during the growing season, and significant amount of rainfall received during the wheat growing period, salts added to soil with irrigation remained at insignificant level and did not affect the biomass yield of wheat. Harvest index values from the different treatments varied from 0.36 to 0.42. However, there was no significant difference among the treatments. Generally soil salinity increased with salinity content of irrigation water used in the study. Soil salinity decreased almost linearly with increasing depth in the profile. SAR values increased with increasing salinity of irrigation water. However, SAR values observed in all treatments did not constitute a serious threat to wheat growth under the study conditions. Thus, saline irrigation water can safely be used for irrigation of wheat crop in the Mediterranean region because of effective winter rainfalls leach the salts out of the root zone as long as an efficient drainage system is provided.

Key words: Saline water, wheat, trickle irrigation, water management

INTRODUCTION

The world is facing water scarcity in both quantity and quality. Limited supplies of fresh water are increasingly in demand for competing uses and create the need to use marginal quality water in agriculture (Hamdy, 1995). From the viewpoint of irrigation, the use of marginal quality waters require careful planning, more complex management practices and stringent monitoring procedures, than when good quality water is used (FAO, 1999; Beltran, 1999).

The decreasing availability of fresh water for agriculture use, while the need for production of food and fuel from plants is increasing, which is nowadays a problem common to many countries in the region. Under such condition of fresh water scarcity, agriculture is forced to use more and more waters of poorer quality or saline ones. Fortunately, there are abundant sources of those water sources that could be used successfully in irrigation, but they are still marginally used in the arid and semi arid countries of the Mediterranean. Water availability for irrigation in the region could be enhanced through proper use and management of saline water and the recycling of treated sewage water.

Saline water is a potential source for irrigation. Recent research developments on plant breeding and selection, soil crop and water management, irrigation and drainage technologies enhanced and facilitated the use of saline water for irrigating crops with minimum adverse effects on the soil productivity and environment. From the point of irrigation, the use of marginal quality waters will require careful planning, more complex management practices and stringent monitoring procedures than when good quality water is used (Hamdy, 1993; and Hamdy, 1996).

There is usually no single way to achieve safe use of saline water in irrigation. Many different approaches and practices can be combined into satisfactory saline water irrigation systems; the appropriate combination depends upon economic, climatic, social, as well as edaphic and hydrogeologic situations (Rhoades et al., 1992).

Salinity of irrigated agricultural soils can be managed satisfactorily for salt-tolerant and moderately salt tolerant crops when using saline water for irrigation (Ayars et al, 1992). Irrigation with saline water usually causes a progressive soil salinization, which is more or less severe according to salt supply, soil properties (whether clay or sandy), leaching caused by rainfall and applied irrigation technique. As the soil salinity rises, the osmotic potential soil water decreases resulting in reduced water availability and physiological diseases (Para and Cruz Romeo, 1980).

A careful selection of the crop and the variety most suited to a given environment is of paramount importance for obtaining high efficient production (Doorenbos et al, 1979). In general, Crops tolerate salinity up to threshold level above which, the yields decrease approximately linearly as salt concentrations increase (Mass and Hoffman, 1977). Using proposed linear response model (Mass and Hoffman, 1977), the maximum allowable salinity without yield decrease per unit increase in salinity beyond the threshold.

Deviation from the linear decrease occurs at yields considerably less than 50% of potential, at which level yields are unacceptable. Exceeding the threshold and knowing the threshold and slope obtained from the model, relative yield (Yr) for any given soil salinity exceeding the threshold could be calculated according to the following equation:

$$Yr = 100 - B\,(ECe - A')$$

Where:

- Yr: Relative crop yield expressed in percentage (%)
- A': The salinity threshold just beginning to decline expressed in dS/m.
- B: The slope expressed in (%) per dS/m (yield losses per unit increase in salinity).
- Ece: The mean electrical conductivity of the saturated soil extract of root-zone.

In a field experiment in 1983-86 at Kholapur, Maharashtra, wheat cv. HD2189 was grown after irrigated cotton cv. AHH 468 (crowbar method or furrow irrigation with saline water) or rainfed sorghum cv. CHS 9. Wheat was irrigated with saline water (2.4 dS/m) every 12 d (8 irrigations), at 6 growth stages (crown-root initiation, late-tillering, late-jointing, flowering, milk stage and dough stages) at 4 growth stages [not given] or at late jointing + milk stage. Wheat grain yields were decreased by 36 and 33% from 4 and 2 irrigations, respectively. Soil salinity levels increased with decrease in irrigation frequency, but this salt build up was leached out by the monsoon rains before the next winter season. The highest net returns were obtained from cotton with furrow irrigation-wheat cropping sequence (Deshmukh *et al.*, 1992).

Data *et al.* (1998) estimated the production function of wheat crop under saline conditions for determining the optimal mix of saline drainage water and good quality canal water at Sampla experimental station of the Central Soil Salinity Research Institute, Karnal (India). The electrical conductivity of soil (ECe) ranged from 25 to 80 dS/m in 0-15 cm layer to about 20 dS/m at depth 100 cm. The experiment was conducted under a fix wheat-fallow rotation, a common practice generally followed in the region where good quality irrigation water is not available in adequate quantities. The experiment consisted of five level of saline irrigation treatments (ECiw = 0.5, 6, 9, 12, 18 and 27 dS/m) along with recommended agronomic and cultural practices. They obtained quadratic form of the production function, which gave the best results. Optimum yield was obtained from the treatment irrigated with canal water as 5.9 t/ha, followed by 6 dS/m as 5.69 t/ha, and 9 dS/m as 5.39 t/ha. The treatment irrigated with saline water of 12 dS/m resulted in yield of 5 t/ha; 15dS/m gave 4.51 t/ha. As the salinity level of irrigation water increased yield level decreased accordingly.

The response of wheat to varying depths of irrigation, quantity of water applied and to the drainage conditions was studied in lysimeters filled with a sandy loam soil in India. Saline water with an electricial conductivity of 8.6 dS/m was used for irrigation. (Khosla and Gupta, 1997). They concluded that the reduction in growth as well as grain yield of wheat during saline water irrigation in the undrained lysimeters was mainly associated with larger depth increments and due to the sharp rise in water table depth. The occurrence of saline water table at rather shallow depths limited the proliferation of roots to lower depths and the soil water uptake was adevesely affected.

The main objectives of this study are (1) to investigate new ways of using saline water for wheat production under arid, and semi-arid conditions; (2) to obtain the characterizing the plant growing parameters of investigated varies as a function of irrigation with saline water of different salt concentration levels; (3) to evaluate the yield production and yield loss in relation to the salt concentration level of irrigation water; (4) to asses the salt balance under different irrigation programs; (5) to classify the investigated wheat crop with respect to its salt tolerance degree; and (6) to obtain the suitable leaching fractions for obtaining high yield from investigated wheat crop irrigated with saline water; (7) to determine the WUE under saline water conditions, which is a key parameter in water saving program.

MATERIALS AND METHODS

The field experiment was conducted at the Research Station of the Irrigation and Agricultural Structures Department of the Cukurova University in Adana, Turkey during 2001/2002 wheat growing season (November-June, 2002). Description of some physical and chemical characteristics the experimental soil is given in Table 1a and 1b.

Table 1a. Description of the some physical characteristics of the experimental soil

Soil Depth	Particle Size Distribution (%)			Soil Texture	Field Capacity	Wilting Point	Saturation Water Content	Bulk Density
cm	Sand	Silt	Clay		cm^3/cm^3	cm^3/cm^3	cm^3/cm^3	g/cm^3
0-5	28	21	51	C	42	23.8	51	1.19
5-15	28	21	51	C	42	23.8	51	1.19
15-30	28	21	51	C	42	23.8	51	1.19
30-60	28	19	53	C	45	23.2	54	1.16
60-90	28	18	54	C	44	21.8	55	1.15
90-120	27	19	54	C	42	18.8	50	1.25

As shown in Table 2a, the soil of the experimental site is classified as Mutlu soil series (*Palexerollic Chromoxeret*) with clay texture throughout the soil profile. Available water holding capacity of the soil is 256.2 mm in the 120 cm soil profile.

Table 1b. Description of the some chemical characteristics of the experimental soil

Soil Depth	Soil Salinity	pH	$CaCO_3$	O.M.	Cations (me/l)				Anions (me/l)		
(cm)	(dS/m)		(%)	(%)	Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	SO_4^{-2}	Cl^-
0-10	0.335	6.95	5.92	1.28	1.48	1.10	0.40	0.10	2.06	0.10	0.92
10-20	0.310	6.63	5.92	1.28	1.66	1.10	0.32	0.08	2.14	0.26	0.77
20-40	0.353	6.81	6.11	1.14	1.94	1.17	0.35	0.07	2.24	0.40	0.89
40-60	0.354	6.93	6.38	0.98	1.48	0.80	0.43	0.05	1.84	0.10	0.83
60-80	0.314	7.15	6.65	-	1.45	1.31	0.44	0.05	2.04	0.34	0.88
80-100	0.324	6.99	7.40	-	1.52	1.09	0.56	0.05	2.14	0.21	0.87
100-120	0.295	6.95	7.45		1.16	0.97	0.57	0.05	1.90	0.12	0.74

Table 1b indicates that soil salinity at planting time is well below the salinity threshold level for reducing wheat yields of ECe=6.0 dS/m. Wheat is classified as medium tolerant to soil salinity (Maas, 1986).

Crop Variety

Balatilla, a bread variety of wheat (*Triticum aestivum* L.) was planted on 24 November 2001 at a row spacing of 12.5 cm, and after plant establishment dikes were constructed around each plot since border irrigation was used due to close growing nature of wheat crop. Wheat grain yield will be determined by harvesting all plants in an area of 8 m^2 in each plot.

All plots received the same fertilizer treatment. At planting, 40 kg/ha urea (46% N) was applied. Ammonium nitrate (26% N) was applied at a rate of 400 kg/ha on February 23, 2002; Plots also received 160 and 200 kg/ha urea on March 12, and April 15, 2002, repectively.

Saline Irrigation Water

The saline water was prepared by mixing fresh water (0.5 dS/m) with sea water (54 dS/m) in order to obtain an average salinity level of 12 dS/m in a concerete pool with dimensions of 10m x 10 m x 2.5 m at the experimental site. Sea water was transported by a tanker from the Mediterranean Sea 65 km away from the experimental field. Saline irrigation water with electrical conductivities (ECw) of 3.0, 6.0, 9.0, and 12.0 dS/m (being various dilutions of stock solution in the pool with irrigation canal water) along with 0.5 dS/m canal water was applied commencing on March 29, 2002.

Treatments and Experimental Design

There were 6 different treatments in the study. Saline irrigation water with ECw of 3.0, 6.0, 9.0, and 12.0 dS/m (being various dilutions of stock solution in the pool with irrigation canal water) along with canal water with salinity of 0.5 dS/m. In addition, a treatment was included in the study by applying a 10% leaching fraction to 12.0 dS/m treatments after flowering. Thus, a total of 6 treatments were studied. Namely, 0.5, 3.0, 6.0, 9.0, and 12.0 dS/m; and 12.0+10% leaching after flowering stage were condidered. A completely randomised block design with three replications was utilized for the wheat experiment. Each plot will be 5 m long and 2.15 m wide. There will be a total of 18 plots in the study.

Saline irrigation water was prepared by mixing sea water with fresh water and stock saline water with electrical conductivity of 12.0 dS/m will be attained. Gated pipes were used for applying water to plots. For mixing saline water and fresh water at specified salinity level, tanks were utilized at the head of each plot. Flow meters were utilized to determine the volume of water applied to each plot. The amount of water to be applied to each treatment plot will be based on soil water deficit within the 120 cm soil profile during the irrigation interval of 14 days (Sezen *et a*l., 2001).

Measurements

Phenological growth stages

The phonological growth stages were observed weekly throughout the study. For this purpose, plants in each replicate for each treatment were randomly selected representing all the characteristics of its treatment. Occurrences of different growth stages were monitored on these plants. Plant height measurements were also carried out on these selected plants and average plant height was calculated for each treatment.

Dry matter and leaf area index

The development of the above-ground portion of the crop was monitored by destructive sampling during the season. Plant samples consisted of all plants within 0.5 m of a row were taken at two- week intervals. The plants were bagged and taken to the laboratory for determination biomass yield and leaf area index. Leaf area of the samples was measured with an optical plant area meter. After leaf area measurements, all leaves and stems were dried in the oven at 68°C until constant weight was achieved.

Stomatal conductance

Stomatal conductance measurements were carried out on five main treatments (0.5, 3.0, 6.0, 9.0, and 12.0 dS/m) during the vegetative growth stage before and after irrigation. The measurement is done with an automatic porometer (LICOR, inc, Model LI-1600), that diffuses water vapor. From each treatment fully developed upper two leaves were taken for measurement. Measurements were carried out during noon time.

Soil water

Soil water in each experimental plot was monitored with a neutron probe as well as by gravimetric sampling at 0-20, 20-40, 40-60, 60-80, 80-100 cm depths every two-week prior to each irrigation application. An access tube was installed in each treatment plot to a depth of 120 cm. A calibration equation developed for the experimental site was used to calculate the soil water in the profile prior to irrigation.

Soil salinity

At planting, and at flowering stage all treatment plots were soil sampled at depth intervals of 0-10 10-20 cm, 20-40 cm, 40-60, 60-80, 80-100 cm using an auger. Soil samples were air-dried and thencrushed to pass through a 2 mm sieve. The electrical conductivity of the soil samples was measured on saturation extracts (Ece).

Crop water use (evapotranspiration)

Water consumption of the wheat was calculated through use of water balance equation described by Garrity et al. [1].

$$ET \quad I \quad P \quad S \quad D \tag{1}$$

where ET is evapotranspiration (mm), I irrigation (mm), P precipitation (mm), D deep percolation (i.e., drainage, mm) and S is change of soil water storage in a given time period t (days) within plant rooting zone. The amount of water above the field capacity is considered as deep percolation in yhis study.

Water use efficiency (WUE)

Water use efficiency (kg/m^3) was computed as the ratio of grain yield (kg/m^2) to water use (m). Irrigation water use efficiency was determined as the ratio of grain yield for a particular treatment to the applied water for that treatment (Howell et al., 1994).

$$WUE= Y/ET \tag{2}$$

Where WUE is water use efficiency (kg/m^3); Y is grain yield (kg/m^2); and ET is water use (m).

Harvest Index (HI)

Harvest index (HI) is defined as the ratio of grain yield (kg/m^2) to aboveground biomass yield and calculated as:

$$HI=Y/DM \tag{3}$$

Where HI is harvest index, Y is grain yield (kg/m^2), and DM is dry matter yield (kg/m^2).

RESULTS AND DISCUSSION

The 2001-2002 wheat growing season in the experimental area had significantly higher than the long-term average annual rainfall of 630 mm during the season as 742 mm (Figure 1). Table 2 summarizes the average monthly climate data compared to the long-term mean climatic data for the Lower Seyhan Plain, where the experiment was carried out. Because of the above normal rainfall during the wheat growing season in the experimental area, wheat was irrigated twice. The first irrigation application was made on March 22, 2002 and 100 mm of water was applied to treatments with different salinity levels. Treatment of 12.0 dS/m+ 10% leaching received 110 mm. The second irrigation was applied on May 7, 2002 and 80 mm of irrigation water with different salinity contents were applied to the treatment plots. Treatment of 12.0 dS/m+ 10% leaching received 88 mm of irrigation water. Thus, a total of 180 mm of irrigation water with different salinity levels were applied to treatments except treatment 12dS/m+10% LF received 198 mm of irrigation water. Wheat in the Lower Seyhan Plain is not irrigated in general due to the sufficient winter rainfalls received during the growing season. However, the distribution of rainfall sometimes results in water shortages during the growing season and then supplemantary irrigation is required in the Mediterranean region of Turkey.

Table 2. Histori cal mean monthly and growing season climatic data of the experimental area

Climatic Parameters	Nov.	Dec.	Jan.	Feb.	March	April	May	June
Long-term average								
Average Temperature (C)	15.1	11.1	9.9	10.4	13.1	15.2	21.4	28.0
Rainfall (mm)	67.2	118.1	111.7	92.8	67.9	25.4	25.6	4.8
Relative Humidity (%)	63	66	66	66	66	69	67	66
Wind Speed (m/s)	1.6	1.9	2.2	2.2	2.3	1.6	1.9	2.5
Evaporation, CAP (mm)	66.3	47.0	47.3	56.1	84.9	118.6	195.6	320.5
2001-2002 Growing Season								
Average Temperature (C)	13.9	10.7	7.9	12.3	14.7	16.5	21.4	26.6
Rainfall (mm)	88.1	320.9	109.2	68.1	40.3	88.8	22.0	0.8
Relative Humidity (%)	67.4	78.2	66.1	64.7	67.4	76.0	68.4	62.9
Wind Speed (m/s)	1.6	1.8	2.1	2.3	2.3	1.7	2.0	2.4
Evaporation, CAP (mm)	73.4	36.1	58.9	64.0	88.9	72.5	155.2	215.5
Solar Radiation (cal/cm^2)	6527	3987	6923	8578	11108	12223	15710	16875

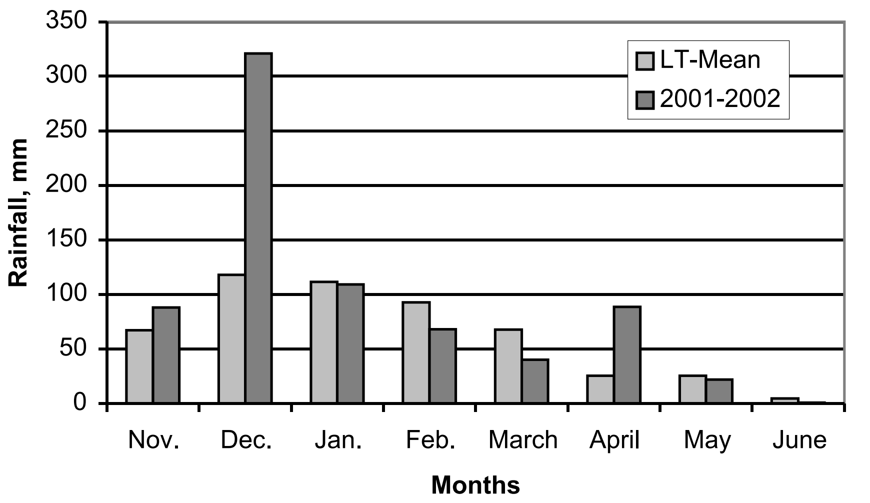

Fig. 1. Long-term and 2001-2002 wheat growing season monthly rainfalls, mm

Wheat grain yields, dry matter yields, waster use, water use efficiency, harvest index and 1000-grain weight values obtained from treatments irrigated with water with different salinity levels are shown in table 3. As indicated in table 3, the average grain yields ranged from 5940 to 6484 kg /ha in different treatments. Variance analysis of the grain yield data showed that the effect of salinity levels of irrigation water used in the study on grain yields was not significantly different (Table 4). Therefore, treatments resulted in similar wheat grain yields in this experiment. This result is expected because wheat was irrigated twice during the growing season due to significant amount of rainfall receivedin the study area in year 2002.

Table 3. Grain and dry matter yield, water use and water use efficiency data for the treatments

Salinity Of Irrigation Water (dS/m)	Dry Matter Yield (kg/ha)	Grain Yield (kg/ha)	HI	Seasonal Irrigation (mm)	Water Use (mm)	WUE (kg/m^3)	1000 Grain Weight (g)
0.5 (FW)	11500	6176	0.41	180	480	1.286	45,2
3.0	12000	5940	0.40	180	461	1.288	46,1
6.0	12620	6484	0.40	180	496	1.307	46,4
9.0	12850	6373	0.36	180	462	1.379	45,1
12.0	11650	6391	0.42	180	452	1.414	46,2
12.0+10%	11530	6427	0.38	198	445	1.444	46,8

Table 4. Analysis of variance for grain yield data

Variation Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	1572352.111	786176.056	7.0769	0.0122
Treatments	5	626553.778	125310.756	1.1280	0.4057
Error	10	1110906.556	111090.656		
Total	17	3309812.444			

Coefficient of Variation: 5.29%

Average dry-matter yields varied from 1154 to 1349 g/m^2 from the different treatments at harvest time. However, treatments resulted in similar biomass yields. Since wheat was irrigated only twice during the growing season, and significant amount of rainfall received during the wheat growing period, salts added to soil with irrigation remained at insignificant level and did not affect the biomass yield of wheat.

As indicated by the table 3, a total of 180 mm of irrigation water with different salinity concentration were applied to treatments without any leaching. The treatment with 10 % leaching received a total of 198 mm of irrigation water. Seasonal water use of wheat in different treatments ranged from 452 to 596 mm.

Since significant amount of rainfall received during the growing season, approximately 40 % of the total rainfall was considered as effective rainfall. Thus, the amount of rainfall greater than soil water deficit in the soil profile was considered as deep percolation. Thus, considerable amount of deep percolation occurred in this particular year, and leached out significant amount of salts from the profile. Water use efficiency (WUE) values from the treatments ranged from 1.286 to 1.444 kg/m^3. As the salinity level of irrigation water increased WUE values also increased slightly. However, the WUE values were not significantly different among the treatments studied.

Harvest index (HI), defined as the ratio of grain yield to dry matter yield, values from the different treatments are given in table 3. As shown in table 3, harvest index values from the different treatments varied from 0.36 to 0.42. However, there was no significant difference among the treatments as indicated by the variance analysis table.

Average 1000-grain weight values from the different salinity treatments ranged between 43.78 and 47.32 g. The variance analysis of the 1000-grain weight data is given in table. As indicated in the table, 1000-grain weight values obtained from the treatments were not significantly different. Thus, salinity of irrigation water did not have any effect on grain weight of wheat under the Mediterranean climatic conditions.

Soil Salinity (Ece)

Soil salinity profiles resulting from the different salinity treatments are shown in figures 2 through 7 Soil salinity profiles were established at planting, at flowering, and at harvest for each treatment studied. As shown in the figures, soil salinity at planting varied from 0.27 dS/m in surface soil layers to 0.50 dS/m in deeper layers. However, soil salinity throughout the soil profile was very low in the experimental soil. Soil salinity increased slightly in the surface layer (ECe=0.35 dS/m) in the treatment irrigated with fresh water.

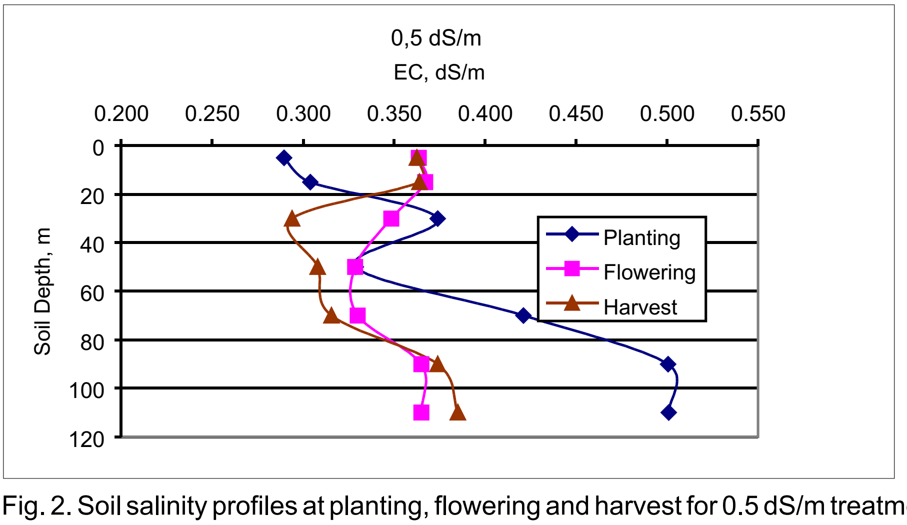

Fig. 2. Soil salinity profiles at planting, flowering and harvest for 0.5 dS/m treatment

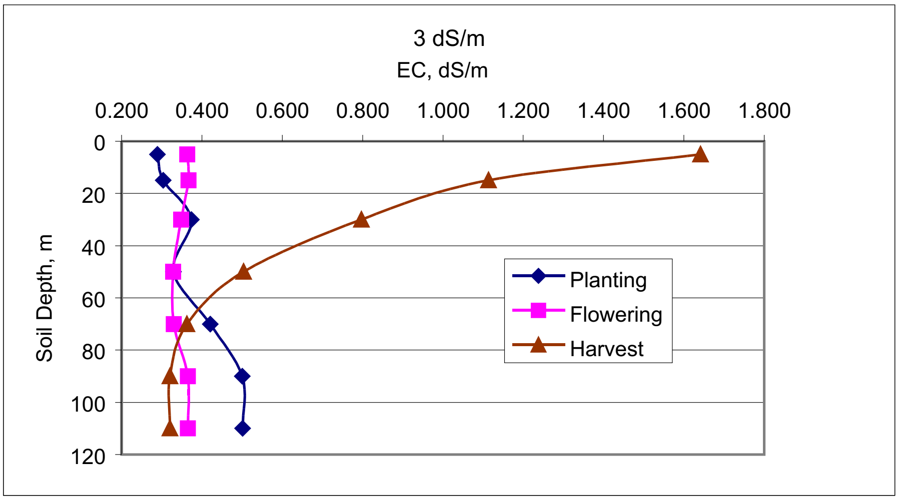

Fig. 3. Soil salinity profiles at planting, flowering and harvest for 3.0 dS/m treatment

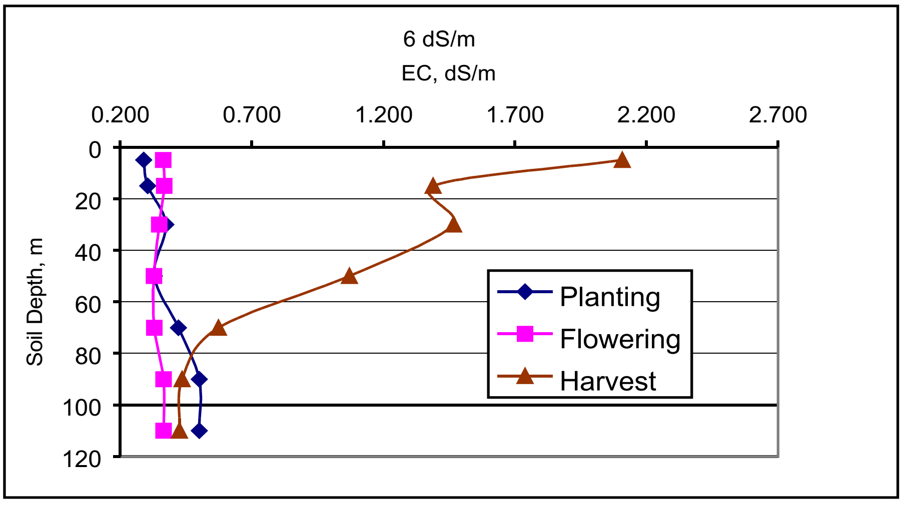

Fig. 4. Soil salinity profiles at planting, flowering and harvest for 6.0 dS/m treatment

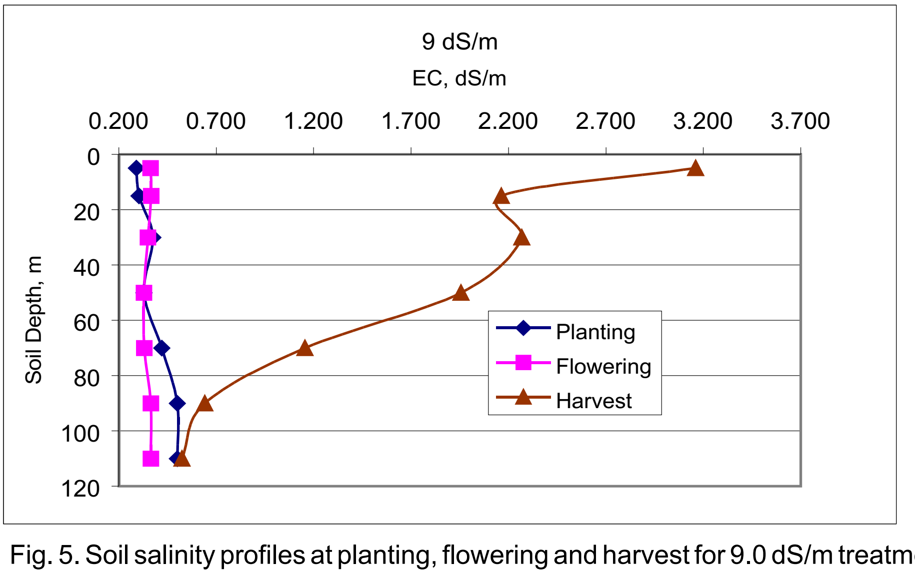

Fig. 5. Soil salinity profiles at planting, flowering and harvest for 9.0 dS/m treatment

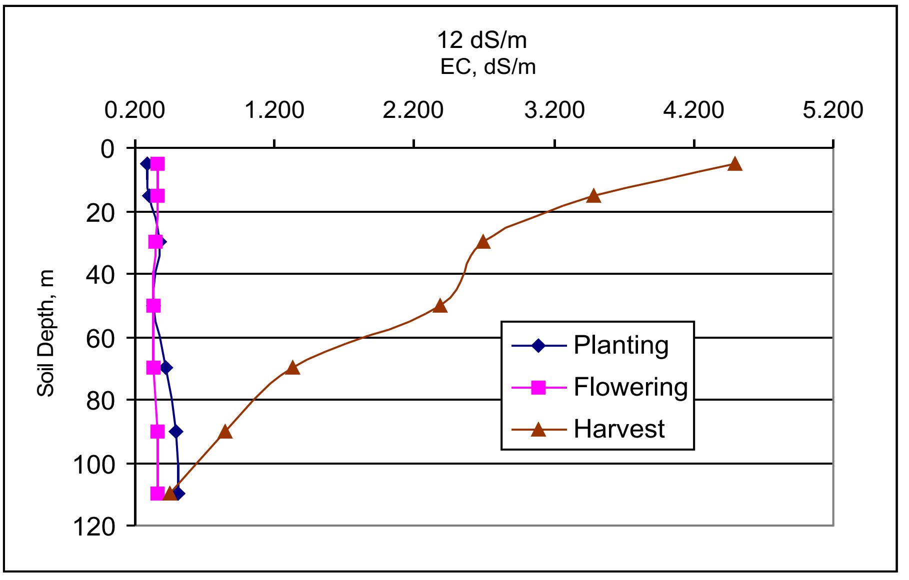

Fig. 6. Soil salinity profiles at planting, flowering and harvest for 12 dS/m treatment

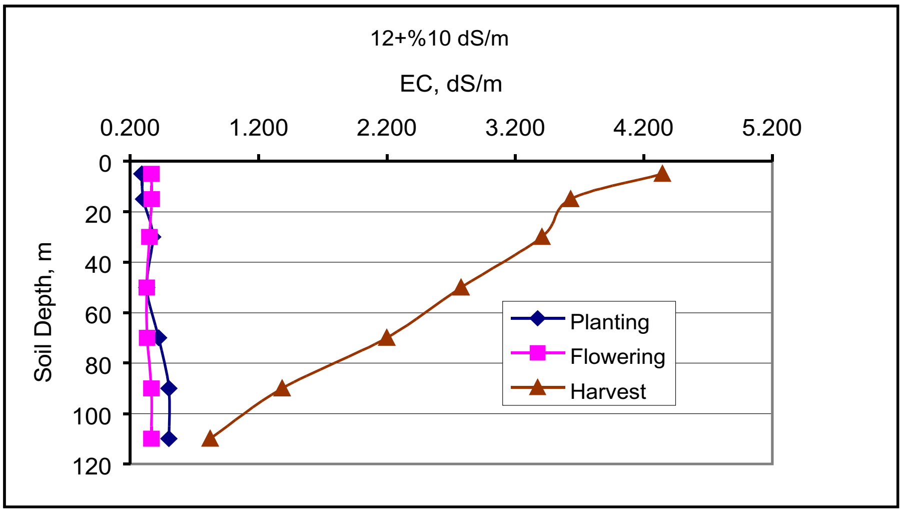

Fig. 7. Soil salinity profiles at planting, flowering and harvest for 12+10% dS/m treatment

Generally soil salinity increased with salinity content of irrigation water used in the study. Highest soil salinity was observed in the 0-10 cm soil layer in treatments irrigated with ECw of 12 dS/m and 12 dS/m+10% leaching as ECe=4.3 dS/m. Then soil salinity decreased almost linearly with increasing depth in the profile. Soil salinity in the 100-120 cm soil layer was 0.8 dS/m in these two most saline treatment plots. There was no significant difference is soil salinities in these two treatments. Soil salinity during the wheat growing period did not reach the threshold salinity level of 6.0 dS/m (Ayers and Westcot, 1985).

The treatment irrigated with saline irrigation water of 9.0 dS/m resulted in soil salinity of 3.2 dS/m in the top layer (0-10 cm) and 2.2 dS/m in the 10-20 cm layer. Then soil salinity decreased with increasing depth. The lowest salinity in the soil profile was observed in the 100-120 cm soil layer with 0.6 dS/m. Soil salinity during the flowering growth stage was very similar in all treatments and had salinities lower than 0.5 dS/m throughout the profile.

The treatment irrigated with saline irrigation water of 6.0 dS/m resulted in soil salinity of 2.1 dS/m in the top layer (0-10 cm) and 1.4 dS/m in the 10-20 cm layer. Then soil salinity decreased with increasing depth. The lowest salinity in the soil profile was observed in the 100-120 cm soil layer with 0.5 dS/m.

The treatment irrigated with saline irrigation water of 3.0 dS/m resulted in soil salinity of 1.65 dS/m in the top layer (0-10 cm) and 1.1 dS/m in the 10-20 cm layer. Then soil salinity decreased with increasing depth. The lowest salinity in the soil profile was observed in the 100-120 cm soil layer with 0.4 dS/m.

Rainfalls received during the growing season especially prior to flowering stage leached out the salts from the profile in all treatments studied. Irrigation application after the flowering stage resulted in increased soil salinities in saline irrigation water treatments since the rainfall received after flowering stage was not sufficient to leach out salts from the profile. Thus, saline irrigation water can safely be used for irrigation of wheat crop in the Mediterranean region because of effective winter rainfalls leach the salts out of the root zone as long as an efficient drainage system is provided.

Variation of pH of the saturation extracts under different treatments at harvest is given in Table 3.11. As indicated by the table, average pH values remained between 7.0 and 8.0 in all plots. There were no significant difference among the treatments with respect to pH values of the saturation extracts. Thus, pH is not affected by the saline irrigation water applications.

Average Na and Ca+Mg contents at different depths under different salinity treatments are given in table 3.12 and 3.13 , respectively. As shown in table, average Na contents generally increased with increasing salinity of irrigation water. Highest Na content was measured in the treatment irrigated with 12 dS/m +10% leaching as 26.88 meq/L in the top layer (0-10 cm), followed by 12.0 dS/m treatment as 25.50 meq/L. Na concentration decreased with increasing depth in the soil profile. Lowest Na concentration in general was determined in the 100-120 cm soil layer.

Highest average Ca+Mg contents were also measured in the surface layer of 0-10 cm under the treatment irrigated with 12 dS/m +10% leaching as 15.50 meq/L, and followed by 12.0 dS/m treatment with 13.50 meq/L in the 0-10 cm layer. In treatment irrigated with fresh canal water, highest Ca+Mg content was measured in 80-100 cm soil layer.

Highest average SAR value was determined in the top layer of soil as 9.74 in the treatment irrigated with water of 9.0 dS/m, followed by 12.0 dS/m treatment as 7.53 and 7.11 in the treatment irrigated with 12 dS/m +10% leaching. In general, SAR values increased with increasing salinity of irrigation water. However, SAR values observed in all treatments did not constitute a serious threat to wheat growth under the study conditions.

Stomatal Conductance (mmol/m^2 s)

Average stomatal conductances of wheat leaves measured in different dates under different treatments are given in table 5, and in figures 8 and 9.

Table 5. Stomatal conductance variation with salinity content of irrigation water

Salinity Treatments	Observation Dates					
	April 8	April 12	April 15	May.03	May.10	May.17
0,5 dS/m	760,7	698,7	398	1046	678	571,7
3.0 dS/m	936,7	661,3	309,7	776	763,7	688,7
6.0 dS/m	752,7	664,3	293	989	705,3	552,3
9.0 dS/m	382	608,7	253,3	666	678	704
12.0 dS/m	559	632,7	232,3	1012	695,3	758
12.0 + 10% dS/m	826	839	305,3	1034	607,3	830,7

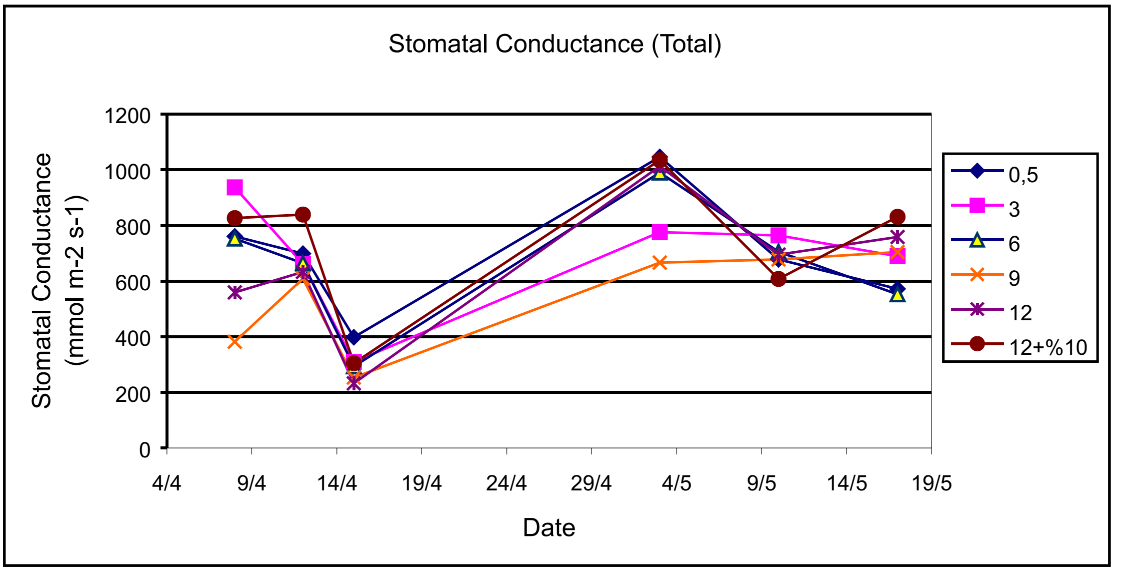

Fig. 8. Variation of stomatal conductance values of wheat leaves under different treatments

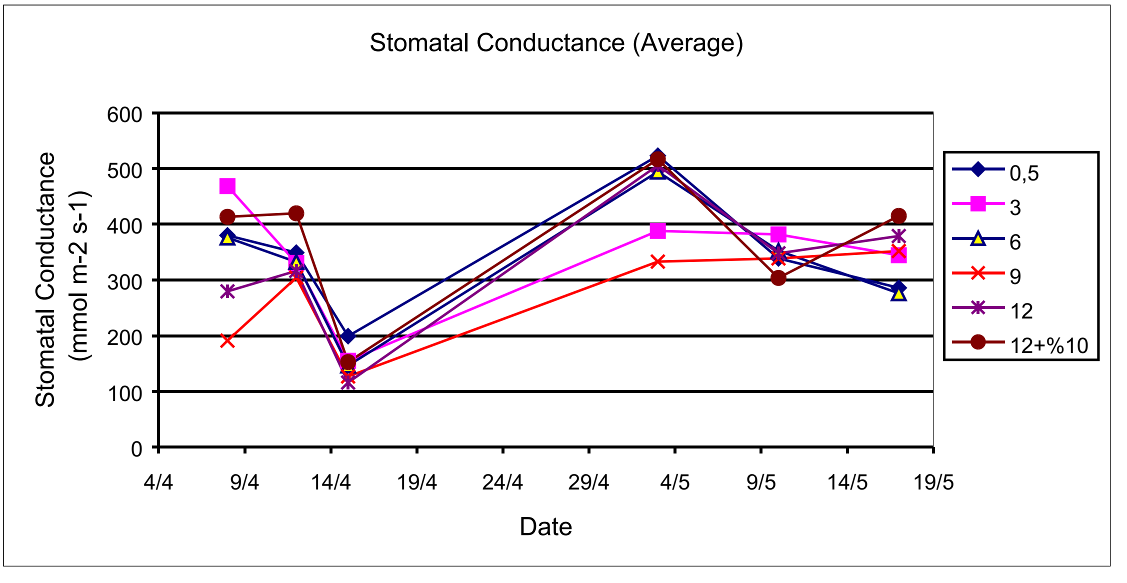

Fig. 9. Variation of stomatal conductance values of wheat leaves under different treatments

As indicated in the table, stomatal conductance measurements were started on April 8 and continued until May 17, 2002. Stomatal conductance (upper+lower epidermis) values on April 8, was highest in 3.0 dS/m treatment followed by 12 dS/m+10% leaching treatment. The lowest average stomatal conductance was observed in treatment of 9.0 dS/m as 382 mmhol/m^{2}s. A total of 5 mm of rainfall recieved prior to measurements on the same day. On April 12, stomatal conductances were very similar in all treatments except in 12 dS/m+10% leaching, in which highest value was measured as 839 mmol/m^{2}s. Stomatal conductance values decreased in all treatments on April 15. The highest stomatal conductance was measured in treatment irrigated with fresh water, and the lowest was observed in treatment of 12.0 dS/m. On May 3 a total of 2 mm of rainfall was received before the measurements, stomatal conductances reached their highest values in most treatments excep in treatment of 3.0 dS/m. Highest stomatal conductance was measured in treatment irrigated with fresh water followed by 12dS/m+10, and 12 dS/m treatments. On May 7, 80 mm of irrigation water of different salinity content was applied to treatment plots. Average stomatal conductance values slightly decreased on May 10 as compared to May 3 values. A total of 2 mm of rainfall was received on May 16. On May 17, slightly decreased on low salinity treatments, and slightly increased on higher salinity treatments.

CONCLUSIONS

The response of wheat (*Triticum aestivum* L.) to different salinity levels of irrigation water under the Mediterranean climatic conditions was investigated in a field study at the experimental station of Cukurova University in Adana, Turkey during the 2001-2002 growing season. Saline waters with electrical conductivity values of 0.5 (fresh water), 3.0, 6.0, 9.0, and 12.0 dS/m were used for irrigation of wheat.

The average grain yields ranged from 5940 to 6484 kg /ha in different treatments. Variance analysis of the grain yield data showed that the effect of salinity levels of irrigation water used in the study on grain yields was not significantly different.

Average dry-matter yields varied from 1154 to 1349 g/m^2 from the different treatments at harvest time. However, treatments resulted in similar biomass yields. Since wheat was irrigated only twice during the growing season, and significant amount of rainfall received during the wheat growing period, salts added to soil with irrigation remained at insignificant level and did not affect the biomass yield of wheat.

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Generally soil salinity increased with salinity content of irrigation water used in the study. Highest soil salinity was observed in the 0-10 cm soil layer in treatments irrigated with ECw of 12 dS/m and 12 dS/m+10% leaching as ECe=4.3 dS/m. Then soil salinity decreased almost linearly with increasing depth in the profile.

Highest average SAR value was determined in the top layer of soil as 9.74 in the treatment irrigated with water of 9.0 dS/m, followed by 12.0 dS/m treatment as 7.53 and 7.11 dS/m in the treatment irrigated with 12 dS/m +10% leaching. In general, SAR values increased with increasing salinity of irrigation water. However, SAR values observed in all treatments did not constitute a serious threat to wheat growth under the study conditions.

Rainfalls received during the growing season especially prior to flowering stage leached out the salts from the profile in all treatments studied. Irrigation application after the flowering stage resulted in increased soil salinities in saline irrigation water treatments since the rainfall received after flowering stage was not sufficient to leach out salts from the profile. Thus, saline irrigation water can safely be used for irrigation of wheat crop in the Mediterranean region because of effective winter rainfalls leach the salts out of the root zone as long as an efficient drainage system is provided.

Water use efficiency (WUE) values from the treatments ranged from 1.286 to 1.444 kg/m^3. As the salinity level of irrigation water increased WUE values also increased slightly. However, the WUE values were not significantly different among the treatments studied.

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AGRICULTURAL DRAINAGE WATER REUSE OPTIONS , POTENTIAL, COSTS AND GUIDELINES

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INTRODUCTION

The population growth rate and rising living standards are the most water related challenges facing Egypt. The most important challenge is Egypt's expected population growth from 59 million in 1997 till 83 million in 2017, and related water demand for public water supply and economic activities, in particular agriculture. Both challenges have put more stress on both land and water resources. Increased industrial growth together with intensified agriculture also has a direct impact on surface as well as ground water quality.

To satisfy the needs of this growing population Egypt has been engaged in an intensive program of economic development. New towns were built, modern industrial and agricultural projects were introduced, water resources management were adjusted and changed from supply management to demand management policy….etc.

Increasing pressure on available fresh water resources in many areas of the world creates continued interest in the use of marginal quality water for irrigation. The reuse of agricultural drainage water is already practiced on a large scale in several countries. Egypt is one of the leading countries in the reuse of drainage water for irrigation. Annually, Egypt uses 85% of its available fresh water resources in the agricultural sector, a situation that has resulted in a National Policy for the reuse of drainage water. Consequently, since 1988, an area of approximately 1million feddan in the Nile Delta depended on drainage water for irrigation. By the year 2017 it is expected that drainage water would contribute 8 billion cubic meters per year to country water resources. However, increased salinity is expected to limit full utilization of this amount. Intrusion of saline groundwater from the Mediterranean Sea contributes to the increased salinity conditions, in particular in the northern part of the Nile Delta.

The drainage water that flows out of the Delta to the sea represents part of the irrigation water that is in excess of crop evapotranspiration, in addition to canal tail water losses, and water disposed into or collected by the drain throughout its course(seepage from the aquifers. Under reuse practices, some of the drainage water is lifted out of the drains to the irrigation system at certain locations. A portion of this water flows back again to the drainage system either to the same drain or another drain and is conveyed out of the system to the sea.

The combined impact of urbanization and industrial production has created acute environmental problems. The compulsion for economic growth and lack of understanding of the long-term damage potential of pollution has resulted in the manifest deterioration of Egypt's natural resources. The Egyptian government has recently become increasingly aware of the importance of environmental risk management for economic development, health, and quality of life. The challenges facing the country in implementation of a nation wide program to improve the quality of the Egyptian Water Resources for generations to come, are taken seriously into planning consideration.

To protect the water resources environment from over consumption, pollution and rising threats from limited water resources and increased demand a concerted action from the government has to be promoted. The Drainage Water reuse became one of the major elements in water resources planning to increase water availability of different sectors and activities.

Background and Experiences on Drainage Water Reuse

The idea of reuse of drainage water in Egypt is as old as the construction of drainage projects. In the year

1928 the Upper Serw Pumping Station was constructed in the north-eastern part of the Nile Delta to lift water from the Serw drain and blend it with fresh water of Domietta Branch. The apparent reason for this is two-fold:

1. The quality of drainage water was reasonable and its quantity was small when compared with the discharge of Domietta Branch.
2. There was a need for additional supply of water at the tail-end of the system even at that early date.

Since then, mixing of drainage water with fresh water continued to cover the whole delta as well as different orders of irrigation canals.

The number of mixing points in the three parts of the delta (east, middle and west) has reached almost twenty-five stations so far.

In the Upper and Middle Part of country where the cultivated land is formed by a narrow strip running parallel to the River Nile, all drainage water is disposed back to the river. This was carried out early in the sixties when the High Aswan Dam was constructed and the majority of agricultural land in thins region was converted from basin into perennial irrigation.

The above mixing policy is adopted by the Ministry of Water Resources and as a part of its official policy. However, drainage water the spatial distribution of irrigation water in Egypt can never be absolutely even.

The areas at the heads of irrigation canals get more water on the expense of the areas at the tail-ends. Canals getting water at the beginning of the network obtain more discharges than those at the bottom of the system.

The Egyptian farmer, upon feeling that fresh water supply is becoming short, especially during period of peak demand, directly moves his portable pump to the nearest drainage to irrigate his field. This is not done automatically without knowing its consequences. Farmers have some clue about drainage water salinity, they know how tolerant their crop to this water, they use the appropriate management procedure of keeping the soil profile in the root zone always in a wet condition and finally they leach accumulated salts during low demand in winter when the supply is plentiful and the demand is minimal. It is worthwhile mentioning that the crop rotation plays an important role in this respect. If a low water consuming crop is grown in winter (like wheat), it is usually followed by rice, which leaches any accumulated salts. If a deep-rooted crop is grown in summer (like cotton) it is usually followed by berseem which is a highly water consuming crop. This succession system of cropping appears to be the main reason for having a state of equilibrium in most of the delta lands and it explains the constant and rather low salinities of these lands.

Another experiences gained from drainage water reuse when it was used to reclaim new areas in northern of the Nile Delta, where since 1948 Edko and Burolus lakes started to dried out to create new agricultural lands. These areas completed its drying up by year 1950, land reclamation. Authority received the areas in 1955 to continue reclamation operation. The main source of water used to reclaime these area was drainage water of Edko main drain in Western Nile Delta and Gharbia main drain in Middle Delta. The Drainage Research Institute was the lead institute to study the impact of such water quality on land reclamations process. The evaluation took place in pilot areas of about 7700 feddans laying to the east of lake Edko and of about 28,000 feddans falls to the north of the delta at the south east of lake Borollos. The results of these studies proves the possibility of using drainage water for land reclamation and leaching as long as salt concentration in water sources is less than that of the soil, provided that a complete, good, and sound drainage system should be available. Additional finding was the possibility of using drainage water for irrigation with good farm management and organization, which means application of suitable irrigation methods together with carrying out leaching operation from time to time.

The drainage system in Egypt is only a juvenile when compared with the irrigation system. Although some drainage projects were executed as early as 1920, yet, it was only late in the sixties when intensive drainage projects started. Since then, measurements on drainage water were carried out in order to quantify the factors that affect irrigation-drainage relationship and to finally get an insight into the conveyance, application and overall efficiencies of the irrigation system. Preliminary investigations revealed that vast quantities of drainage water of reasonable quality flow to the Mediterranean Sea and the coastal lakes every year. This fact strengthened the desire to conduct accurate measurements aiming at either the reduction of these flows by improving irrigation efficiencies or the reuse of good quality drainage water for irrigation purposes or both.

The present prolonged drought in South and East Africa, which started to affect water resources in Egypt, changed this desire into a real must.

The Drainage Research Institute with the continuous help and assistance of Dutch government took the lead in establishing a network of measuring stations on the key points of main drains in the Nile Dleta and Fayoum in the late seventies and continued till almost year 2000 and then extended by Canadian government. In less than ten years, a semi-automated network was kept functioning, measurements on regular basis are made, rating curves for each location were furnished and regularly updated, measuring equipment installed and periodically maintained and a smooth flow of data from the field until the publication of yearbook including all details was accomplished. The measurement programme enables obtaining information about quantity and quality of drainage water at the present time. Future estimates can only be known by prediction. Mathematical models are the appropriate tools used in this respect.

The SIWARE model (Simulation of Water Management in Arab Republic of Egypt) was formulated in a fashion that follows mathematically the flow of water from the source (Delta Barrages) down into the conveyance network till the lowest order to the distributary canals from which farmers abstract water to irrigate their fields. On-farm irrigation, evapotranspiration, drainage water generation and redistribution of salts in the soil profile is then simulated to get the change in quantity and quality of drainage water when any expected changes in water management policies, cropping patterns, water duties,... etc. take place. Thanks for the Dutch continuous help and Assistance for DRI in this field.

Currently; with the support of the Canadian AID for development, the Drainage Research Institute extend the work done by the African development bank (DWIP) studies on the impact of drainage water irrigation on the soil characteristics and crop yield production. The study include different new dimension such as the impact on socio economic conditions, health aspects , development of indicators to measure the awareness of the new graduated students, investors by the environmental status in the area. The study also involve the private sectors in the development and management process by introducing the soil and water extension services; and farmer and grower participation on farm management.

Generally; Fig (1) shows the current on going reclamation project in both Eastern and Western Nile Delta which depend on agriculture drainage water, which evaluated as in total of 823,000 feddans(330,000 hectares)

All the above experiences gained in the field of drainage water reuse withrespect to management, operation and prediction were used in the current studies to fulfill the following objectives:

Crop yield responses to farm management;
Potentiality of Drainage Water Reuse ;
Farmer Participation and Water User Associations;
Costs / Benefits of Drainage Water use;
Application of Drainage Water Reuse Guidelines.

Drainage Water Reuse Options

Description of the Experimental Field

Mariut experimental field station is located just off the Cairo/Alexandria desert road, about 35 km south of Alexandria. The site is situated within a traditional farming area that is composed of small farms near the tail end of main irrigation canal. Farmers in this area use the traditional Egyptian farming methods including surface irrigation in furrows and basins. The irrigated land is provided by subsurface drainage systems, which was installed in May 1999. The site is irrigated directly from the intake of distributory canal taking its water from Abu-Khalifa Canal which already use mixed supplied water from drainage water by Mariut Pumping Station with fresh water taking from Nubaria main canal.

The experimental field suffers from problems related to irrigation practices. These problems are:

Water shortage due to the over-irrigation by farmers at the head of the canal (the site is at the tail-end of the distributory canal)
Increased salinity of the irrigation water.
Increased ground water salinity and increased $CaCO_3$ contents

General water quality of the irrigation canal ranges between 2-4 mmhos/cm, depending on the mixed quantity of drainage water with the fresh water. The irrigation and drainage water mixing is carried out, based on water levels in irrigation canals and not on preset mixing ratios.

The nature of the soil is calcareous soil with predominantly light composition.

The growing seasons in the region are two main growing seasons per year. The winter season which runs from about October to May and the summer season which runs from April-May to October. The selected crops during the experiment period were maize and sunflower for summer season.

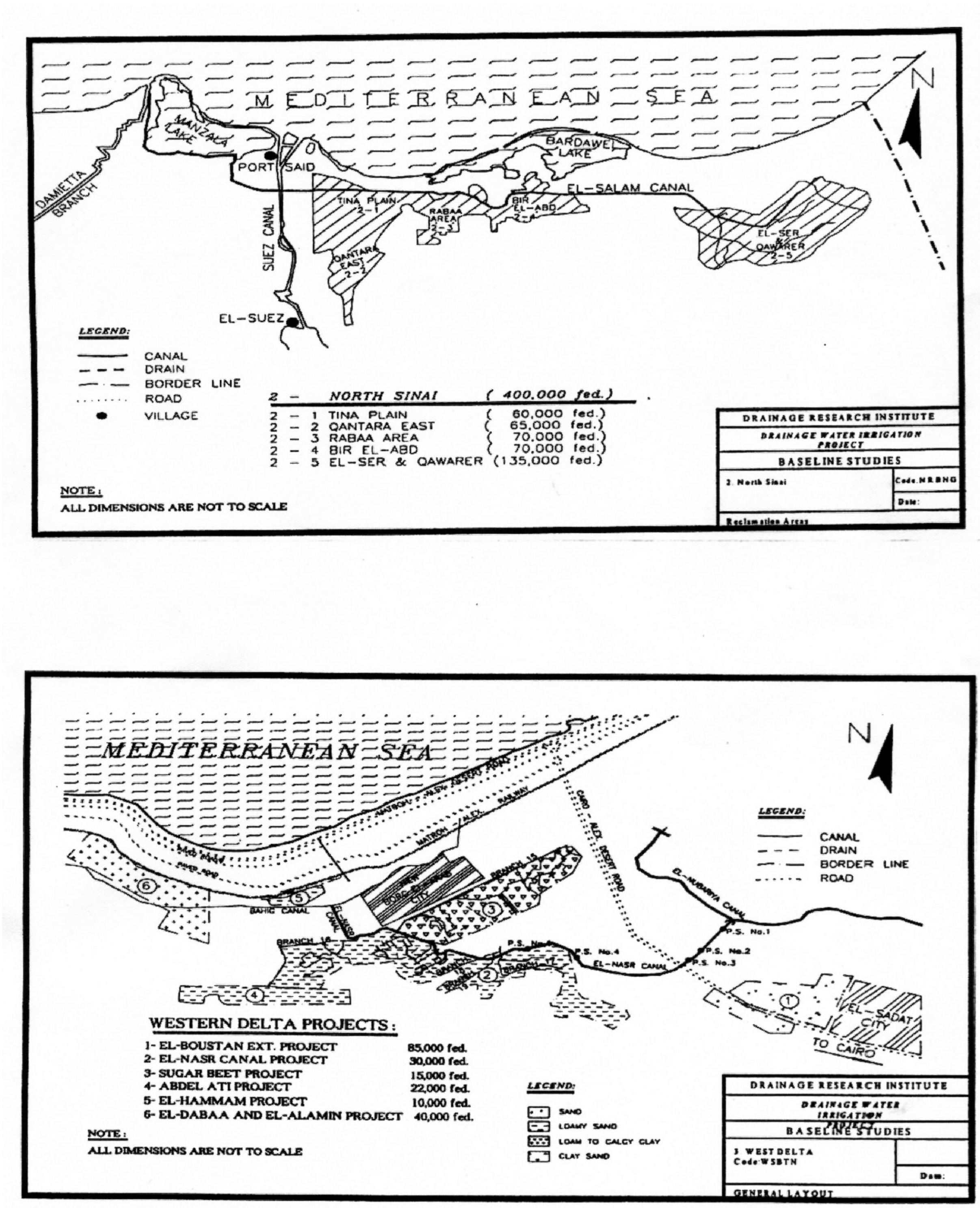

Fig. 1. New reclamation project using agriculture drainage water

Experimental Design

The field study was carried out in a 4.2 ha. field with a sand-silty loam soil. The area was provided with line field irrigation canal with constructed gated pipe to each field plot. See Fig.(2) below:

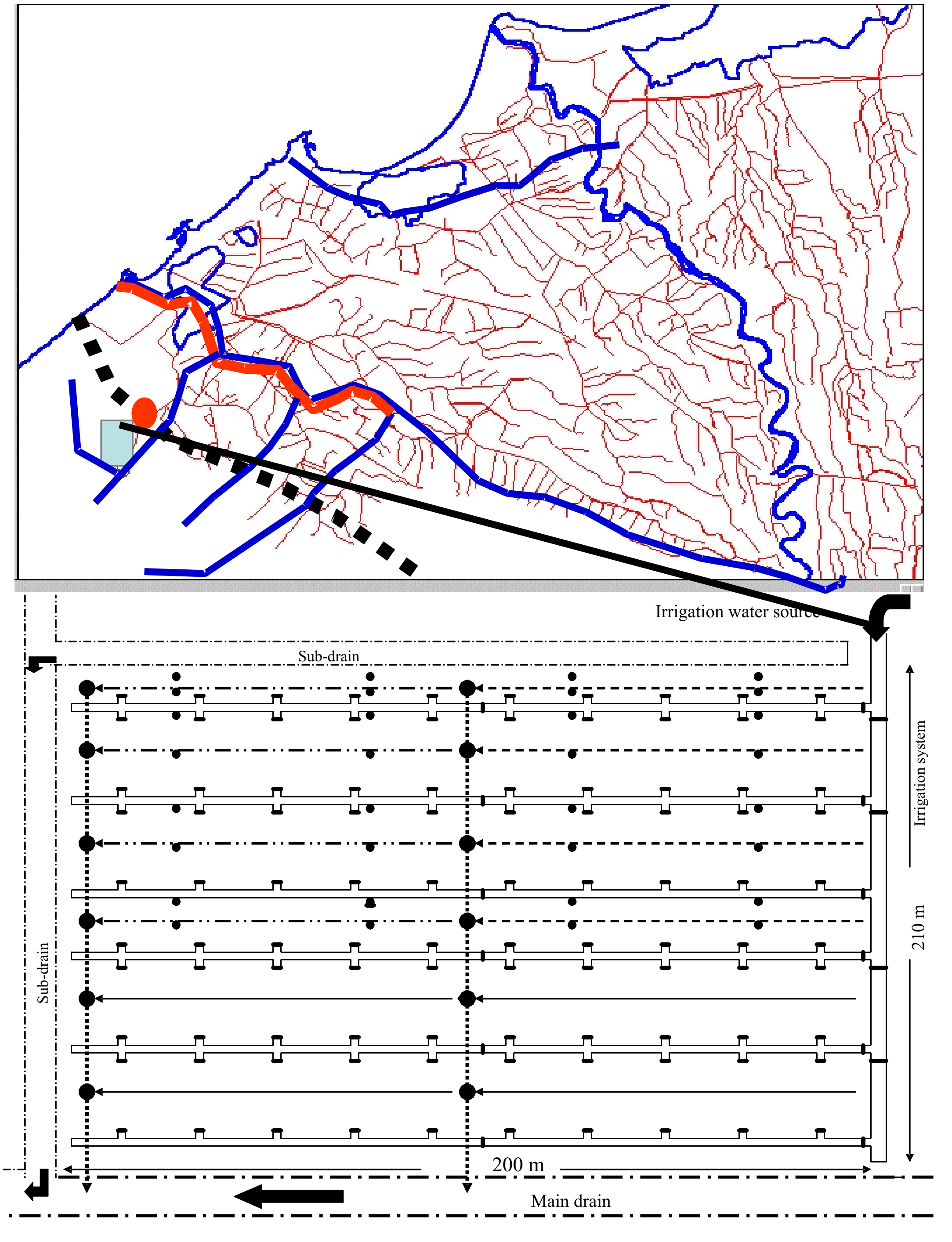

Fig. 2. Layout of the irrigation and drainage system in the experimental fields

The treatment strategies tested in the area are:

- Fresh water (FW) strategy where the sole use of canal water supplied to 50% of the experimental field. This strategy is considered as the overall control treatment

- Drainage water (DW) strategy where the sole use of the drainage water supplied from main drain serving the area to the other 50% of the experimental farm.

This strategy represents the conventional method for utilizing drainage water in areas suffering from water shortage of irrigation water supplies.

The irrigated crops within each part of the experimental field are: maize and sunflower used in the area as animal fodder and oil extraction respectively.

Soil characteristics

The experimental field is located in Western Delta, specifically in the new old land that have been reclaimed and extended since early 1960. The area is considered to have sandy soil type with very low soil moisture content and with active internal drainage in the presence of quite a high percentage of calcium carbonate $CaCO_3$, which has some impact on soil characteristics.

A soil profile of six tensiometers were installed in the study area. Installation depth were .15, .30, .40, .80, 1.2, and 1.6 m. theses were monitored daily in the growing season . the tensiometers measured total and matric potential of water in the soil profile at different depths. The total potential values were used to indicate direction of water movement in the soil and the matric potential values were used to give a measure of soil wetness. The samples were collected in three stages during the summer seasons: initial, middle and at the end of the season to be able to follow up salinity status during irrigation. Results of the analyzed samples showed the following :

soil texture analysis showed that about 52% of the samples collected from the area were loam soil texture and about 11% are silty loam and 9% sandy loan soil texture respectively. In general, the tested soil type could be considered as loamy soil.

The $CaCO_3$ percentage was as high as 53%, and the overall average of $CaCO_3$ content about 48%, even the minimum value of $CaCO_3$ is considered as very high where it reached 19%. Therefore, the experimental field soil is considered as loamy calcareous soil.

Soil moisture release curves were prepared in situ for the study site using coinciding soil moisture and potential measurements at five depths in the soil profile. These curves indicate how much water will be lost from the soil profile for a given decrease in potential caused by, for example, root water abstraction or gravity drainage. As the pressure potential in soil decreases, the largest pores empty of water first, followed by successively smaller pores.

As the soil dried beyond this it became increasingly difficult to extract water. Thus, the soil is characterized by large pores which hold most water. It is very permeable and dries out rapidly following water application. As expected for a sandy soil, it drains quickly and has a small water holding capacity.

The moisture content for a given potential value became higher with depth. This implies there are textural differences with depth. The soil's water holding capacity increased with depth, implying a higher percentage of small pores. This is borne out to some extent by the textural analysis which indicated increasing proportions of fine soil particles with depth.

Field capacity matric potential vary between -50 and -200 cmH_2O. This equates to a moisture content between 18% and 22% by volume. This is low moisture content for field capacity and highlights the poor water holding capacity of this soil.

The soil chemical analysis of soluble salts along the season (initial, middle and end of the season) showed the following results.

- Saturated soil paste of the samples was almost around 40-50% because of its sand and loam content.
- Soil salinity in soil extracts was ranged between 2-4 mmhos/cm except at the end of the seasons where it was observed at higher values (5-6 mmhos/cm).

- Dominant salts are Na, Cl and Ca or Mg SO_4. Na concentration was found to be 15-30 meq/l, while Ca and Mg ranged between 4-6 and 4-10 meq/l respectively. The chloride and sulphate ions ranged between 16-30 and 5-15 meq/l respectively.

Soil salinity analysis during different stages of growing season were done and results are presented in Table 1. It was obliviously that an increase in soil salinity from 4 to 7 mmhos/cm within canal water irrigation treatment, and also it could be observed an increase of soil salinity to about 9 mmhos/cm within the drainage water irrigation treatment.

Salinity distribution along the soil profile showed no trends and no significant changes. Sometimes there is salinity build up on the top soil layer rather than the lower layers, which may be explained by the fact that salts are moving up from lower layers to the top soil layer during the dry period between irrigation intervals and during the non-irrigation period at the end of the season.

Due to irrigation with low water quality (in both irrigation water treatments) salinity build-up is expected. This observation may be considered for the next irrigation season by applying proper leaching fraction. Also this salinity build-up is not harmful in soil characteristics when soil texture is loamy (which is considered as light soil) and allow fast removal of salts to the drainage system in the next sequence irrigation. Problems of such leaching fraction should be determined according to irrigation water quality and soil salinity.

Table 1. Soil Salinity status in dS/m under different irrigation conditions

	Fresh (Mixed Nile and drainage) Water Treatment			**Pure drainage Water Treatment**		
Sun Flower	**initial-sum**	**Mid-sum**	**end-sum**	**initial-sum**	**Mid-sum**	**end-sum**
	4.65	5.45	5.62	19.85	26.50	53.00
	3.45	5.95	5.43	20.65	64.50	37.65
	3.60	5.10	6.76	20.40	21.30	35.25
	5.10	5.60	7.13	19.75	17.80	27.90
Maiz	3.30	5.40	5.92	7.25	5.745	9.17
	5.35	5.55	7.28	3.4	5.915	6.905
	4.45	5.30	6.19	3.4	5.805	7.405
	3.30	4.75	8.43	3.65	5.985	6.855

Irrigation

Irrigation water supply and its salinity are considered as major parameters in on-farm management where they contribute to sustainable water and salt balance in the experimental farm, especially when salt content of such supplied water is classified as "salty water". Generally, it was observed that farmers are using extensive water to overcome salinity. Results of irrigation measurement (quantity , quality and average salt load) are given in Table 2 ,3, 4, 5 where one can find the following:

Irrigation water quantity given for each gift expressed as depth in cm. the overall quantity of irrigation water for each treatment also given as depth and m3/feddans.

Maize crop receives about 4486m^3 of canal irrigation water treatment and 4473m^3 drainage water per feddan ; while in the Nile Delta areas such crop receives about 3230 m^3/feddan, of canal good water quality. It was noticed that maize crop received 8 gifts while the normal field in Nile Delta receives from 6 - 7 irrigation gifts during the growing season.

The irrigation process adds about 10.14 and 10.5 tons of salt to the irrigated fields, while the normal field irrigated with good water quality of 300 ppm adds about 0.96 tons of salt

Sunflower crop receives 6 irrigation gifts. The quantity delivered through irrigation water is estimated as 2956m^3 with canal and 3007m^3 with drainage water m^3/feddan/season. These quantities add about 7.10 and 7.4 tons of salt respectively to both treatments. While in comparisons with irrigated sunflowers in Nile Delta with good water quality it receives about 3000 m^3/feddan/season through about 5-6 irrigation gifts.

Table 2. Irrigation Water depth (in Cm) Given under different Treatment

Date	**Treatment**			
	Fresh Water		**Drainage water**	
	Maize	Sunflower	Maize	Sunflower
08/06/01	11.75	13.38	12.00	14.12
19/06/01	14.09	7.54	12.20	8.47
27/06/01	12.57	11.39	13.23	9.59
12/07/01	14.83	14.16	14.27	13.71
29/07/01	13.20	11.94	12.57	13.23
16/08/01	14.18	11.99	14.04	12.48
02/09/01	13.83		14.42	
16/09/01	12.36		13.78	
Total quantities in (Cm depth)	106.82	70.40	106.52	71.60

Table 3. Irrigation Water Salinity (dS/m) Given under different Treatment

Date	**Treatment**			
	Fresh Water		**Drainage water**	
	Maize	Sunflower	Maize	Sunflower
08/06/01	4.57	5.10	4.38	4.44
19/06/01	4.32	4.25	4.60	4.46
27/06/01	3.74	3.72	3.87	4.11
12/07/01	2.81	2.88	3.55	3.25
29/07/01	3.35	3.40	3.34	3.48
16/08/01	3.30	3.30	3.38	3.49
02/09/01	3.12		3.21	
16/09/01	3.22		3.22	

Table 4. Quantity of Salts(in Tons) added with supplied irrigation water

Date	**Treatment**			
	Fresh Water		**Drainage water**	
	Maize	Sunflower	Maize	Sunflower
08/06/01	1.44	1.83	1.41	1.68
19/06/01	1.64	0.86	1.51	1.02
27/06/01	1.26	1.14	1.38	1.06
12/07/01	1.12	1.10	1.36	1.20
29/07/01	1.19	1.09	1.13	1.24
16/08/01	1.26	1.06	1.27	1.17
02/09/01	1.16	0.00	1.24	0.00
16/09/01	1.07	0.00	1.19	0.00
Total Salts added in Tons	10.14	7.09	10.50	7.36

Table 5. Quantity of Salts added with irrigation under different Irrigation Treatment Compared with Nile Water Irrigation (400ppm)

item	Treatment			
	Fresh Water		Drainage water	
	Maize	Sunflower	Maize	Sunflower
Within The Study Area				
Supplied Water m3/feddan	4486.23	2956.75	4473.64	3007.33
Added Salts Ton/feddan	10.14	7.09	10.50	7.36
Within Delta Areas				
Supplied Water m3/feddan	3230	3230	3230	3230
Added Salts Ton/feddan	0.969	0.969	0.969	0.969
Ratio				
Supplied Water	1.39	0.92	1.39	0.93
Added Salts	10.47	7.31	10.83	7.60

Notice : 1 feddan = 4200 m2

Figure 3 shows the quantity of irrigation water and salts added to different treatments supporting these findings. Analyzing the above mentioned results the following information could be concluded :

There is no clear difference between quality of canal water and drainage water used in the pilot farm. This may be explained based on the fact that such areas are located at the tail end of irrigation distribution systems and are subject to supplementary irrigation water by drainage system crossing the canal to increase the irrigation canal water levels. This increases salinity of irrigation water supplied by such canals, and contributes to the increase of salts quantity added to the agricultural fields in these areas.

Irrigation water supplied to these areas are 40% more if it is compared to areas in the Nile Delta. Therefore, it could be considered that the leaching fraction used in such areas is about 0.4 to overcome salinity of the supplied irrigation water. This fraction is considered a very large fraction which adds more salts to the irrigated areas and adds additional costs for farm irrigation. Therefore the leaching fraction of such areas should be determined according to its irrigation water quality and soil characteristics

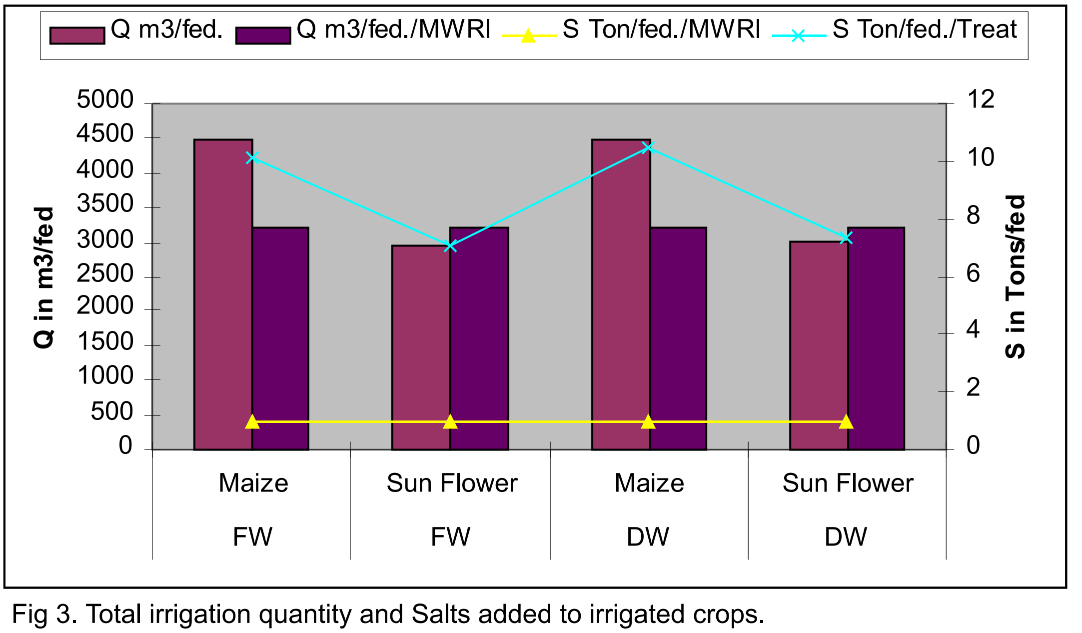

Fig 3. Total irrigation quantity and Salts added to irrigated crops.

Drainage

Drainage conditions play an important role in providing plants with suitable environment with respect to salinity stress conditions, water logging and air exchange process. These conditions contribute to crop production. Therefore, drainage conditions were evaluated by monitoring the water table, drainage discharges and water quality to estimate quantities of salt removed from cultivated fields. Results of drainage performance showed that groundwater table was subject of fluctuation in midway between drains as a result of irrigation practices. This fluctuation was mainly due to the natural drainage condition rather than the functionality of the laterals in some areas where the drains did not show much flow. This may be due to over designed drainage system in some areas and under design drainage system in another. It was very important to report that a very small significant difference was observed in drainage outflow quantities from different irrigation treatments under different crops. This observation leads to the following results:

Total volume of drainage water flow under irrigation with canal water and drainage water for maize were 454 and 504 m^3/season. These quantities remove only 1.43 and 1.86 tons of salt respectively. Thus low drainage outflow quantities; referred to unsuitable discharge measurement under submerged conditions and also no measurements of downward flow through seepage from agricultural land to the aquifer. It is not logic to find that low values of drainage outflow from irrigated areas receive such quantities of irrigation water unless the natural drainage is very active. In other words, the drainage rate in the experimental fields is found to be as 10.1% and 7.7% of the total supplied irrigation water, which seems to be very low values.

Similar results were observed in irrigation of sunflower crop where the drainage quantities estimated were 376 m^3 for canal water irrigation and 334 m^3 for drainage water irrigation respectively. The quantity of salt removed were about 1.2 and 1.23 ton/salt, which seem very low. The volume of drainage water outflow represented about 12.7 and 11.5% respectively of the irrigation water supply.

From the above results the following conclusion can be made as :

The drainage system serving the experimental field is not functioning very well due to under design of collectors and maybe blockages of the system. The system should be redesigned and properly maintained

It is very important to develop methods to measure and/or estimate natural drainage in such areas

Most salts removed naturally or artificially should be properly estimated. The total volume of drainage water in areas with good drainage conditions range between 35 - 40% of the total irrigation gifts which includes all field drains and irrigation system losses through cracks and ground surface.

Evapotranspiration

The actual evapotranspiration or consumptive use depends mainly on soil physical condition as well as on the maximum evaporative demand and crop water use characteristics and finally on crop properties. Based on the available climatic data, the empirical relationship "Modified Pennman" were selected to estimate the maximum evaporative demand. According to crop development (as crop height and fraction of soil cover) the environmental factor (Kc) were applied to estimate the actual Evapotranspiration. The estimated results showed the following :

The overall quantities of water used by crops and lost from soil surface are estimated as 1607 and 1497 m3/season for maize and sunflower crops

These values are found to be less than what was expected where it represents about 36% and 50% of the total irrigation water supplied to the field, while the estimated crop Evapotranspiration for such crops (maize) within the Delta area is estimated as 2560 m^3/season which represents about 79%; and about 1690 m^3/season for sunflower crops which represent about 60% of the supplied irrigation water in the Delta agricultural lands

These estimated values can be explained based on the reduction factor used in the calculation is much lower than one unit; in addition these kc values are an average of values of crops in different areas within climatic region.

The differences in estimation of crop Evapotranspiration depend only on the kc values, which consider the environmental conditions affecting crop growth. The average values used in these estimates are 0.68 and 0.65 for maize and sunflower respectively; and the monthly distribution of the kc values is as follows

	June	July	August	September
Maize	0.59	0.92	0.76	0.44
Sunflower	0.51	0.68	0.76	0.56

The reduction factor for crop environment should be evaluated for each crop within each test area using direct method based on “on-farm management”. In addition , from the current study, the kc value seems to be more than a unit, because it does not give the large evapotranspiration values that are found under arid conditions.

Although the irrigated crops receives much irrigation water, more than similar crops grown in the Delta areas, by about 40%; the crop water use in this experimental field is less than for crops grown in the Delta. This may be due to high salinity that can affect the crop water extraction and dominate the stress condition. This fact may denote that the plants can sustain soil moisture conditions for a much longer period than the salinity stress condition.

Overall field water and salt balance

To achieve favorite water and salt balance, the following assumptions could be made:
All salt are highly soluble and do not precipitate,
The amount of salts supplied by rainfall is negligible,
The amounts of salt supplied by fertilizers are exported by crops are negligible
No seepage, long term equilibrium between the root zone and the subsoil ($C_g = C_r$)
All irrigation water mixes with the soil water in the root zone at field capacity ($C_{fc} = C_r$)

In the case of salt equilibrium (i.e., without a long-term change in salt content), the changes in salt content in the root zone can be estimated as

$$Z` \quad \frac{IC_i \quad \frac{R^x Z`_1}{W_{fc}}}{1 \quad \frac{R^x}{2W_{fc}}} \qquad 1$$

Where:

Z` = Change in salt quantity in the rootzone (meq/m2) = Z`2 - Z`1

Z`2 = Salt quantity in the rootzone at the end of the period (mq/m2)

Z`1 = Salt quantity in the rootzone at the beginning of the period (meq/m2)

I = Applied Irrigation Water gift (mm)

Rx = Percolation below rootzone as subsurface drainage (mm)

Ci Salt concentration in supplied irrigation water (meq/l)

Wfc The amount of soil water at field capacity in the rootzone expressed in mm or l/m2 can be determined from: where Volumetric soil water content (%) and D Depth of the rootzone (mm)

Cfc The salt concentration At field capacity of the soil water in the rootzone it is determined as

The above mentioned Equation named as the salt storage equation. If the initial salt content of the root zone, Z`1, is known (e.g., from soil sampling), the Z`can be calculate directly. This equation can then be used to predict the Stalinization or the desalinisation processes of soils under the influence of irrigation water quantity and quality. If, however, one are interested in finding the seasonal deviations from the long-tem equilibrium soil salt content, Z` will not be known, and the only condition is that the sum of the quantities Z` should be zero over a long period. This approach has been used to describe the water and salt balance status after each irrigation event in the study area. The results of average salinity of the root zone are shown in table 6. The results can show the following :

Differences between initial salt load at the beginning of the season and the final one at the end of the season are (+610) and (+532) for fresh water irrigation and drainage water irrigation respectively which may indicate salinity buildup in both treatments. This is due to increased salt contents in the supplied water. The Corresponding soil salinity in extract showed an increase from 3.78 to 4.39 dS/m for fresh water irrigation treatment while it showed the same trend in drainage water treatment where the salinity increased from 3.63 to 4.24 dS/m.

Insignificant differences between measured and calculated average soil salinity in both initial and final soil salinity where within the fresh water irrigation these values were 2.68 and 3.63 dS/m for initial status (difference is 0.94dS/m), and 4.43 and 4.24 dS/m for the final status. On the other hand and for the drainage water treatment the initial soil salinity was 3.03 and 3.78 dS/m for the measured and simulated one respectively while for the final status these values were 5.47 and 4.43 dS/m

Seasonal input water and salts during the growing season evaluated as 1048 mm and 1045 mm which are equivalent to about 4486 m3/feddan for both treatment and the corresponding added salts found as 10.4 tons. On the other hands the average seasonal drainage water and salts removals under different treatment showed about 450 and 504 m3/feddan for fresh and drainage water irrigation, with corresponding salts removal of 1.19 and 1.86 ton of salts respectively. This indicates that salinity buildup in both treatments is the dominant processes in the reuse strategies.

The same conclusion could be drawn when comparing the salt concentration in initial and final soil analysis for samples taken along the soil profile representing the different locations within each treatment.

Table 6. Field Water and Salt Balance For Drainage Water Reuse Area

(in Equlibrium State)

Fresh Water Treatment

Part 1 : Basic Information

Water at Field Capacity %	0.4
Studied Root Zoon Depth (m)	0.6
Water at Field Capacity (mm)	240
Relation Between ECe and ECfc	0.5
average ECe in Root Zone(dS/m)	4
Capillary rise contribution (mm)	0

Land Use : S u m m e r C r o p s (Maize + Sunflower)

Simulation Period			total (mm)	Jun	Jul	Aug	Sep
E	(mm)		395	75	135	110	75
P	(mm)		0	0	0	0	0
E-P	(mm)		395	75	135	110	75
ECi	(dS/m)		0	4.3	3.11	3.3	3.17
(E-P)*ECi	(mm.dS/m			322.5	419.85	363	237.75
Part 2 : Distribution of irrigation water with maximum percolation in summer							
deficit			-83				
I	(mm)		1020.1	**353.6**	270.65	133.95	261.9
Delta W	(mm)		0	83	0	0	0
R*	(mm)		625	196	136	24	187
Zi1	(E.C*mm)		**1416**	***1416***	1676	1594	1863
Delta Z1	(E.C*mm)			260	-82	270	-447
Zf1	(E.C*mm)			1676	1594	1863	**1417**
E.Ce	(dS/m)	simulated		**4.74**	**4.50**	**5.26**	**4.00**
		measured		3.76			6.52

continued

Part 1 : Basic Information

Water at Field Capacity %	0.4
Studied Root Zoon Depth (m)	0.6
Water at Field Capacity (mm)	240
Relation Between ECe and ECfc	0.5
average ECe in Root Zone(dS/m)	4
Capillary rise contribution (mm)	0

Land Use : S u m m e r C r o p s (Maize + Sunflower)

Simulation Period		total (mm)	Jun	Jul	Aug	Sep
E	(mm)	395	75	135	110	75
P	(mm)	0	0	0	0	0
E-P	(mm)	395	75	135	110	75
ECi	(dS/m)	0	4.31	3.43	3.44	3.17
(E-P)*ECi	(mm.dS/m		323.25	463.05	378.4	237.75

Part 2 : Distribution of irrigation water with maximum percolation in summer

deficit		-83				
I	(mm)	1031.5	**348**	268.9	132.6	282
Delta W	(mm)	0	83	0	0	0
R*	(mm)	625	190	134	23	207

Zi1	(E.C*mm)	**1416**	***1416***	1676	1594	1863
Delta Z1	(E.C*mm)		260	-82	270	-447
Zf1	(E.C*mm)		1676	1594	1863	**1417**

E.Ce	(dS/m)	simulated	**4.74**	**4.50**	**5.26**	**4.00**
		measured	4.54			8.21

Cost-Benefits of Low Water Quality Irrigation

Based on the available data collected from the experimental farm dealt with on production capital costs and operational costs of the irrigation system; The cost and benefits of crop production irrigated with low water quality can presented as follows :

- **Cost of Crop Production :**

Table 7 shows that in case of Maize crop fresh irrigation water; the total variable costs estimated as 796.88 LE/Feddan which represent 61.45% of the total production costs. The total physical input represent 46.3% and the machinery costs is about 28,24%. The total labor cost represent 25,47% of the total variable costs. While in case of Drainage water irrigation reuse, the total variable costs is evaluated as 914.7 LE feddan which represent 64.66^ of the total production costs. The physical input represented 47.29%; the machinery costs is estimated as 29.51%, finally the labor cost was estimated as 23.2% of the total variable costs.

On another hand and in case of sunflower crops; fresh irrigation water; the total variable costs were estimated as 543.3 LE/feddan which represent about 49.7% of the total production costs. The total inputs of physical costs represented by 51.04%; then the total machinery costs of about 32.03% and the total labor cost estimated as 16.93% of total variable costs.

The Drainage water irrigation for the same crop showed the total variable costs were estimated as 677.65 LE/feddan which represent 55.20% of the total production costs. In addition the percentage of the total physical inputs, labor costs and the machinery costs were 51.98%, 16.061 and 31.96% respectively out of the total variable costs.

Table 7. Costs of crop production under different Irrigation conditions in L.E)

Crop	Item	Fresh Water	Drainage
Maize	Production Inputs	368.88	432.6
	Labor Cost	203	212.1
	Machinery Cost	225	270.0
	Variable Cost	796.88	914.7
	*Total Production Costs	1296.88	1414.7
Sunflower	Production Inputs	277.3	352.25
	Labor Costs	92.0	108.8
	Machinery Cost	174	216.6
	Variable Costs	543.3	766.6
	* Total Production Costs	1093.29	1227.6

Total Production Costs = Total variable Costs + Land rent value

Relatively importance laborer works for irrigation:

To be able to analyze the costs of irrigation process under different conditions Table 8 showed the following:

In case of Maize crops, the fresh irrigation treatment showed that labor work costs about 48,6 LE/feddan which represent about 23,94% of the total labour force used and bout 6.1% of the total variable costs.

It also showed that the total machinery costs used for irrigation is about 68.1 LE feddan which represent about 30,27% of the total machinery work used in the Farm, and about 8.55% of the total variable costs.

The total cost of irrigation then evaluated as 116.7 LE/feddan which used in maize farm production, this represent about 428 LE/feddan and about 14.64% of the total variable costs.

In case of maize crop irrigated with drainage water; the labor work used for irrigation estimated as 57 LE/feddan which represent about 26,9 % of total labor work used in the farm and about 6,23% of the total variable costs. The machinery work used in irrigation were estimated as 84.15 LE/feddan which represent about 31.16% of the total machinery works in production process; and of about 9,20% of the total variable costs.

The total costs of irrigation processes in this case were estimated as 141.15 LE/feddan which represent about 29.28% of the total costs of labor and machinery works used in the farm which evaluated as 482.1 LE/Fed and represented by 15.43% of the total variable costs.

In case of sunflower crop irrigated with freshwater: the costs of labor work used for irrigation process; were estimated as 17 LE/Feddan which represent about 18.48% of the total labor costs in the production processes, and about 3.13% of the total variable costs. The machinery costs used for irrigation processes were estimated as 42.75 LE/feddan which represent 24.57% of the total machinery costs used in the farm and about 7.87% of the total variable costs.

The total costs of all kind of works in irrigation processes were evaluated as 59.75 LE/feddan; which represent about 22.46% of the total labor and machinery costs which evaluated as 2.66 LE/feddan and about of 11% of the total variable costs.

In case of sunflower irrigated with drainage water: The total labor used for irrigation processes were estimated as 25.4 LE/feddan which represent about 23.35% of the total work costs and it represent about 2.75% of the variable costs. The machinery costs (used in irrigation processes) were estimated as 56.34 LE which represent 26.01% of the total machinery work in the farm, and also represent about 8.31% of the total variable costs. The total costs of all kind of work used for irrigation were estimated as 81.74 LE/feddan which represent 25.12% of all kind of work in the farm which evaluated as 325,4 LE/feddan which also represent about 12,00% of the total variable costs.

Table 8. Evaluation of Irrigation costs under different irrigation conditions.

Crop	Irrigation Farm Activities	Fresh Irrigation			Drainage Irrigation		
		LE	%	$\%^2$	LE	%	$\%^2$
Maize	Labour Work	48.6	23.9	6.1	57	26.9	6.2
	Machinary Work	68.1	30.3	8.5	84.1	31.1	4.3
	Total	116.7	27.3	14.6	141.	29.3	15.4
Sunflower	Labour Work	17.0	18.48	3.13	25.4	23.3	3.75
	Machinary Work	42.7	24.57	7.87	56.3	26.0	8.3
	Total	59.7	22.46	10.9	81.7	25.2	12.1

Net Return Value

Within the current contexts, the net return value of irrigated crops with different water quality; will be presented the following economic indicators:

- Value of the overall production which calculated by multiplication of the marketable production times average cost at the farm gate.
- The total marginal production which estimated by subtracting the total variable costs from the overall productions costs.
- The net return value which estimated as the overall production costs after subtracting the total production costs (variable and fixed costs).

These economical indicators of the current study are shown in table (9) of which the following facts and information can be concluded:

In case of maize crop; The fresh water irrigation gave 1807.95, 1011.07 and 511.07 LE/feddan of the above mentioned economical indicators respectively; while the drainage water irrigation gave 1609.9, 695.2 and 195.2 LE/fed resp.

In case of sunflower crop; The fresh water irrigation gave 1647.3, 1104, 544.01 LE/fed while the drainage water irrigation gave 1425, 747.35 and 197.3 LE/fed for the same economic indicator respectively.

Table 9. Economical Indicators for Irrigated crops with different water quality:

Crop	Water Resource	Overall Production Value L.E	Marginal Production L.E	Net Return L.E
Maize	Freshwater	1807.95	1011.07	511.04
	Drainage Water	1609.90	695.20	195.20
Sunflower	Freshwater	1647.3	1104.0	554.01
	Drainage water	1425.0	747.35	197.35

Drainage water potentiality

The first requirement for implementing the drainage water reuse policy on an environmentally sound basis is to have the necessary tools which provide information about the temporal and spatial distribution of drainage water. The drainage Research Institute (DRI) has established a monitoring network consisting of more than 192 sites for measuring the flow and water quality parameters. These monitoring sites are located along the main a branch drains and it is in full operation since 1984. These measuring sites were selected at different drainage pumping stations and at strategic sites along the open drains. Annual data is supplied and reported in a Yearbook published and distributed by DRI to all concerned authorities and decision makers. Based on results of this activity running at DRI one can conclude the potentiality of drainage water reuse in the Nile Delta Table 10. It is obvious that most drainage water is officially reused through state-constructed pump stations and is of salinity less than 1500 ppm. It is pumped into the irrigation canals and mixed with canal water. The salinity of the mixture is often kept below 1000 ppm, which is a conservative level.

Table 10. Drainage water reuse for irrigation and its salinity ranges mm3/year

Salinity class	**East**	**Middle**	**West**	**Total**
640 – 960	365	671	384	1420
960 - 1280	960	96	292	1348
1280 – 1600	-	-	-	-
1600 – 1920	-	-	-	
1920 -2240	53	-	-	53
>2240	-	-	-	-
Total Average	1378	767	676	2821

The drainage water flowing to the sea still includes about 241million m^3/year with salinity less than 1500 ppm Table 11. Mostly, these quantities are allocated to new land reclamation projects under construction such as El Salam Canal and El Umum Drain Projects. It is expected that the total drainage water reused after implementation of these projects will be about 8.0 billion m^3/year. The allocation of drainage water for further reuse depends not only on its quantity and quality but also on the time and place it is found in addition to the lifting head and corresponding energy required. (Abu Zeid and Abdel Dayem 1991).

Table 11. Drainage water flowing to the sea and its quality class

Salinity class	**East**	**Middle**	**West**	**Total**
960 – 1280	-	-	-	-
1280 – 1600	2411	-	-	2411
1600 – 1920	1813	-	-	1813
1920 -2240	-	1611	-	1611
>2240	193	3017	1170	4380
Total Average	4417	4628	1170	10215

Limitations and threats facing drainage reuse strategies

Drainage water or more specifically drain water (which is collected in the drains) is a mixture of a number of water resources. These resources are:

Surface runoff due to poor land leveling
Agriculture surface and subsurface field drainage
Tail-ends and spillways of irrigation canals connected to open drains
Upward seepage Water collected by drainage systems.
Sea water intrusion to the drains connected to the sea
Seepage from highly elevated water bodies
Possible disposal of domestic seepage or industrial wastewater treated or partially treated or untreated

With this collection of different types of water(s) one expects to have several kinds of pollutants in drainage water: excessive salts, nutrient (P, N), pesticides, herbicides, insecticides, heavy metals, toxic elements, etc. Even if the concentration of these pollutants is small, the accumulation with time will certainly cause harm.

Having stated that drain water is a collection of the above named water(s), it is clear that part of this water, especially surface runoff and tail-end losses can be kept to a minimum in the operation of the irrigation system and improvement of farm management. Doing this will certainly reduce the drainage water availability in the network on one hand, and on the lifting of drainage water to the irrigation canals on the other.

Another limitation of reuse of drainage water in irrigation is that this drainage water is not always available and found in a favorable location. The quantity of drainage water is at its maximum quantity near the tail-end of the system where canal water is at its minimum quantity and the available lands to be irrigated are also scarce.

Finally, not every crop can be irrigated with this water. If sensitive crops are irrigated with unsuitable water, production is significantly affected.

The strategy of drainage water reuse in Egypt was based on one fact which is

"No alternative but to plan for the use, reuse and recycling of each drop of available water"

and to minimize any adverse effects of reusing the drainage water in irrigation purposes. Therefore, the following measures were taken:

- Mixing fresh water with drainage water on the lower scale of secondary drains and canalsrather than the scale of main canals and drains. This helps in the selection of better quality water and the lower lifting head.
- Improved on-farm water management by mixing fresh water during germination, early stages of growth and for leaching, then drainage water or mixed water can be used during other stages
- Use of drainage water only for fiber crops (cotton, flax, timber trees, flowers, etc.)
- Reducing the use of chemical fertilizers, pesticides to the maximum possible extent.

The above-mentioned measures can only be taken and implemented if the present and future statuses of drainage water are known. In addition the impacts of the drainage water reuse are adequately predicted. Therefore, the drainage water reuse strategies were formulated based on:

- Production of the impacts on soil salinity and crop yield using water management simulation models, both for short and long term
- Improvement of the on-farm water and soil management to minimize the adverse effect of salt accumulation using updated drainage water reuse guidelines

Drainage Water Reuse Guidelines

One major objective of the Drainage Water Irrigation Project (DWIP) has been to develop guidelines for the safe and sustainable reuse of drainage water for irrigated crop production in the Nile Delta. One of major objectives of the current study is to apply these guidelines. Such guidelines are intended to help minimize long term degradation of crop productivity and soils in the Nile Delta primarily due to salinity, to preserve environmental values, and to promote social and economic wellbeing of the farmers involved in the use of drainage water

The application of these guidelines intended to:

- Minimizing long term degradation of crops and soils;
- Preserving environmental values and public health; and
- Ensuring the social and economic wellbeing of the farmers

The developed gridlines include three major groups: the agricultural, environmental and socio-economic guidelines. The environmental guidelines include standards for pollutants which should be observed in order to prevent or avoid adverse effects on the crops and their productivity. Likewise, the socio-economic guidelines recognize adverse impacts on crop productivity that may result from the introduction of drainage water for irrigation and the potential loss of farmers' income that may result there from. The current study will focus only on the agricultural guidelines and its application.

Agricultural Guidelines for drainage Water Re-use:

The agricultural guidelines presented her enable the user to rate salinity hazard factors and suggest irrigation and crop management practices to overcome such hazards. They form a decision support system in reuse of drainage water for irrigation. The guidelines are intended for use on currently cultivated lands as well as on new lands being brought into production by reclamation. They are meant to be applied to a specific crop or to a crop rotation, that are to be irrigated with a water of known quality under particular soil salinity and hydrologic conditions. The guidelines are presented in the form of three matrices or tables, each applicable to crops with a specific level of tolerance for salt. They enable the user to evaluate the potential hazards of drainage water reuse for irrigation. These matrices are classified based on the crop tolerant to salinity and defined as:

Matrix for salt tolerant crops (cotton and wheat)
Matrix for moderately salt tolerant crops (maize and rice)
Matrix for salt sensitive crops (faba beans and berseem)

The footnotes provided at the bottom of each matrix give directions to the user as to the determination of the appropriate indices. The technical nature of these footnotes is the reason for limiting the use of the matrix to trained persons. The matrices are designed to identify the relative potential for crop yield reduction and soil salinization when using one of four different types of irrigation water.

Fresh water (F, Canal and Nile Water)
Drain water (D, Drainage water generated from fields normally irrigated);
Mixed water (M, Canal water that has been mixed with drain water);
Groundwater (GW, stress/deficit irrigation)

For a specific crop or crop in a rotation and knowing the type of water to be used (vertical column on the left), the matrix identifies conditions that are known to be associated with yield reductions in saline and/or sodic soils facilitates the identification of factors that can lead to the development of saline and/or sodic soil conditions.

The three winter crops (wheat, berseem and faba beans) and the three summer crops (cotton, maize and rice) which are included in the three matrices are grown on some two-thirds of the 7.5 million feddan cultivated in the Delta. The guidelines are applicable to other crops with comparable tolerance to salt.

Three major effects were considered in the organization of each matrix.

The direct impact of irrigation water quality on crop yield reduction via irrigation water salinity and sodicity hazard
Irrigation water management as regards meeting the consumptive use and leaching needs of the crop; soil quality. This last factor rates the potential of the soil to remain a suitable medium for plant growth in regards to soil salinity and sodicity

These three effects are listed at the top of each table, as headings of the three main columns. The effects are subdivided into sub factors across the top of each matrix, for which categorical criteria levels are set for each crop/irrigation water combination. The criteria within each matrix become more restrictive as crop salt tolerance decreases (from top to bottom of a table, and from Table 12 -1 to Table 12 -3), or as irrigation water salinity increases i.e. fresh to mixed to drainage water , from top to bottom for each crop. The criteria levels were set based on general principles of crop production in saline and sodic soils. They were then modified based on results of the monitoring data collected by the DWIP project where appropriate. The sequences of evaluation of the action to be taken are based on questions to be answered as it is shown in Fig 4 and as the following example which started from question 6 as below :

List the following values required to answer Question 7:	
a. Productivity Cutoff ECiw (also called threshold)………………….	______ ______
b. Productivity Cutoff SARiw……………………………………...	______ ______
c. Irrigated Water Quantity (for the cropping season) allocated per the Department of Irrigation (m^3/fed) …………………………..	______ ______
d. Water Table Depth:……………………………………………...	______ ______
e. Groundwater Salinity ECgw……………………………………….	______ ______

f. Depth to restrictive layer: …………………………………………….	______
g. Sodium Adsorption Ration of the soil SAR: ………………………	______
h. Establish the ECe (soil electrical conductivity, indicative of its salinity) at planting time for the crop to be grown. Obtain this data from laboratory testing on soil samples. Or, use the ECiw of the previous crop (this is based on the assumption that steady state has occurred during the previous growing season, in which case ECe = ECiw). Alternately, calculate the ECe from the irrigation water salinity ECiw by using the formula: ECe = 1.839 + 0.813 ECiw (1) Both ECe and ECiw are expressed in dS/m. The formula (1) results from a correlation between soil salinity at the end of an irrigation season and water salinity as observed in some monitoring sites in Egypt. Enter ECe…………………	______
Evaluate the six sub factors in the appropriate matrix on the basis of the values listed in what have been mentioned above:	
1. Is the ECiw (measured irrigation water electrical conductivity), indicative of its salinity > cutoff (threshold) value? (see sub factor 1 in matrix)	**Y or N**
2. Is SARiw > cutoff value? (see subfactor 2 in matrix) Note that knowledge of the water's SARiw (Sodium-adsorption ratio of the irrigation water, which expresses the relative activity of sodium ions in exchange reactions with the soil, is derived by application of a formula to the measured concentrations in the water of Sodium, Calcium and Magnesium ions expressed in meq/l of the respective ions) requires sampling and laboratory testing.	**Y or N**
3. Is irrigation water quantity **not** sufficient? (see subfactor 3 in matrix). Note that a Y answer means that irrigation water quantity is not sufficient. The appropriate leaching fraction LF is determined from Figure 5 by entering the average root zone soil salinity ECe and the irrigation water salinity ECiw. Adding this leaching fraction to the appropriate crop water requirement, one obtains the total water requirement, which is compared to the irrigation water quantity to be provided to farm to answer the question "is irrigation water not sufficient?". Other accepted methods are available for estimating leaching requirements (see, for example, the procedure outlined in section 623.0205 – Leaching requirements for salinity control pages 2-98 to 2-123 of Chapter 2 of the S.C.S. National Engineering Handbook, Sept. 1993, US Department of Agriculture). Note that if ECe obtained from Figure 5 is greater than ECiw, the value of ECiw should be used for ECe.	**Y or N**
4. Is there a potential for soil salinization due to either water table depth, water table salinity, restricting soil layer of insufficient leaching fraction (LF) ? (see subfactor 4 in matrix)	**Y or N**
5. Is there a potential for soil dispersion and related permeability reduction? (see subfactor 5 in matrix) The sodium adsorption ratio of the soil, measured or estimated, is entered on Figure 6 in ordinate, and the irrigation water salinity (ECiw) is entered in abscissa. The potential for dispersion (reduced infiltration rate) is indicated if the point falls above the demarcation line on Figure 6. the answer would then be Y.if it falls below, the answer would be N.	**Y or N**
6. Is ECe at planting (or at harvest of the previous crop in the rotation) greater than productivity cutoff (crop threshold) ECiw (the productivity cutoff or threshold, is the point at which crop yield begins to decline as salinity increases)? (see subfactor 6 in the matrix)	**Y or N**

Determine matrix overall rating for the crop: If no factor is rated positive (no Y answer in the above), then matrix overall rating for current crop = **SLIGHT which** no special management practices as regards soil salinization need be considered. If one factor is rated positive (one Y answer in the above), then matrix overall rating for current crop = **MODERATE which** consider practice or practices to minimize adverse impact from matrix factor rated positive to prevent yield reductions for current crop or short-term soil degradation. If two or more factors are rated positive (two or more Y answers), then matrix overall rating for current crop = **SEVERE which** require change(s) in practice or practices to prevent significant yield reductions for current crop or soil	

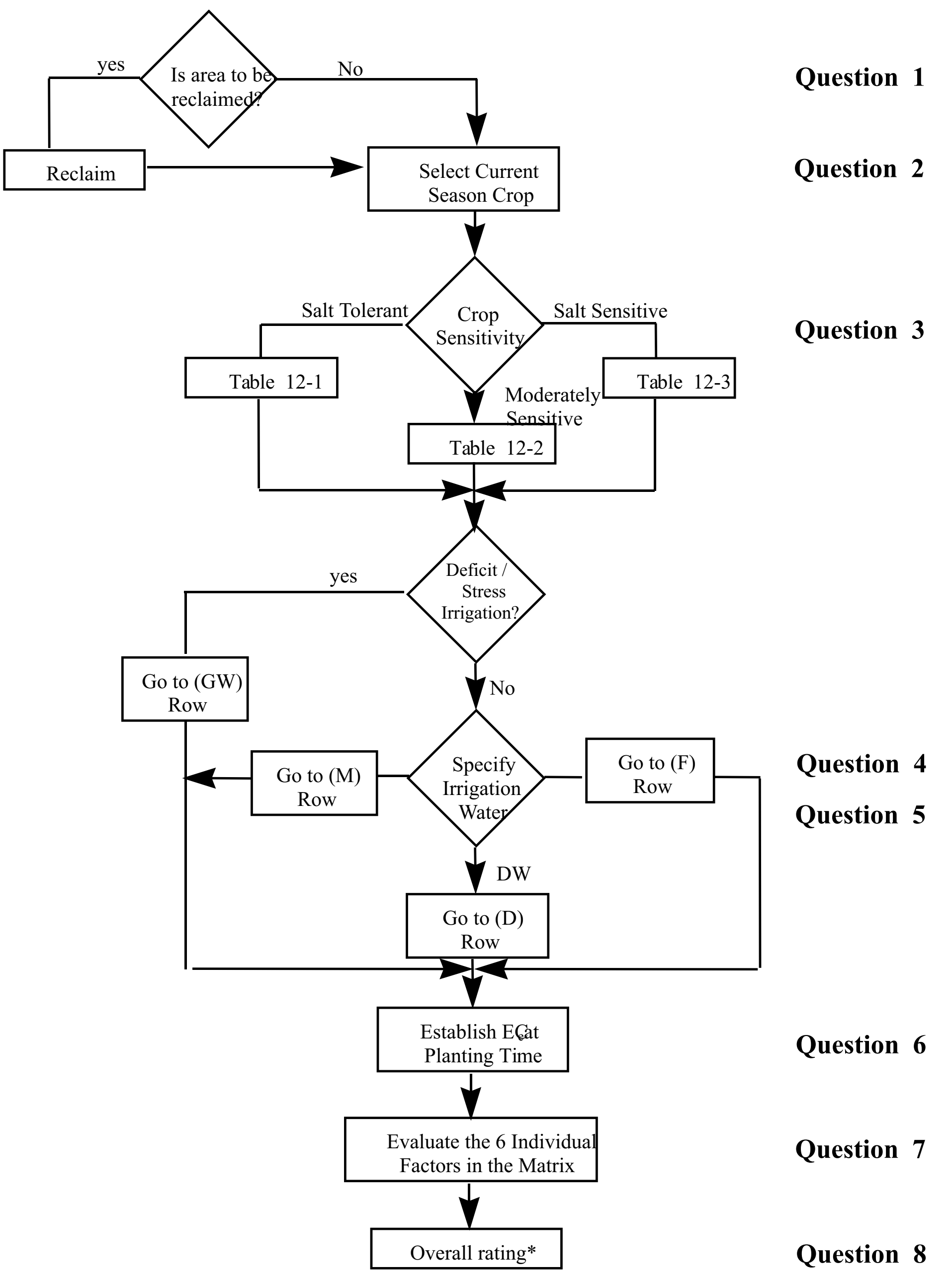

Fig 4. Chart Describing the Use of a Guidelines Matrix for Irrigation Water Management and Crop Production

Table 12 -1. Agricultural Guidelines Matrix for Salt Tolerant Crops

	Irrigation Water Quality		Irrigation Water Management	Soil Quality		
	Subfactor 1	Subfactor 2	Subfactor 3	Subfactor 4	Subfactor 5	Subfactor 6
Crop and Irrigation Water[1]	Productivity Cutoff ECiw	Productivity Cutoff SARiw	Irrigation Water Quantity[2]	Soil Salinitzation Potential[3,4]	Soil Dispersion Potential	ECe @ Planting[5]
Cotton(F)	Not applicable	SAR > 13	Consumptive use	no[6]	Refer to Figure 5 Soil SAR > 13	>Productivity cutoff ECiw
Cotton(M)	6	SAR > 13	Consumptive use + LF	WT < 1m or restrictive layer[7] < 1 m and ECgw > 4 or LF < Fig. 7-2[8]	Refer to Figure 5 Soil SAR > 13	>Productivity cutoff ECiw
Cotton(GW)	6	SAR > 13	Consumptive use	WT < 1m and ECgw > 4[9]	Refer to Figure5 Soil SAR > 13	>Productivity cutoff ECiw
Cotton(D)	6	SAR > 13	Consumptive use + LF	WT < 1m or restrictive layer[7] < 1m and ECgw > 4 or LF < Fig. 7-2[8]	Refer to Figure 5 Soil SAR > 13	>Productivity cutoff ECiw
Wheat(F)	Not applicable	SAR > 13	Consumptive use	No	Refer to Figure 5 Soil SAR > 13	>Productivity cutoff ECiw
Wheat(M)	4	SAR > 13	Consumptive use + LF	WT < 1m or restrictive layer < 1m or LF < Fig. 7-2	Refer to Figure 5 Soil SAR > 13	>Productivity cutoff ECiw
Wheat(GW)	4	SAR > 13	Consumptive use	WT < 1m [9]	Refer to Figure 5 Soil SAR > 13	>Productivity cutoff ECiw
Wheat(D)	4	SAR > 13	Consumptive use + LF	WT < 1m or restrictive layer < 1m or LF < 40	Refer to Figure 5 Soil SAR > 13	>Productivity cutoff ECiw

[1]By assumption ECiw : D > M > F; GW is stress irrigation and F is < 400 ppm total dissolved solids.
(F - Fresh water, M - Mixed fresh water and drainage water, D - Drainage water, GW - Ground water)
[2]This is the quantity of water necessary over the cropping season to maintain crop production at optimum level regarding soil-plant water relationships. The leaching fraction (LF) will vary based on salt tolerance of crop and irrigation water salinity. Use Figure 4
[3]Not applicable to sandy soil.
[4]Salinization potential is relative to the current crop and rotation.
[5]ECe @ Planting is that measured at the time of planting, or taken as equal to the EC_{iw} at the end of the previous season's irrigation. It must not be greater than the productivity cutoff of the new crop.
[6]A “No” because with freshwater the LF needed for salt tolerant crops is so low that irrigation inefficiencies will maintain an adequate LF.
[7]Restrictive layer: soil layer with clay texture, tillage pan, or other water restrictive layer.
[8]If ECiw is > crop productivity cutoff value (subfactor 1) **and** the LF needed to maintain average rootzone salinity at or below the ECiw cutoff value based on ECiw is not met, salinization detrimental to the current crop and any subsequent crop of equal or lesser salt tolerance is possible. Refer to Fig. 4 to determine average rootzone soil salinity for given ECiw. WT= water table
[9]Leaching fraction not applicable with stress irrigation; ECgw taken as approximately 0.60 (i. e. 1-LF) of ECiw; ECgw left out as criteria for all but cotton, as it was not a significant parameter in explaining soil salinity in the monitoring data, and values are almost always > 2 dS/m . Therefore, for the more salt-tolerant crops like wheat, less restrictive criteria were set by dropping the ECgw requirement. In addition, for the salt tolerant crops (i.e. cotton) most soil ECe's in the monitoring data were < ECgw that corresponds to a soil ECe of <6. In other words, the ECgw distribution is skewed significantly towards soils with an ECe of <6, reflecting less potential salinization in cotton from saline groundwater

Table 12 -2. Agricultural Guidelines Matrix for Moderately Salt Tolerant Crops

	Irrigation Water Quality		Irrigation Water Management	Soil Quality		
	Subfactor 1	Subfactor 2	Subfactor 3	Subfactor 4	Subfactor 5	Subfactor 6
Crop and Irrigation Water[1]	Productivity Cutoff ECiw	Productivity Cutoff SARiw	Irrigation Water Quantity[2]	Soil Salinization Potential[3,4]	Soil Dispersion Potential	ECe @ Planting[5]
Maize(F)	Not applicable	9	Consumptive use	LF < 5[10]	Refer to Figure 5Soil SAR > 10	>Productivity cutoff ECiw
Maize(M)	1.7	9	Consumptive use + LF	ECiw > 1.7 or ECgw > 10[6] or WT <1 m or restrictive layer[7] < 1 m or LF < Fig. 5	Refer to Figure 5 Soil SAR > 10	>Productivity cutoff ECiw
Maize(GW)	1.7	9	Consumptive use	WT <1 m[9]	Refer to Figure 5 Soil SAR > 10	>Productivity cutoff ECiw
Maize(D)	1.7	9	Consumptive use + LF	ECiw > 1.7 or ECgw >10[6] or WT < 1 m or restrictive layer < 1 m or LF < Fig. 5	Refer to Figure 5 Soil SAR > 10	>Productivity cutoff ECiw
Rice(F)	Not applicable	13	Flood	No	Not applicable	>Productivity cutoff ECiw
Rice(M)	3	13	Flood	ECiw > 3	Not applicable	>Productivity cutoff ECiw
Rice(GW)	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	>Productivity cutoff ECiw
Rice(D)	3	13	Flood	ECiw >3	Not Applicable	>Productivity cutoff ECiw

By assumption ECiw : D > M > F; GW is subirrigation and F is < 400 ppm total dissolved solids.
[1]F - Fresh water, M - Mixed fresh water and drainage water, D - Drainage water, GW - Ground water
[2] This is the quantity of water necessary over the cropping season to maintain crop production at optimum level regarding soil-plant-water relationships. Leaching fraction (LF) will vary based on salt tolerance of crop and irrigation water salinity. Use Figure 5.
[3]Not applicable to sandy soil.
[4] Salinization potential is relative to the current crop and rotation.
[5]ECe @ planting is that measured at the time of planting, or taken as equal to the EC_{iw} at the end of the previous season's irrigation. It must not be greater than the productivity cutoff of the new crop.
[6]ECgw value derived from assessment of middle-delta monitoring data suggesting that in maize with values of >10 dS/m there is a greater likelihood of having soil EC's above 3 dS/m, even for deep water tables (> 1m). Therefore, a more restrictive criterion was chosen.
[7]Restrictive layer: soil layer with clay texture, tillage pan ,or other water restrictive layer.
[8]If ECiw is > crop productivity cutoff value (subfactor 1) **and** the LF needed to maintain average rootzone salinity at or below the ECiw cutoff value based on ECiw is not met, salinization detrimental to the current crop and any subsequent crop of equal or lesser salt tolerance is possible. Refer to Fig. 5 to determine average rootzone soil salinity for given ECiw. WT = water table
[9]No ECgw criteria, as ECgw generally ranges greater than the maize productivity cutoff value (based on monitoring data). Therefore, any elevated groundwater table poses a potential salinity hazard for maize. Elevated groundwater tables would probably be normal for stress irrigation (GW).
[10]Based on the freshwater ECiw of 0.4 dS/m, as per the definition of fresh irrigation water.

Table 12 -3. Agricultural Guidelines Matrix for Salt Sensitive Crops

	Irrigation Water Quality		Irrigation Water Management	Soil Quality		
	Subfactor 1	Subfactor 2	Subfactor 3	Subfactor 4	Subfactor 5	Subfactor 6
Crop and Irrigation Water1	Productivity Cutoff ECiw	Productivity Cutoff SARiw	Irrigation Water Quantity2	Soil Salinization Potential3, 4	Soil Dispersion Potential	ECe @ Planting5
Faba(F)	1	SAR > 5	Consumptive use	LF < 106	Refer to Figure 6 Soil SAR > 5	>Productivity cutoff ECiw
Faba(M)	1	SAR > 5	Consumptive use + LF	ECiw > 1 or WT <1 m or restrictive layer7 < 1 m or LF < 408	Refer to Figure 6 Soil SAR > 5	>Productivity cutoff ECiw
Faba(GW)	1	SAR > 5	Consumptive use	WT < 1m9	Refer to Figure 6 Soil SAR > 5	>Productivity cutoff ECiw
Faba(D)	1	SAR > 5	Consumptive use + LF	ECiw > 1 or WT <1 m or restrictive layer < 1 m or LF < 40	Refer to Figure 6 Soil SAR > 5	>Productivity cutoff ECiw
Berseem(F)	1.5	SAR > 10	Consumptive use	LF < 5	Refer to Figure 6 Soil SAR > 10	>Productivity cutoff ECiw
Berseem(M)	1.5	SAR > 10	Consumptive use + LF	ECiw > 1.5 or WT <1 m or restrictive layer < 1 m or LF < 40	Refer to Figure 6 Soil SAR > 10	>Productivity cutoff ECiw
Berseem(GW)	1.5	SAR > 10	--	WT < 1 m	Refer to Figure 6 Soil SAR > 10	>Productivity cutoff ECiw
Berseem(D)	1.5	SAR > 10	Consumptive use + LF	ECiw > 1.5 or WT <1 m or restrictive layer < 1 m or LF < 40	Refer to Figure 6 Soil SAR > 10	>Productivity cutoff ECiw

[1] By assumption ECiw : D > M > F; GW is subirrigation and F is < 400 ppm total dissolved solids.
(F - Fresh water, M - Mixed fresh water and drainage water, D - Drainage water, GW - Ground water)

[2] This is the quantity of water necessary over the cropping season to maintain crop production at optimum level regarding soil-plant-water relationships. Leaching fraction (LF) will vary based on salt tolerance of crop and irrigation water salinity. Use Figure 5.

[3] Not applicable to sandy soil.

[4] Salinization potential is relative to current crop and rotation.

[5] ECe @ Planting is that measured at the time of planting, or taken as equal to the EC_{iw} at the end of the previous season's irrigation. It must not be greater than the productivity cutoff of the new crop.

[6] Based on the freshwater ECiw of 0.4 dS/m as per the definition of fresh irrigation water.

[7] Restrictive layer: soil layer with clay texture, tillage pan ,or other water restrictive layer.

[8] If ECiw is > crop productivity cutoff value (subfactor 1) **and** the LF needed to maintain average rootzone salinity at or below the ECiw cutoff value is not met, salinization detrimental to the current crop and any subsequent crop of equal or lesser salt tolerance is possible. Criteria set at more restrictive LF of < 40 based on assuming ECiw is near productivity cutoff value for mixed or drainage water.

[9] No ECgw criteria, as ECgw generally ranges greater than the faba or berseem productivity cutoff value (based on monitoring data). Therefore, any elevated groundwater table poses a potential salinity hazard for maize. Elevated groundwater tables would probably be normal for stress irrigation (GW).

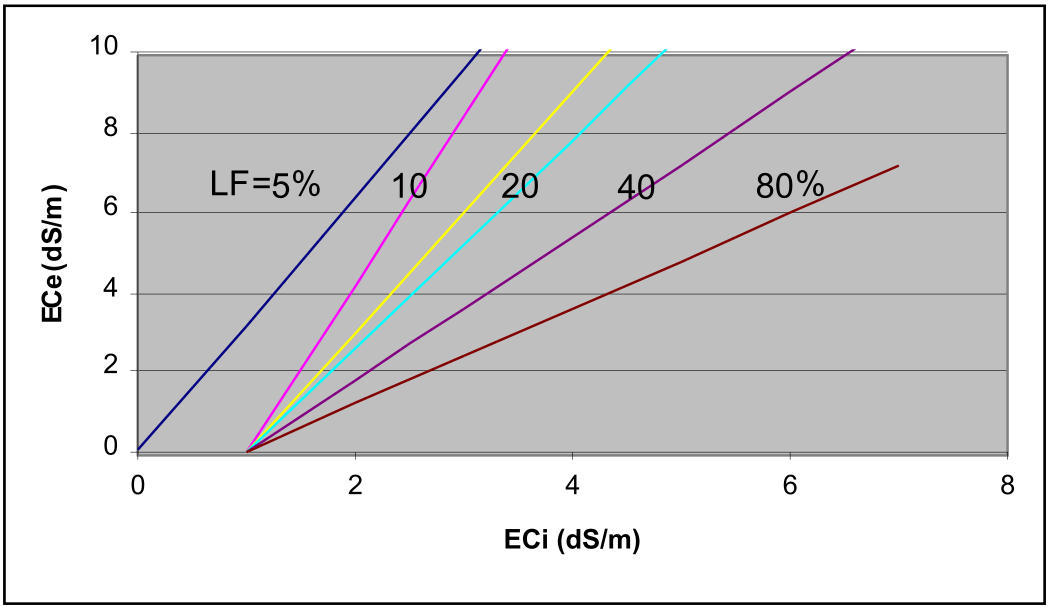

Fig 5. Agricultural Salinity and Drainage by Blaine Hanson et al (1993)

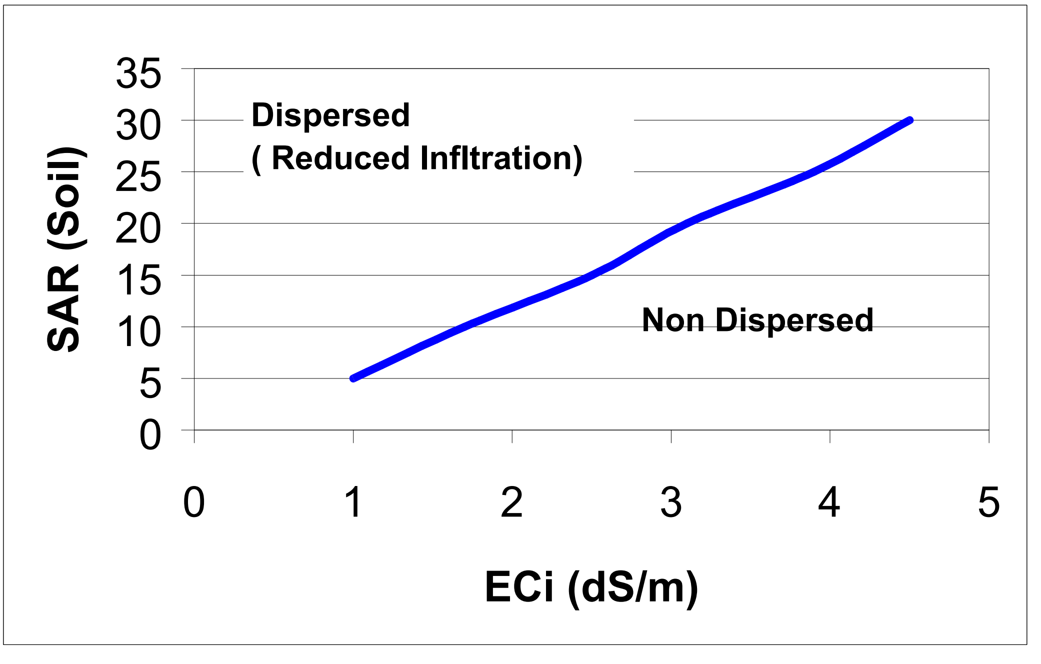

Fig 6: Agricultural Salinity and Drainage by Blaine Hanson et al (1993)
Water Infiltration Rate as Affected by Salinity and Sodium Absorption Ratio SAR-Soil

Conclusions and Recommendations

The regular monitor the effect of reuse of different types of drainage water used for irrigation under different management policies on the accumulation of salts and other harmless or harmful substances in the soil profile as well as the effect on the toxicity of crops especially those eaten raw by humans for animals. This activity has not started yet, and a complete research program has to be formulated and to start soon. Being capable of obtaining historic and present situation with regard to drainage water quantity and quality, getting sound estimates of the change in these parameter with the possible changes in the existing conditions and being aware of the effect of using this water for the irrigation of different crops grown in different soils and under different climatic conditions, this whole set up of information covers the complete picture and enables taking the proper decision at the proper time.

Farmer participation in irrigation schemes especially in newly reclaimed areas has become synonymous with the decentralization of water management strategy. From the extension services provided by MWRI in the irrigation improvement projects, currently farmers in the desert and newly reclaimed areas are willing to engage in organization (from local areas) for water user associations. This organization should provide services on management of all water resources in the areas till the field level. This success factor of the ongoing activity of this organization will be farmer personal benefits. Because of building a sustainable organization require a time and support of different agencies; the current experimental area is considered to be in the designed phase of water user associations and needs to be supported in a significant institution framework to be able to achieve sustainable water management in different stress and low water quality conditions.

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IN VITRO SALINITY TOLERANCE SCREENING OF SOME LEGUMES AND FORAGES CULTIVARS

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ABSTRACT

The increasing water demand for dmestic and industrial water users in the water-scarce Mediterranean region is effecting the availbility of fresh water supplies for agriculture. Whereas much research has been done on the effect of irrigation with low-quality water on saline tolerant species, little is known about the salinity tolerance of legume and forage cultivars. The salinity tolerance of 200 lentil cultivars(*Lens culinaris*), 205 chickpea cultivars (*Cicer arietinum*) and five tall fescue cultivars (*Fescua Arundinacea* Schreb.) was tested in vitro, using four different salinity levels (0.5, 4, 7,10 dS/m). A second screening was done after pre-soaking the seeds for 24 hours in water (0.5 dS/m). The effect of X-ray (96 Kv, 200 mas,/sec, 5 sec interval) on the germination of lentil under these conditions was also tested. In addition, 21 promising lentil varieties were tested in sand-filled pots in the greenhouse.

Average germination of the 200 lentil cultivars varied between 3% for the dry seeds at an EC of 10 dS/m to 59% for the pre-soaked seeds at an EC of 0.5 dS/m. For the 205 chickpea varieties germination varied between 40% for the dry seeds at an EC of 10 dS/m to 84% for the pre-soaked seeds at an EC of 0.5 dS/m.The experiment indicated that the chickpea cultivars were more saline tolerant than the lentil and tall fescue cultivars. The X-ray treatment had no clear effect on the germination and shoot growth of lentil. Results of the top 50 cultivars of each screening test indicated that even for the more resistant cultivars shoot growth becomes severly impaired at an EC of 4 dS/m and higher. In the greenhouse, 8 of the 21 pre-soaked lentil cultivars survived at an EC of 7 dS/m. The tall fescue cultivars did not survive the saline water treatment (4 dS/m and above). This study indicated that the chickpea cultivars were more saline tolerant than the lentil and tall fescue cultivars.

Keywords: salt tolerance, shoot growth, chickpea, lentil, tall fescue

INTRODUCTION

The limited water resources in arid and semi arid areas form a major constraint for agricultural and socio-economic development (Hamdy., et al., 2002). In the Mediterranean region, increasing demands from domestic and industrial water users are restricting agricultural expansion. To achieve both water and food security we have to find alternative strategies. One of the options is to increase the use of marginal quality water for irrigation to solve this problem. Marginal quality water could include treated sewage effluent, recycled drainage water, or brackish groundwater. These water resources often have an elevated chloride content. The main management issues involved in using saline water are the control of soil salinity by adequate leaching and drainage, and the selection of crops adapted to the salinity level of the soil.

The use of saline water for irrigation of various food, fuel and fodder crops has been reported by Epstein (1983, 1987), Glenn and O'Leary (1985), Jyengar (1982), Hamdy et al. (1993), Katerji et al. (1997, 2001a, 2001b) and others. Among crop species, legumes are considered salt sensitive (Maas and Hoffman, 1977). Within the legumes, chickpea, faba been and pea are particularly salt sensitive (Maas and Hoffman, 1977; Lauchli, 1984). Lockerman et al. (1983) indicated that faba been may have greater salinity tolerance than the other cool-season food legumes. Food and forage legumes improve soil health and could reduce crop pests and diseases when grown in rotation. These crops are also important protein sources.

Crop salt tolerance depends primarily on (i) morphological features of the plant, (ii) uptake and transport of salt, and (iii) physiological and metabolic processes at the cellular level (Winicov,1993).

Differences in salt tolerance exist not only among different genera and species, but also within certain species. For example, there are reports on the response to salinity of different varieties of chickpea (Katerji et al., 2001a; Gandour, 2002); barley (Touchan and Coons, 1991; Flowers and Hajibagheri, 2001), lentil (Katerji et al., 2001b), and maise (Abdel-Samed and Azooz, 2002) Tall fescue (Wu et al,1996; Leskys et al, 1999). Much less information is available about the effect of X-ray on germination and seedling growth (e.g., Khanna, 1990; Eianev ,1986 for wheat and Abejec ,2003 for barley). Abejec (2003) found that the use of a low dose of X-ray increases field germination, as opposed to the high dose. Hinkovski (1987) reported that increasing the X-ray (10-15 Kr) increased the vegetative growth and the seed yield of alfalfa. Shoot growth, however, was lower for F1X than for F1. This could have been caused by an increase in auxine rate (Khanna, 1990).

Improvement of germination and early growth depend on the dose of mutagen, on the percentage of the morphological variations and on the genetic abnormality. Increasing the mutagen doses increased the genetic abnormality and the number of sterile plantes (Kumar and Shauban, 1979). However, the use of low dose of mutagen chemicals activates the seeds longevity and their tolerance to biotic and abiotic stress (Demchenko, 1987).

The objective of the study was to identify legume and forage cultivars that are tolerant to salinity and to develop an understanding of the mechanisms that affect this tolerance. The effect of X-ray on lentil germination was also studied.

MATERIALS AND METHODS

During the 1999-2001 seasons, 200 lentil cultivars, 205 chickpea cultivars, and five tall fescue cultivars were screened for salinity tolerance in plastic dishes in the laboratory (in vitro). The seeds were tested at four salinity levels: 0.5 (control), 4, 7, and 10 dS/m. Groundwater with an EC of 0.5 dS/m was mixed with NaCl until the required salinity level was obtained. No salt was added for the control (EC0.5). For chickpea and tall fescue, five seeds were applied per dish. For the lentil cultivars 10 seeds were used. All dishes were regulary filled with water to counter-balance evatranspiration. Each dish received the same amount of water. The seeds were checked for germination every other day. The length of the shoots was measured around day 14 after germination. The relative humidity in the laboratory varied between 33 and 66%; the temperature generally varied between 20 and 30 ^{0}C.

The experiments included two phases: seeds that were pre-soaked for 24 hours in groundwater (F1) and dry seeds (F2). The lentil seeds were also treated with X-ray (96 KV, 200 mas, 1 sec shot, 5 sec interval). The screening tests of the X-rayed seeds are referred to as F1X and F2X. After the initial screening, 20 to 40 chickpea cultivars that performed well in the laboratory were tested in the greenhouse. Five seeds were put in 15-cm diameter plastic pots(top diameter of 19.5 cm and a depth of 18 cm) filled with approximately 3 kg sand. Every other day 40 ml water of the selected EC-level was added.

The in-vitro screening of lentil was conducted in April 2000 for phase 1 (F1) and in May, 2000 for phase 2 (F2). The in-vitro screening of the X-rayed lentils was carried out in July and August, 2000. The greenhouse study started on January 4, 2001, with 21 varieties for Phase 1 (F1G) and on March 28, 2001 with 19 cultivars for Phase 2 (F2G).

Phase 1 of the chickpea screening started in the laboratory on January 7, 2001. Phase 2 of the chickpea screening was conducted in February. The in-vitro experiment was repeated with two replicates for the 40 cultivars that were selected for the greenhouse pilot study. Chickpea seeds were planted in the greenhouse in April, 2001 (Phase 1 only). The observations in the greenhouse continued until crop maturity at the end of June. For the Phase 1 greenhouse study (F1G), seven cultivars from the top 10, and 14 cultivars ranking between 11 and 70 were selected. Five seeds of each variety were planted on January 4, 2001. Ten days after planting.

The in-vitro experiment for the tall fescue started on June 26, 2001. Three replicates of fives seeds each were observed.Germination of the seeds was checked for 82 days. Lengths of shoots were measured weekly during 108 days.

A scoring system was used to rank the varieties of each in-vitro screening test for their tolerance to salinity. The aggregated score was computed as:

$$Score = G_{0.5} * L_{0.5} + 2\,(G_4 * L_4) + 3*(G_7 * L_7) + 4*(G_{10} * L_{10})$$

where G_i is the number of germinated seeds, L_i is the average length of the shoots of the germinated seeds, and i is the EC-level. The highest score obtained rank number 1, the second highest score rank number 2, and so on and so forth.

RESULTS AND DISCCUSION

Lentil

Average germination of the 200 lentil cultivars varied between 3% for the dry seeds (F2) at an EC of 10 dS/m to 59% for the pre-soaked seeds (F1) at an EC of 0.5 dS/m (Table 1). The pre-soaking improved germination and shoot growth, especially at the higher salinity levels. The effect of the X-ray treatment on the lentils varied per cultivar. On average, the X-ray had no positive effect on the germination and shoot growth of the pre-soaked seeds. The X-rayed dry seeds (F2X) performed better than the dry seeds without X-ray treatment (F2).

Table 1. Average percentage germination and shoot length of lentil cultivars(at 14 days after germination) under four different treatments and four salinity levels.

	Germination (%)				Average shoot length (cm)			
	EC0.5	EC4	EC7	EC10	EC0.5	EC4	EC7	EC10
200 cultivars								
F1	59	58	51	39	15.3	10.3	6.3	3.1
F1X	54	50	42	38	9.5	6.8	3.3	1.7
F2	48	28	16	3	8.1	2.6	0.5	0.0
F2-X	57	47	21	3	8.4	3.7	0.7	0.1
Top 50 cultivars								
F1	82	81	76	68	19.5	14.7	10.5	5.1
F1X	93	85	81	74	16.0	12.1	7.3	4.7
F2	76	54	31	7	12.7	5.9	1.2	0.1
F2X	91	85	52	9	12.8	8.3	1.7	0.4

The average germination percentage and shoot lengths of the top 50 cultivars of each screening test are also summarized in Table 1. These results indicate that even for the more resistant cultivars shoot growth becomes severely impaired at ECs of 4 dS/m and higher. Interestingly, the top 50 cultivars of the pre-soaked seeds that were treated with X-ray (F1X) had higher germination percentages than the pre-soaked seeds without X-ray treatment (F1). This result conform the findings of Eianev (1986) for wheat and Abejec (2003) for barley. Hinkovski (1987) reported that increasing the X-ray (10-15 Kr) increased the vegetative growth and the seed yield of alfalfa. Shoot growth, however, was lower for F1X than for F1. This could have been caused by an increase in auxine rate (Khanna, 1990).

Increased germination of irradiated seed could be due to the induction role of X-ray in increasing the hydrolysis enzyme such as lipase, protease, B-amylase, and x-amylase, which could accelerate the nutrient reserves' transformation from a complex state to a simple state; and the transport of these reserves to the embryon, which will accelerate the division and elongation of the embryon (Kuzin, 1980). This induction could also cause differences in seeds hormone equilibrium, which will increase the activation hormones such as gebrillic acid and auxine, in comparison with the inhibitors hormones. Grodzinski (1989) reported that the X-ray treatment could activate physical and biochemical processes.

To examine the overall resistance of the tested lentil cultivars against salinity, the top 10 of the four EC levels screening tests were compared. Varieties that occured in more than one top 10 and their associated rankings are sumarized in Table 2. The table also indicate if the varieties were tested in the greenhouse studies.

Table 2. Rankings of the lentil cultivars that occurred in the top 10 of more than one screening test.

Screening	ILL8010	ILL8008	ILL7686	ILL7520	ILL2815	ILL2501	ILL4402	ILL7554	ILL3597
F1	12	5	13	50	2	6	10	1	166
F1X	4	11	9	1	32	24	16	2	3
F2	3	11	18	5	2	1	8	65	7
F2X	4	1	6	2	24	34	36	3	51
Total	23	28	46	58	60	65	70	71	227
Greenhouse	F2G		F1G,F2G		F1G,F2G	F1G,F2G	F1G,F2G	F1G	F2G

Because not all seeds had germinated, a total of 78 seeds were added on January 16. On January 31, the average length of the shoots varied from 12.5 (at EC 4 dS/m) to 9.7 cm (at EC 10 dS/m). On day 76, all cultivars at the lower two EC levels had survived. The average length of the shoots was 16.1 cm at EC 0.5 dS/m and 15.6 at EC 4 dS/m. At an EC of 7 dS/m only eight cultivars survived, ILL1712, ILL2501, ILL 2815, ILL4402, ILL7521, ILL7522, ILL7553, and ILL7620. Cultivar ILL7521 was also the only surviving cultivar at and EC of 10 dS/m. Of the eight surviving cultivars, ILL2501, ILL2815, and ILL4402 were identified as tolerant cultivars during the initial screening (Table 2).

The greenhouse study for the dry seeds (F2G) included eight cultivars from the top 10 and 11 cultivars that ranked between 11 and 60 during the in-vitro screening of the dry seeds (F2). The seeds were planted on March 28, 2001. After 62 days all varieties had died at the highest three salinity levels. The lenghts of the shoots irrigated with water with an EC of 0.5 dS/m varied between 10 and 22 cm. On day 71 four of the 19 cultivars had also died at the lowest salinity level. Of the six cultivars that were identified in Table 2, Cultivar ILL2501, ILL2815, ILL3597, ILL4402, and ILL7686 survived.

Chickpea

Germination of the 205 chickpea cultivars varied between 40% for the dry seeds (F2) at an EC of 10 dS/m to 84% for the pre-soaked seeds (F1) at an EC of 0.5 dS/m (Table 3). As with the lentils, the pre-soaking improved germination and shoot growth at the higher salinity levels. For the top 50 cultivars the length of the shoots of the pre-soaked seeds at the highest salinity level was less than half of the length of the shoots at an EC of 0.5 dS/m. Without pre-soaking (F2) there was almost no shoot growth at the two highest salinity levels. Seed germination was the least affected growth stage. The primary growth stage was slightly affected at a low salt concentration. However, this effect increased with increasing salt concentrations. Similar results were found by Katerji et al. (2001b) and Gandour (2002).

Table 3. Average percentage germination and shoot length of lentil cultivars under four different treatments and four salinity levels.

	Germination (%)				Average shoot length (cm)			
	EC0.5	EC4	EC7	EC10	EC0.5	EC4	EC7	EC10
205 cultivars								
F1	84	79	71	55	13.1	13.4	8.1	4.8
F2	83	74	64	40	16.1	4.6	0.2	0
Top 50 cultivars								
F1	94	85	88	73	17.2	18.2	12.7	7.8
F2	94	83	81	54	21.8	9.9	0.5	0

Five cultivars ranked in the top 20 of both the F1 and the F2 screening test (Table 4). Of the 40 cultivars that were tested in the greenhouse, FLIP 97-266, FLIP 98-100, FLIP 98-107, FLIP 98-131, FLIP 98-162, FLIP 98-169 performed the best.

Table 4. Rankings of the chickpea cultivars that occurred in the top 40 of both screening tests.

	FLIP 87-59	FLIP 97-158	FLIP 97-205	FLIP 97-259	FLIP 98-128
F1	2	3	10	18	19
F2	16	17	12	4	8
Total	18	20	22	22	27

Tall fescue

At the lower EC levels (0.5 and 4 dS/m), pre-soaking of the seeds did have little effect on the germination, (Table 5), except for *Centurion* and *Lunibelle* thid result is conform the finding of (Leskeys et al,1999) that thr irrigation of Tall fescue with 2.5 dS/m an acceptable practice. At an EC of 4 dS/m these two species clearly benefitted from pre-soaking. The pre-soaked seeds of *Lunibelle* had consistently higher germination percentages than the other species at the higher EC levels (EC 4-10 dS/m). Without pre-soaking, zero germinated seeds remained after 24 days at an EC of 10 dS/m. None of the species stood out as being saline tolerant.

Table 5. Germination percentage of tall fescue species at four different salinity levels after 24 days, with (F1) and without (F2) pre-soaking.

	EC0.5		EC4		EC7		EC10	
	F1	F2	F1	F2	F1	F2	F1	F2
Bariane	67	87	67	73	67	33	40	0
Centurion	87	73	80	47	60	20	47	0
Lunibelle	73	67	93	53	80	7	67	0
Madra	53	60	53	60	27	27	60	0
Mylena	60	80	53	73	67	20	33	0

The development of the shoot lengths was similar for all species. The growth of the shoots at the highest two salinity levels was very limited this result is comfrom the finding of (Hoffman et al,1997 and MaAdam et al,1997) the shoot growth of Tall fescue was not affected by irrigation water treatment ranging from 1.2 to 3.6 dS/m. Fot the pre-soaked seeds shoot lengths did not exceed 10-cm and all plants died after 80 days. Without pre-soaking the species performed worse, *Centurion* and *Lunibelle* showed almost no shoot development. The development of the shoots at the lower two salinity levels is illustrated in Figure 1. Clearly, the pre-soaked seeds had a better start, but this advantage dissapeared later on.

At an EC of 0.5 dS/m the average shoot lengths varied between 34.7 and 49.3 for the pre-soaked seeds and 36.3 and 39.3 for the dry seeds, after 108 days. For both pre-soaked and dry seeds, *Centurion* had the shortest shoots and *Lunibelle* the longest.

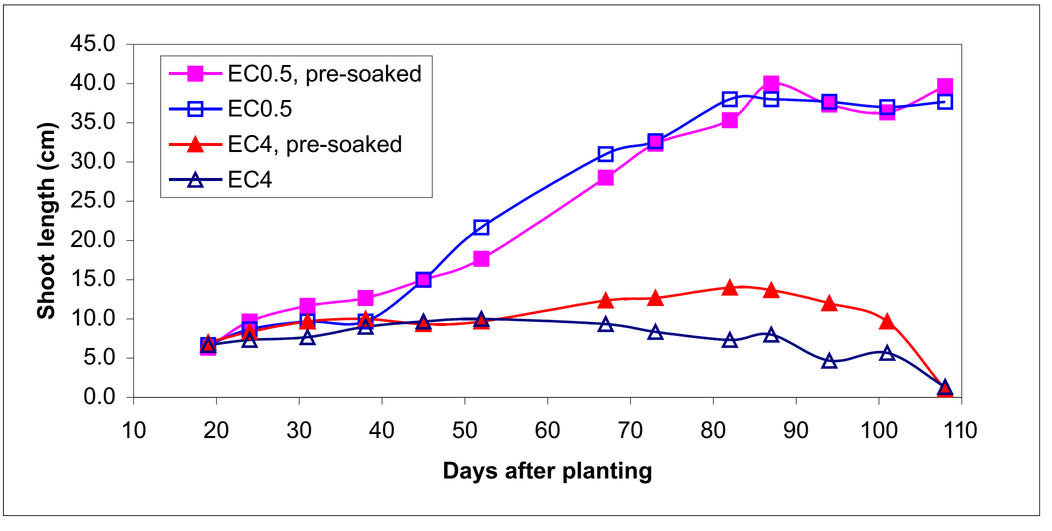

Fig. 1. Average length of *Madra* shoots at EC-levels 0.5 and 4 dS/m

CONCLUSIONS

The in-vitro screening of 200 lentil, 205 chickpea, and 5 tall fescue cultivars indicated that the chickpea cultivars were more saline tolerant than the lentil and tall fescue cultivars. Pre-soaking of the seeds in water (0.5 dS/m) substantially improved emergence, shoot growth, and survival of the species at the higher salinity levels. The different lentil and chickpea varieties showed a large variability in performance at different salinity levels. Therefore, more testing is required.

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SCREENING OF SOME CHICKPEA GENOTYPES FOR SALINITY TOLERANCE IN A MEDETERRANEAN ENVIRONMENT

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ABSTRACT

To understand the mechanisms that affect the response to salinity of legumes, six chickpea genotypes were tested in sand-filled pots in the greenhouse. The chickpea seeds were irrigated with water of four different salinity levels (0.5, 2, 4, 6 dS/m). Physiological and phenological observations were made. The results indicated that the varieties responded differently to different salinity levels. The salinity had little effect on germination. Genotypes F.97-74, F.87-59 and ILC 3279 were found to have higher salt tolerance and produced more dry matter than genotype F.97-265.

INTRODUCTION

Water has always been a central concern in many Mediterranean countries (Hamdy, 1995). Some of the countries in the region experience presently severe water scarcity. With populations growing and standards of living increasing, all countries are facing a trend of declining water availability. Agriculture is likely to be forced to use more and more marginal quality water, either brackish water or treated sewage effluent. High salt concentrations inhibit crop growth and yield. The response of cultivated species to salinity in terms of growth and yield are the ultimate expression of several interacting physiological and biochemical processes.

Numerous studies have been conducted on the management and identification of saline tolerant crops such as cotton or cereals (e.g., Leidi and Saiz, 1997; Hoffman and Jobes, 1978; Pessarakali et al., 1991). Limited attention has been given to legumes and forages, which are known to have low tolerance to salinity. As for most legumes, germination of chickpea is relatively less affected by salinity than subsequent seedling growth (Geol and Vashnery, 1987; Yadav et al., 1989). Kumar (1985) also indicated that later stages of chickpea growth were more sensitive than earlier stages. The sensitivity of all chickpea genotypes increases with plant growth and greater salinity (Sheoran and Garg, 1983; Dua, 1992; Gandour, 2002).

Salinity also affects the photosynthetic C14 assimilation in chickpea leaves (Murumakar and Chavan, 1993). Shoot dry mass declines at higher salinity levels (Rao and Sharma, 1995). Salt stress affects growth, nodulation and nitrogen accumulation in legumes (Saxena and Rewari, 1991; 1992; Saxena et al., 1993). Murumkar and Chavan (1989) and Gandour (2002) reported that salt stress caused accumulation of both sodium and chloride in the shoot parts, especially in the leaves. This was accompanied by a decrease in potassium in different plant parts.

The effect of salinity may create two types of osmotic adjustment: the first corresponds with the phenological development of the plant; the second is achieved by physiological adaptation. The objective of the current study was to enhance our understanding of the mechanisms that affect the response of different chickpea varieties to salinity stress.

MATERIALS AND METHODS

To select the 6 chickpea genotypes, 40 genotypes were re-screened in vitro in the laboratory at ICARDA, before greenhouse study.

During the 2001-2002 season, seeds of different chickpea (*Cicer arietinum)* genotypes were tested.

The experiments were conducted in the greenhouse at ICARDA, with a day and night temperature of 20-30 ^{0}C, 60% relative humidity, and a light intensity of 20.000 lux for 12 hr/day. The set-up consisted of 120 plastic pots (6 genotypesX5 replications X4 treatments) with a top diameter of 19.5 cm and a depth of 18 cm, filled with sand. Ten seeds were sown per pot. Water with three different salinity levels, 2, 4, 6 dS/m, was prepared by adding a mixture of NaCl and $CaCl_2$ in a 3:1 ratio to the water. No salt was added to the control. All experiments were conducted using a randomized block design.

Six chickpea genotypes (FLIP 96-59, FLIP 96-74, ICCV2, FLIP 87-85, ILC 3279, FLIP 97-265) were sterilized with 0.1% mercuric acid for 5 min and washed in sterile water before germination. The chickpea genotypes were sown in April 2002. After the emergence percentage had been determined, the seedlings were thinned out to a number of 5 per pot.

Two inoculums of Rhizobium strain were added immediately to the genotypes. Modified Arnon and Hogland's N free solution was added twice a week. Irrigation with saline water was started 3-5 days after sowing. The pots were weighed after the first irrigation and before each of the following irrigations.

Growth and yield

The leaf area and dry matter accumulation of leaf, stem, and root of chickpea were determined at the successive phenological stages. The seedlings were first used to measure the leaf area with an AM-Licor 1300 apparatus. The dry matter was determined by oven drying at 85 ^{0}C for 48 hours. The water content was determined from the difference between the fresh and dry weight.

Phenological observations

The emergence and the survival of the seedlings were determined by daily counting of the number of plants during the first 15 days after sowing. To determine the phenological dates and the development of the shoot and root lengths and weights at day 25, 35, 45, 55, 65, and 75;leaf initiation (plastochrom) and numbers, flowers and pods, two plants per pot were marked. Thus, the number of leaves and flowers is the average of 10 observations. When the plants had attained a phenological stage, this date was noted.

Physiological observation

Leaf water potential was measured on one plant in each pot at 100% flowering. The leaf area and the dry matter of leaf and stem were determined at the successive phenological stages (25, 35, 45, 55, 65, and 75 days after sowing) on two plants in each pot, first leaf area and afterwards the dry matter. At harvest the yield components (number of pods per plant, weight of pods) were measured from all plants present in the pot.

RESULTS AND DISCUSSION

Germination

At an EC of 6 dS/m germination varied between 20 and 100%. The greenhouse testing of the six selected chickpea genotypes showed that the genotypes responded differently to saline conditions (Fig. 1). Germination capacity decreased with increasing salinity levels for FLIP.92-265. Seeds of FLIP.98-74, FLIP.87-59, FLIP.87-85, and ILC 3279 showed better germination than ICCV2 and F.97-265.

The reduction in germination of the seed (at day 14 after sowing), as compared to the respective controls, was 13% for ICCV2, 18% for FLIP.97-265, and 23% for FLIP.98-74. In general, the germination percentage of the six genotypes of chickpea reduced with increasing levels of salinity. The results of germination indicated that the six genotypes of chickpea differed in their response to different salinity levels. This would suggest the possibility of exploiting genotypes variation in chickpea to specific concentration of salts.

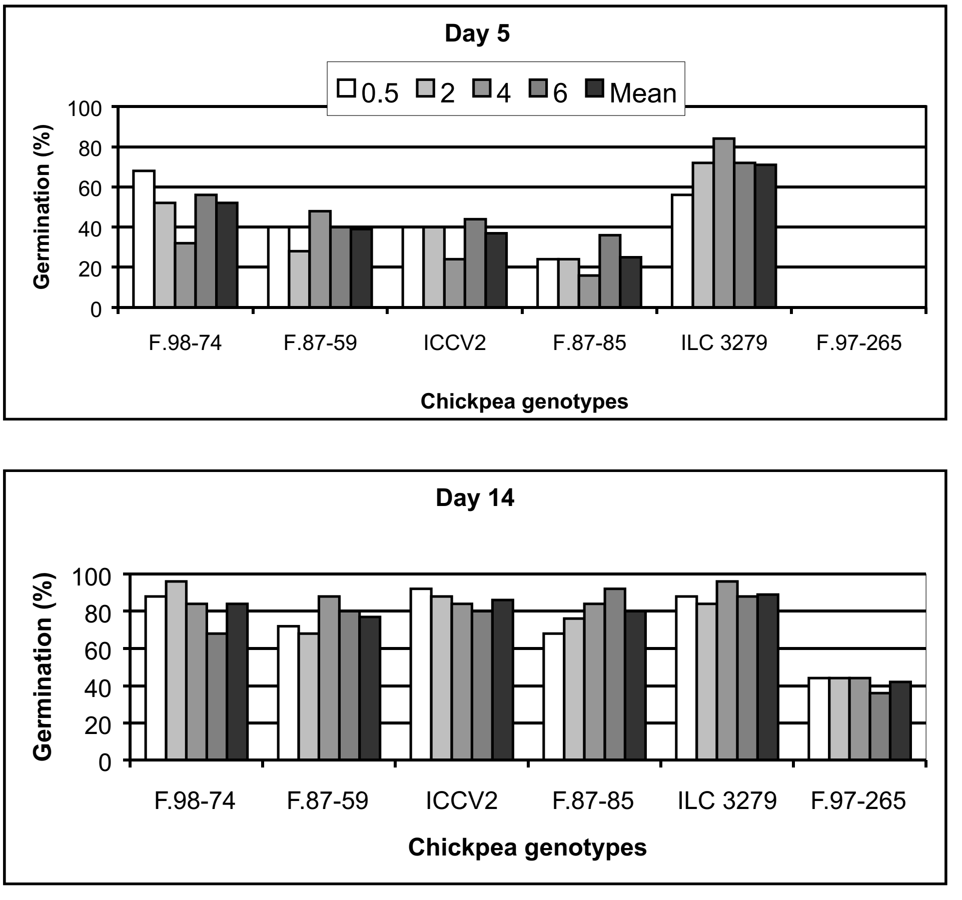


Fig. 1. Effect of salinity on germination of chickpea genotypes at 5 and 14 days after sowing.

Growth parameters

The length of the phenological stages of the chickpea genotypes showed no clear effect of salinity. The average time to ramification varied between 17.9 days at the control to 19.9 days at an EC of 4 dS/m. Start to flowering varied between 42 days at 4 dS/m and 46.8 days at the control. Start to pod setting varied between 47 to 50.8 days at ECs of 4 and 6 dS/m, respectively.

The observed effects of salinity on seedling growth were a function of both salt level and time of exposure. Twenty-five days after sowing, salinity stress did not exert significant effects on shoot and root growth, and fresh and dry weights at salinities up to 4 dS/m for all genotypes, except for FLIP.97-265, and up to 6 dS/m for ILC 3279.

At day 35, seedling growth parameters for FLIP.98-74, FLIP.87-59, ICCV2, FLIP.97-265 demonstrated greater positive response to the inhibitory effect of salinity at 4 dS/m than F. 87-85. There was a gradually delayed shoot growth of FLIP.98-74, FLIP.87-59, ICCV2, and ILC 3279 in relation to increased regimes of salinity levels (0-6 dS/m). At the highest level of salinity (6 dS/m) the reduction in root and shoot lengths relative to the control value was 35, 30, 0, and 26% for the root and 37, 29, 48 and 47% for the shoot of varieties FLIP.98-74, FLIP.87-59, ICCV2, FLIP.97-265, respectively.

As the duration of salinity stress increased a significant reduction in seedling growth and shoot-root ratio was observed (Fig. 2). At day 55 and 65, the growth parameters for all varieties were inhibited at 6 dS/m except for FLIP.87-85. Increasing levels of salinity adversely affected both root and shoot length of chickpea seedling. The shoot-root ratio generally exceeded 1, except for day 25. The ratios decreased with salinity. The reduction in root and shoot lengths of plants, is one of the most commonly observed responses of salinity (Bernstein and Hayward, 1958).

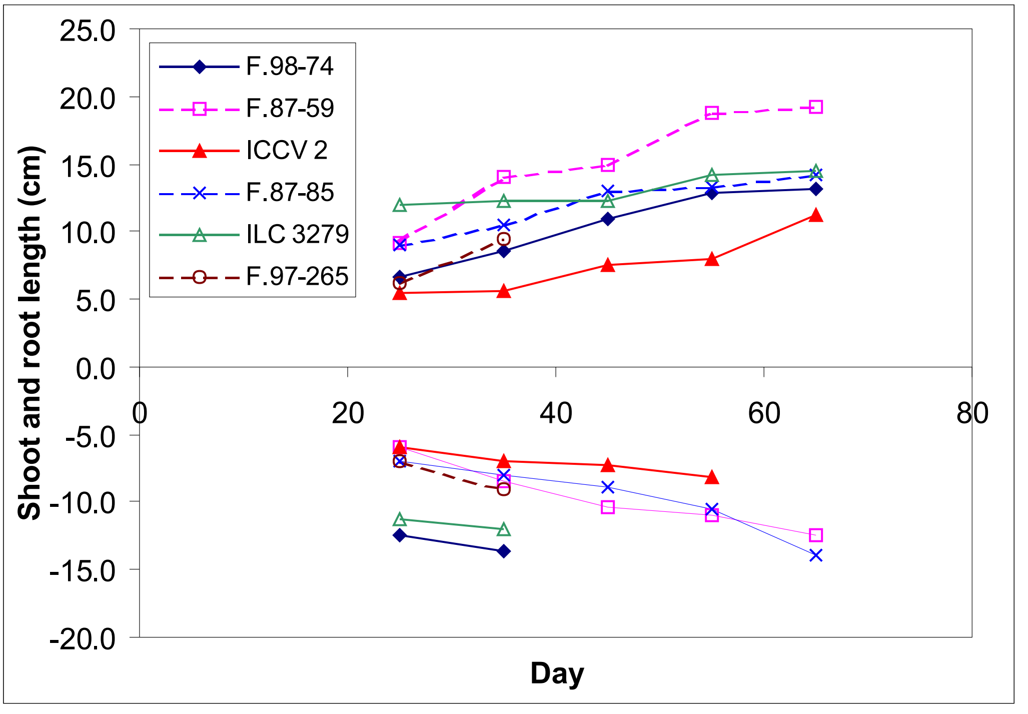
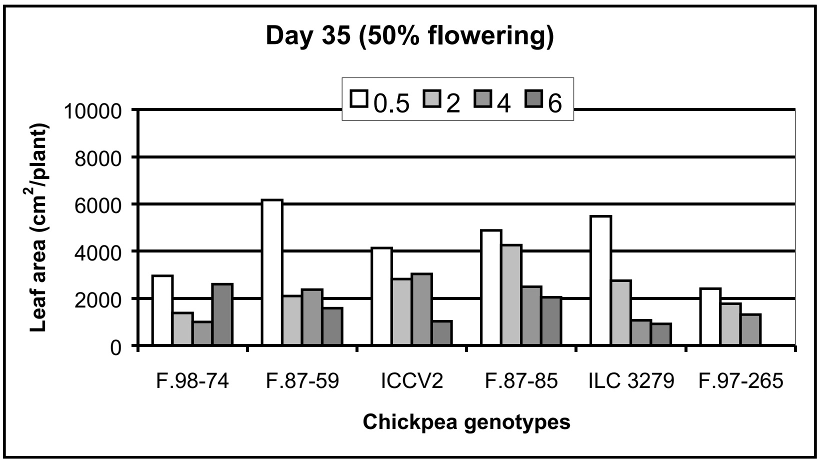
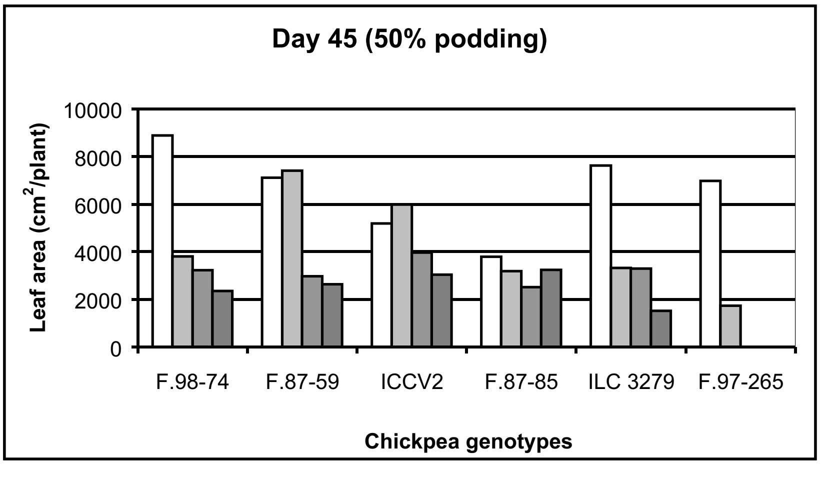


Fig. 2. Shoot and root growth of chickpea genotypes at EC 6 dS/m.

Salinity had effect on the leaf area, but its effect was not strong and decreased with time for the most saline treatment. Figure 3 shows the effect of salinity on the leaf area, determined at 35 days (50% of flowering), 45 days (50% of podding) and 55 days (75% of podding).





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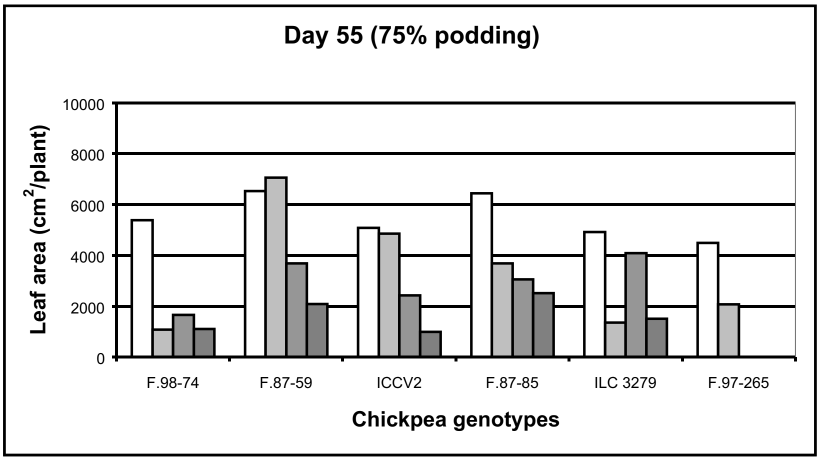


Fig. 3. Effect of four salinity levels on the leaf area of chickpea genotypes at day 35, 45, and 55.

Dry matter accumulation for shoots, leaves and stems developed regularly from transplantation till harvest and was affected by salinity, especially for FLIP.97-265 (Fig. 4). All varieties were affected with time at salinity levels 4 and 6 dS/m. The dry matter seems to be less sensitive to salinity than the leaf area. Similar observations were made by Katerji et al. (2001b).

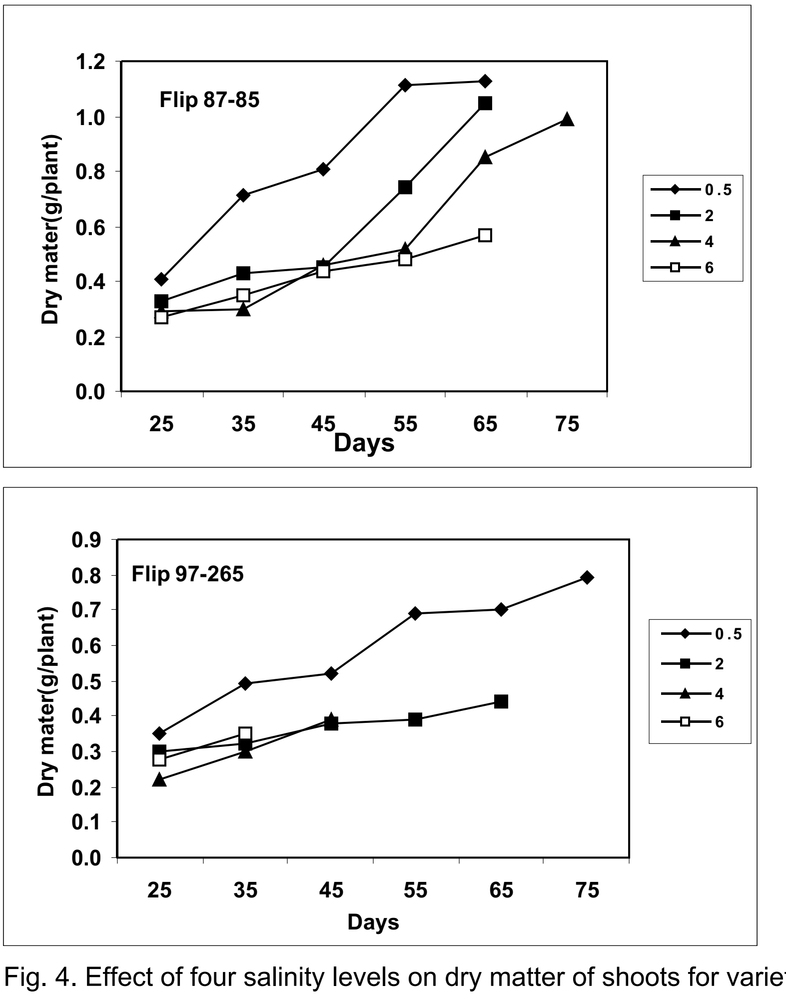


Fig. 4. Effect of four salinity levels on dry matter of shoots for variety F.87-85 and F.97-265.

Leaf water content and potential

The leaf water potential decreases after dawn, attains a minimum around solar noon, and afterwards increases again. The leaf water potential showed high values for all varieties (Fig. 5). There was no significant response of leaf water potential to salinity.

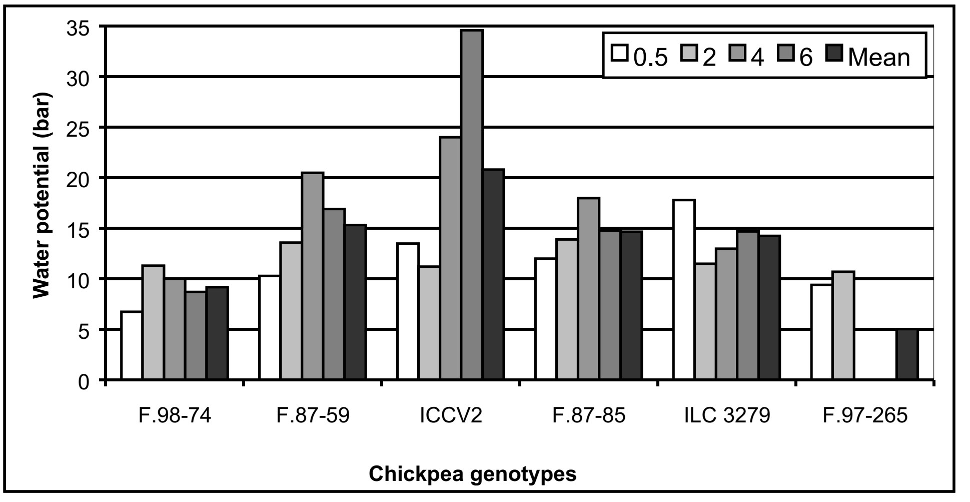
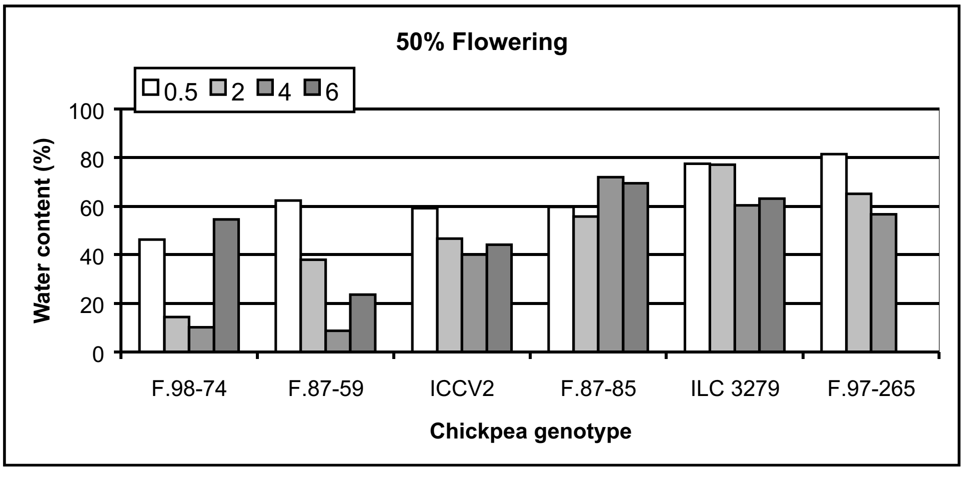


Fig. 5.Effect of salinity on leaf water potential of chickpea genotypes at 100% flowering.

Leaf water content was higher at 50 than at 100% of flowering. The water content (Fig 6) was reduced with increasing salinity level. The reduction values were higher in FLIP.97-265 at 6 dS/m (about 100% at 50% of flowering) than in FLIP.87-59 (24% at 50% flowering and 66% at 100% of flowering). An increase in tissue water content due to salinity was reported in bean plants by Meiri et al. (1971), in lupine and broad bean plants by Shaddad et al. (1990) and in soybean cultivars by Abdel-Samed and Shaddad (1997). Hasegawa et al. (1986) reported that salt tolerance at the whole plant level seems to be related to the capacity of cultivars to resist dehydration. In addition, the ability to accumulate water during the vegetative growth period could be a very important trait to discriminate genotypes by their salt tolerance (Binzel et al., 1985).



(continued Fig.6)

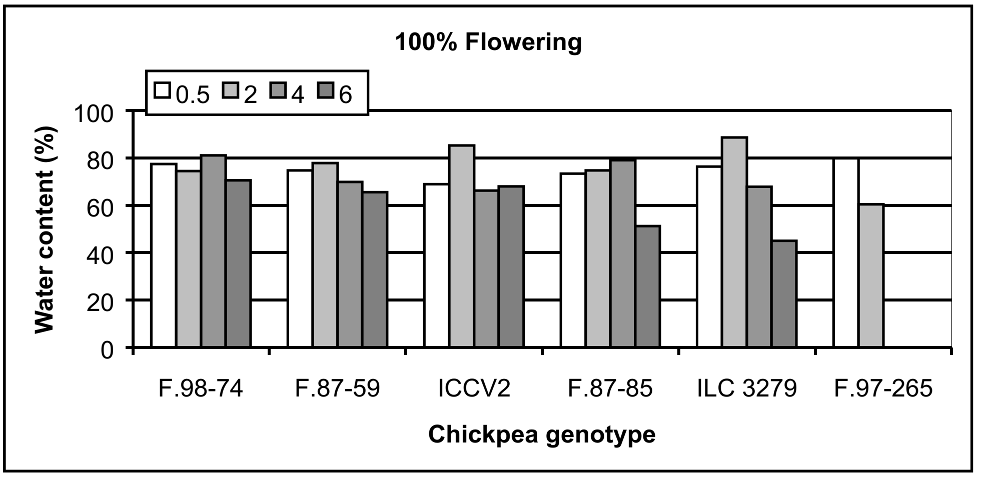


Fig. 6.Effect of salinity on leaf water content of chickpea genotypes at 50 and 100% flowering.

Plastochron

Plastochron was higher for genotypes FLIP.98-74 and FLIP.87-59 than for the other varieties. There was no significant effect of salinity on plastochron (Fig. 7).

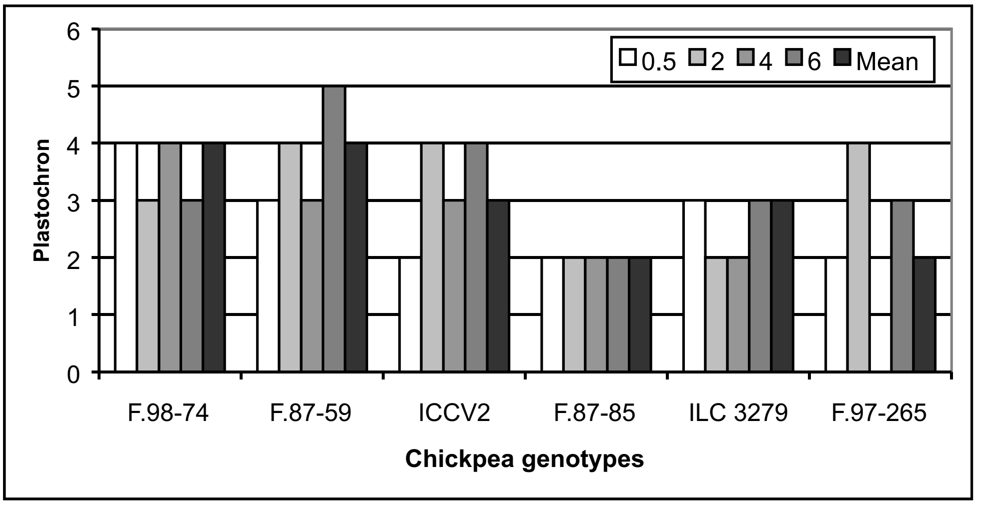


Fig. 7. Effect of salinity on plastochron of chickpea.

Yield components

The results of the growth parameters were confirmed by the yield data. Yield capacity is always one of the primary objectives in crop breeding for increasing crop yield. The decrease in yield is mainly caused by a difference in the grain weight and pods. Flower and pod numbers (Table 1) and pod weights of all chickpea varieties were substantially reduced at a salinity level of 4 dS/m. At 2 dS/m none of the components Of ICCV2 genotype was significantly reduced, as compared with the control. The number of pods decreased from 4 at 0.5 dS/m to 0 at 6 dS/m for all genotypes, except for variety ICCV2, which still averaged 1 pod at 6 dS/m.

Table 1. Effect of salinity on number of flowers and pods of chickpea genotypes.

Chickpea Genotype	0.5 dS/m	2 dS/m	4 dS/m	6 Ds/m
	Number of flowers per plant			
FLIP.98-74	5	0	0	0
FLIP.87-59	9	4	3	2
ICCV2	5	4	2	2
FLIP.87-85	5	5	2	0
ILC 3279	2	1	0	0
FFLIP.97-265	7	2	1	0
	Number of pods per plant			
FLIP.98-74	4	0	0	0
FLIP.87-59	4	1	0	0
ICCV2	4	3	1	1
FLIP.87-85	3	1	0	0
ILC 3279	1	0	0	0
FLIP.97-265	3	1	0	0

CONCLUSIONS

The reduction in seedling survival rates and growth are major causes of the stand loss in salt affected legumes fields. This study indicated that in all genotypes salinity as high as 2dS/m can reduce seedling shoot dry weight and that salinity at 6 dS/m can reduce seedling survival (plant stand). During early seedling, salinity affected the development of the seedlings that showed symptoms of water stress. These symptoms could be observed in the form of leaf water potential, pod number and weights .The six chickpea genotypes studied displayed distinct variation in salinity tolerance during growth. A comparison of the effects of salinity on growth of 6 genotypes indicates that genotypes FLIP.98-74, FLIP.87-59 and ICCV2 seemed to be more salt tolerant than FLIP.97-265, FLIP.87-85 and ILC 3279 at the same salinization levels.

To better understand the difference of responses on osmotic adjustment and water use efficiency, additional greenhouse experiments in sand and soil need to be conducted for chickpea and other legume and forage genotypes. The most promising genotypes of each crop should subsequently be tested in the field. Similar observations should be made in the field as in the greenhouse. The EC and chemical composition of irrigation and soil water should also be analyzed.

ACKNOWLEDGEMENTS

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Water Use Efficiency Network

GROWTH, YIELD AND PERIODICITY OF PISTACHIO UNDER DIFFERENT WATER AND NUTRITIONAL LEVELS: INVESTIGATION IN THE SOUTHEASTERN ANATOLIA PROJECT REGION (GAP)

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ABSTRACT

The effect of two irrigation intervals (I_1: 7 days and I_2: 14 days), four nitrogen doses (N_g, N_0, N_1, N_2 and N_3) and two crop coefficient (K_{pc}:0.60 and K_{pc}:0.90) on the pistachio nut fertigation was studied. The nitrogen levels were 0, 10, 15 and 20 ppm based on irrigation water concentration. In traditional treatment, each tree was given a 500/600/400 g of NPK fertilizer at the beginning of February. Other fertilizer doses were applied in the irrigation water through drip system. Irrigation water amount was calculated based on the pan-evapotranspiration. Wetted percentage in each irrigation was 30%. During the growing seasons extended from 29.05.2001 to 04.09.2001 at the first year and from 04.06.2002 to 10.09.2002 at the second year, experimental treatments were irrigated 15 or 8 times based on the irrigation intervals. Irrigation depth applied ranged from 324 to 906 mm in 2001 and 282 to 724 mm in 2002. In year of 2001, evapotranspiration varied from 518 to 345mm for plot area and 1152 to 572mm for the wetted area except in traditional treatments. Similarly, in 2002 the maximum evapotranspiration were varied from 1227mm for wetted area and 641mm for whole plot area, contrary, minimum values were 700mm (wetted area) and 482mm (plot area). Monthly values of K_c were calculated between 0.21 and 1.32 for 2001 and 0.19 and 1.56 for 2002 as minimum and maximum. All the experimental years have the highest K_c values in July when the highest evapotranspiration was measured.

The maximum nitrogen amount was applied to treatment with high nitrogen and high water ($I_{f1}N_3K_{pc2}$) with 18.1 g.m^{-2} (in 2001) and 15.9 g.m^{-2} (in 2002) among irrigated treatments. In 2001, all pistachio trees have received 4.9 and 3.2 g.m^{-2} phosphorous and potassium while in 2002 year these values decreased to 4.2 and 2.8 gram per square meter. The stomatal conductivity in the irrigated treatments ranged from 0.2 to 0.4 molm^{-2}s^{-1} while changing between 0.1 and 0.2 molm^{-2}s^{-1} in non-irrigated treatment. Net assimilation was recorded between 10 and 20 molm^{-2}s^{-1} in irrigated treatments. Corresponding figures for non irrigated treatment were between 5 and 15 molm^{-2}s^{-1}. The photosynthetic water use efficiency, however, was about 2 molmmol^{-1} in all treatments.

The maximum yields were taken from $I_{f2}N_3$ with average 11.7 kg per tree in 2001 and from $I_{f1}N_0$ with average 11.6 kg per tree in 2002.

Key Words: Fertigation, Drip Irrigation, Pistachio, Leaf Gas Exchange, Photosynthetic Water Use Efficiency, Yield

1. INTRODUCTION

Pistachio (*Pistacia vera L.*) is native of Anatolia, Syria, Iran, Afganistan, Baluchistan and some parts of Northern India (Kaºka, 1998a), as well as Lebanon, Palestine, Iraq, Southern Europe and the desert countries of Asia and Africa (Hendricks and Ferguson, 1995; Vargas, 1998). Pistachio is one of the most important crops in the Southeastern Anatolia Region of Turkey with respect to production and export. Although, it can be grown in many parts of Anatolia, it is most widely distributed in the Southeastern Provinces of Gaziantep, Sanliurfa, Adýyaman, Kahramanmaraþ, and Siirt. The first three cities of the Southeastern Region produce 87.88 % of the total pistachio in Turkey (Ak et al., 1999). However, there are many problems faced by growers, which mainly are: (i) Low Yield, and (ii) Irregularity of the yield.

The low yields can be attributed to factors such as periodicity, inadequate pollination, fertilization and prolonged periods of water stress due to low rainfall and lack of irrigation, and primitive traditional cultural practices such as planting, maintenance, fertilization, and harvesting (Kanber et al., 1986). Although pistachio production in Turkey goes back to very old times, today's production has not increased to the anticipated levels since pistachio are grown in dry and unproductive lands and thus yield per tree is very low. For instance, the average yield is only 1.4 kg per tree in Turkey, whereas U.S.A where modern production and management techniques such as irrigation and fertigation practices were used has 16-18 kg per tree even though they started to grow pistachio after 1960's (Tekin et al., 1990, Ak et al., 1999). Even though it is very drought resistant, its growth rate is very slow. Therefore, Turkey like other countries is not in favor of growing pistachio nut in fertile soils and they devote only marginal areas to pistachio (Kaºka, 2001).

The irregularity of the yield is the biggest problem in Turkey for pistachio production. There are 33 million pistachio trees, but according to the agricultural survey, total pistachio production in Turkey varies from 15000 metric tons in off-yielding years to 40000 metric tons in on-yielding years. This irregularity is caused by periodicity (Kanber et al., 1993). Using modern production and management techniques such as irrigation and fertigation practices can decrease the effect of periodicity. The effects of irrigation, fertigation and nutrient deficiencies as well as the soil on pistachio are not known sufficiently in Turkey (Ayfer, 1990). There are a few studies done in Turkey and other countries on irrigation and fertilization of pistachio. The first study of irrigation on pistachio in Turkey was started in 1973 at the Pistachio Research Institute in Gaziantep (Bilgen, 1973; Kuru, 1992). Those studies show that irrigation is one of the most important preventive cares, which need to be considered to reduce the yield decline due to periodicity. On the other hand, various researchers indicated that both lack of irrigation and inadequate accumulation of nitrogen in plant tissues cause the periodicity. Nowadays, irrigation and fertigation studies on pistachio trees are being done at the same institute since pistachio are grown in dry and unproductive lands and thus the yield per tree is very low (Kanber et al., 1993).

The main purposes of this study are (1) to investigate the water relations of pistachio and (2) to examine the most appropriate irrigation/fertigation practices of pistachio orchards (3) to introduce the new irrigation technology consisting of trickle irrigation system and fertigation techniques.

2. LITERATURE REWIEV

Pistachio is one of the most important crops in the Southeastern Anatolia Region (GAP) of Turkey (Kanber et al., 1992; Kaºka, 1998a), but also in U.S.A (Callifornia), Iran (Kerman Province), Italy, Greece, Syria and Australia (Sheibani, 1994; Vargas, 1998). Althoug it can be grown in many parts of Anatolia, it is most widely distributed in the Southeastern Provinces of Kahramanmaraþ, Gaziantep, Þanlýurfa, Adýyaman, Siirt (Ak, et al., 1999; Kaþka, 1998a, b) Pistachio nuts are grown in steppes areas of Southeastern Anatolia where the winters are cold and summers are long dry and hot annual precipitation is between 200 to 400 mm (Kaºka, 1998a).

There is severe irregularity in pistachio production and it is respected as the major problem faced by the growers in the region. The observed irregularity in yield is caused by periodicity inadequate pollination and fertilization prolonged periods of water stress due to low annual rainfall and no irrigation primitiveness of the existing harvesting methods and the traditional cultural practice of "no maintenance and no care" (Geurts 1982). It is believed that the periodicity is genetically controlled. However the factors mentioned above must significantly enhance the effects of periodicity and cause low yields. This has led us to believe that improved cultural practices especially irrigation may suppress the effect of periodicity and therefore high yields can be attained even in the off-yielding years. Bilgen (1979) indicated that irrigation is among the most important preventive cares, which need to be considered to reduce the yield decline due to periodicity. On the other hand a majority of the pistachio growers in Turkey have a misconception that irrigation may be harmful to pistachio trees.

Sykes (1975) indicates that extreme temperatures both low and high and low annual rainfalls are between the two major constraints, which limit the extension of the pistachio plantations in Turkey. It is reported that the leaf abscission of pistachio occurs as a result of prolonged periods of water stress during dry years when annual rainfall is below 400 mm. The leaf abscission occurring in a given year hinders the bud development in the subsequent year and thereby decreases the fruit yield. Sepaskhah and Maftoun (1981) demonstrated that pistachio has wide genotypic variability for water stress and salt tolerance. However in order to have high yields available soil water content should only be allowed to drop to a minimum of 50% under irrigation practices. Irrigation influences length of new branches leaf area and nut size and weight. The studies by Goldhamer, et al. (1985) showed that marketable yield following one year of severe water stress was only half that of unstressed trees. Therefore irrigation should be considered among the most important cultural practices to sustain high yields in the pistachio orchards (Bilgen, 1982).

The pistachio trees are very drought tolerant and their roots may go as deep as 2.5 m in search of moist soil layers. In the extreme dry years when available soil water content is below wilting point root activity may completely cease for a 4 to 5 week period in all soil layers. This implies that irrigation can significantly improve pistachio fruit yield (Spiegel-Roy et al. 1977). Firuzeh and Ludders (1978) have reported that pistachio is quite salt tolerant but very sensitive to frost and water stress when they are young (up to 5 to 7 years). It is questionable however whether irrigation practices can benefit very old (30 to 40 years) pistachio trees, which are well adapted to long periods of drought. Trees with extended rooting systems may effectively extract soil water from deeper moist soil layers.

There are a few studies done in Turkey and other countries on irrigation and fertilization of pistachio (Kanber, et al., 1990). In some desert and transitional areas pistachio trees are irrigated. Iran and some parts of Syria, Greece, and South part of Italy, Tarragona areas in Spain are the examples for such areas (Kaºka, 1998a).

Pistachio can be grown dry condition in Turkey whereas, pistachio is grown under irrigating condition in some countries such as California (U.S.A.) and Iran (Ak, et al., 1999). Pistachio trees have a reputation of being drought tolerant, for being able to survive and even produce modest crops with very little water. However, drought tolerance doesn't mean that pistachio trees require little water optimal performance (Goldhamer, 1995).

The drought tolerance of pistachio trees refers to its ability to survive under severe waters stress conditions (Goldhamer, 1995; Kanber, et al., 1990). Michailied, et al. (1996) observed that avoiding water stressing of pistachio trees during mid-May (at a time when the shell is growing fast) decreases significantly the incidence of early splits and thus reduces the incidence of aflatoxin contamination.

Kanber, et al. (1990) has investigated relationship of pistachio and irrigation with applying different type of flood irrigation system between 1974-85 years in Turkey (GAP). Irrigation practices in pistachio trees increases fruit yield especially in “on” year trees. The irrigation at 20 days interval was 57.1 kg/tree during the “on” year trees; whereas, the control treatment of no irrigation gave only 34.5 (kg / tree) during the same period. During the “off ” year tree, the non-irrigated treatment was 17.3 kg/tree, whereas the irrigated treatment gave higher fruit yield of 40.3 (kg/tree). Irrigation treatments had no effect on yield quality. Seasonal evapotranspiration during the normal yielding years was 803 mm. The highest monthly evapotranspiration was obtained in August with 205 mm and 6.6 mm per day.

Fertigation is the common term for injecting fertilizers through the irrigation system. Micro-irrigation systems are well suited to fertigation because of the frequency of operation and because water application can be easily controlled by the manager (Schwankl, 1995).

3. MATERIAL AND METHODS

3.1. Site Description

The study is carried out at the experimental garden of the Pistachio Regional Research Institute near the city of Gaziantep. The pistachio orchard is about 3.0 hectares and 26 km far from Gaziantep. The orchard is 37°28'east and 36°57'north longitude and latitude respectively and 705m altitude.

3.2. Variety

Trees of pistachio *(Pistachio Vera L.) Uzun* variety planted with 10x10 m spacing was used for this experiment. This variety is grown widely in all of the country especially in Gaziantep Adýyaman Þanlýurfa and Kahramanmaraþ provinces. Trees have semi upright habitus. Chilling requirement is less than other pistachio varieties such as Halebi and Kýrmýzý, which can be grown in the other places of the GAP region. Since this variety matures 15-20 days earlier than the others it is being recommended for high elevation places. The experimental orchard is 27 years old and was in the off-yielding year in 2001 and on-yielding year in 2002.

3.3. Soils

The soil in the experimental orchard is in the Gaziantep-Birecik sub-basin. The soils in this basin are the *Karacaveran* soil series, which is Calcaric Vertisol. The Profiles represent widely distributed soils developed on calcretes. The main crops, which are pistachio and olive, grow under rain fed condition due to the suitable soil properties. However, irrigation has started at some parts under the Southeastern Anatolia Project (GAP).

The irrigation characteristics of the experimental soil are determined by disturbed and undisturbed soil samples taken from representative places in the orchard using the systematic sampled methods given by Peters and Calvin (1965). Soil samples with 30 cm layers in the 150 cm profile depth were used. For undisturbed soil samples, values of field capacity, bulk density, were analyzed. Soil texture, percentage of $CaCO_3$, clay, silt and sand contents, pH, and permanent wilting point were analyzed using the disturbed soil samples. All analysis was done by methods given by USSLS (1954) and Tüzüner (1990) and the results were in Table 1.

Table 1. Some Physical and Chemical Characteristics of the experimental soil

Soil Depth cm	Soil Type	F.C gr/gr	PWP gr/gr	Bulk density	pH	Salt Content %	Lime %	Clay %	Sand %	Silt %
0-30	C	37.71	21.13	1.33	7.34	0.116	17.23	73.32	4.13	22.54
30-60	C	37.69	21.08	1.15	7.43	0.109	17.24	71.58	2.81	26.27
60-90	C	38.05	21.22	1.33	7.56	0.098	18.31	76.21	3.19	20.59
90-120	C	37.30	21.26	1.29	7.58	0.095	19.92	77.32	2.93	19.76
120-150	C	34.78	21.02	1.39	7.68	0.195	23.75	75.93	4.03	20.27

3.4. Climate

Climatic characteristics of Gaziantep district show the typical transient zone between Mediterranean and desert climates. The hot and dry summer and rainy spring and autumn and snowy and cold winter prevail in that zone. The average rainfall of the zone in the last 45 years is about 531mm. During the experimental years, the total rainfall received in the growing period of pistachio are the almost same of the value occurred in the long-term period.

3.5. Irrigation System

Irrigation water is supplied from two deep wells with almost 220m depth located within the orchard. Water has EC within the range 0.25-0.75 dS m^{-1} and a SAR within the range 0-10 (C_2S_1 class).

The irrigation water is applied by the drip irrigation system, which contains a control unit (pump injection equipments, filters flow and pressure measuring devices etc.) and pipe network. As it is known that trickle irrigation system has high irrigation efficiency therefore it can be considered as a new irrigation technology and a potential tool under water scarce conditions that can arise in places where traditional irrigation methods are used.

3.6. Treatments Description

Different irrigation and fertilization programs were used. Different irrigation intervals (I_{f1}=7; I_{f2}=14 days) pan coefficients (Kpc_1=0.60; Kpc_2=0.90) and nitrogen concentrations (Ng; N_0=0 ppm; N_1=10 ppm; N_2=15 ppm; N_3=20 ppm) were considered in the experiment (Figure 1).

The treatment, Ng, shows the traditional fertilization program in which 500 g N, 600 g P_2O_5, and 400 g K_2O per tree was applied at the projection of tree crown in February. However, these trees are not irrigated. The phosphorus and potassium fertilizers were injected at same concentrations of 15 and 10 ppm respectively to all treatments at the two weeks intervals except for the traditional treatment. For the treatment of N_0 only the phosphorus and potassium were injected to irrigation water.

The experiment has been planned as split-split block design with two replications. The nitrogen contents, irrigation intervals and crop-pan coefficients were placed in the main plots, sub-plots, and sub-sub (mini) plots, respectively. The every mini plots have 8 to 10 trees with 813 square meters area.

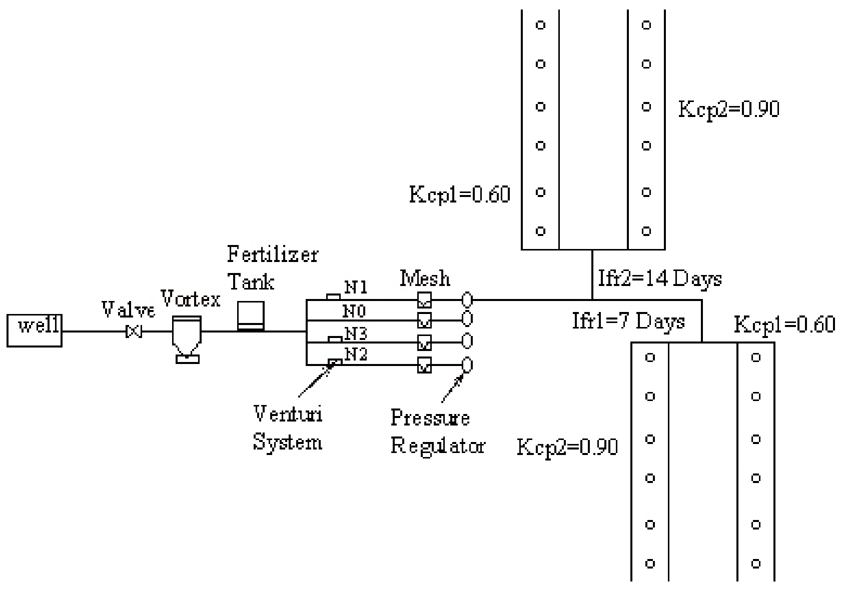

Fig. 1. The fertigation system used in the pistachio experiment

3.7. Amount of Irrigation Water

Amount of irrigation water to be applied to the plots is calculated according to the free water surface evaporation measured from class A pan during irrigation intervals with using as the following equation. Evaporation pan is placed on the bare soil at central point of the four trees in the experimental orchard.

$$I = K_{pc} \; E_o \; C \qquad (1)$$

Where K_{pc} is the coefficient related to crop and pan type; E_o is the cumulative evaporation and C is the wetting percent (30% is used). The wetted area was measured after irrigation events to control wetting percent.

Nitrogen concentrations were prepared and applied using fertigation control units. Water with nitrogen is given directly to the trickle lateral lines that are placed in both sides of the trees.

3.8. Actual Evapotranspiration

Actual evapotranspiration (crop ET) of the treatments was calculated using water balance approach as plot basis using Equation 2 (James 1988).

$$ETa = IR + P + Cp - Dp \; R_f \; S \qquad (2)$$

Where, ETa is the actual evapotranspiration which is calculated for wetted area; IR is the irrigation water applied to the plots; P is the rainfall; Cp is the capillary rise; Dp is the deep percolation R_f is the runoff going into or out of the plots; S shows the change of moisture content in the root depth. Irrigation water, rainfall and moisture content are measured and other components are assumed to be zero.

3.9. Reference Evapotranspiration

Crop ET data were used to develop K_c values based on estimates grass reference evapotranspiration using the Penman-Monteith (Allen et al. 1998; Steduto 1999) FAO-Blaney-Criddle and Pan Evaporation methods (Doorenbos and Kassam 1986) and Jensen Pan Evaporation method (Kanber 1999) with daily weather values. ET estimations were made for pistachio growing season assumed to extend from the end of February when the buds opened to the mid of the November when leaves shed.

3.10. Crop Coefficient (K_c)

The equation given by Koumanov et al. (1997) was used for calculating the Kc values. That equation was changed according to wetting percent used for calculating irrigation water amount.

$ET_c=K_cK_rET_o$ (3)

Where ET_c is crop evapotranspiration, which is estimated by reference ET approach; K_c denotes the crop coefficient; K_r shows the percentage of soil surface covered by the crop canopy as compared with the total surface area ET_o is the grass-reference evapotranspiration estimated using FAO-methods. The actual evapotranspiration for whole plot area was calculated by multiplying 0.30 and put instead of ET_c in the Equation 3 for calculating K_c values.

3.11. Measurement of Soil Moisture Content

Moisture content of soil profile in the treatments were measured before and one day after irrigations. The moisture levels were also determined before the start of the growing period, which is obtained as the leaf freshening time and at the end of the growing period, that is leaf-shedding time. Measurements were done with neutron scattering and gravimetric methods using 20 and 30 cm soil layer in the 120 cm soil profile, respectively.

3.12. Measurement of Gas Exchange Parameters

The pistachio leaf gas-exchange response is being carried out between July and August when the evapotranspiration is high. The "irrigation" and "nutritional" treatments under investigation were chosen as a combination between "high" and "low" status of "water" and "nitrogen". Specifically: *"Traditional"* (which corresponds to a condition of "low nitrogen" and "no irrigation" status); "$N_3I_{f2}K_{pc1}$" (which corresponds to a condition of "high nitrogen" and "low water" status); "$N_3I_{f1}K_{pc2}$ (which corresponds to a condition of "high nitrogen" and "high water" status); "$N_0I_{f1}K_{pc2}$" (which corresponds to a condition of "low nitrogen" and "high water" status).

The purpose of the measurement was to characterize the photosynthetic capacity the stomatal conductance and the photosynthetic water use efficiency of pistachio under different irrigation and nutritional treatments. Furthermore observations on the leaf photosynthetic response and stomatal conductance to different environmental variables (such as leaf water potential light vapour pressure deficit and CO_2 concentration) were conducted as well to acquire insight on the physiology of the plant. In order to take these variables a LI-6400 *Portable Photosynthesis System* (LiCor Inc. Lincoln Nebraska USA) was used. This system is operated as open gas-exchange steady-state system and consisting of two main components: the *system console* and the *sensor head*.

3.13. Measurement of Leaf Water Potential

Leaf water potential of pistachio was measured using a *3000 Series* plant *Water Status Console Pressure Chamber* (Soil Moisture Equipment Corp. Coleta CA USA; Figure 17) for $I_{f1}N_3K_{cp1}$ $I_{f1}N_3K_{cp2}$ $I_{f2}N_3K_{cp1}$ $I_{f2}N_3K_{cp2}$ and *traditional*. **T**he diurnal pattern of leaf water potential was measured at the sunrise, noontime and sunset between the consecutive irrigations. Three or two stem samples on each tree which were full exposed leaves from the canopy were taken on each measurement time.

3.14. Harvest

Pistachio trees were harvested on September 7 and 11 in the experimental years of 2001 and 2002, respectively. Harvests were done after the irrigation seasons, which finished in September. All pistachio nuts from trees were removed by hand to determine gross yield of trees in each plot. Fruits, which reach the physiological maturity stage by having reddish hull, were harvested by shaking the trees. All remaining nuts were picked by hand and separated from clusters. Harvest sub-samples (one kg per tree) were collected from each plot for evaluation of yield components and quality. Blanks (no embryo growth), unsplit nuts, split nuts, fresh and dry weights of hulls, shell and kernels were determined. Some parts of these samples were used to determine water content of the yield. These samples were dried until reach to constant weight in an oven with 65 ºC in the laboratory.

4. RESULTS AND DISCUSSION

4.1 Irrigation and Evapotranspiration

Irrigation dates and water amount applied in the different treatments and other irrigation parameters are given in Tables 2 and 3. Irrigation period in the year 2001 begun on May 29 and ended at harvest which is September 10, whereas it was between May 4 and September 10 in 2002. The irrigation treatments with 7 and 14 days interval were irrigated 15 times and 8 times, respectively during the both irrigation season in the years. Of course the larger water application was for the treatment with 7 days interval and 0.9 K_{pc}. All treatments received the highest amount of water in July. The total irrigation water varied depends on irrigation interval and K_{cp} values. The highest water amount was obtained in treatment with 7 days interval and 0.90 K_{pc} with 906 and 794 mm in the experimental years.

Table 2. Amount of Irrigation Water Given to Treatments in 2001 Year

Irrigation Date	Evaporation (CAP) (mm)	Applied Irrigation Water Amount (mm)							
		If_1=7 days				If_2=14 days			
		Kcp_1=0.6		Kcp_2=0.9		Kcp_1=0.6		Kcp_2=0.9	
		Wetted Area, 244 m^2	Plot Area 813m^2	Wetted Area, 244 m^2	Plot Area 813m^2	Wetted Area, 244 m^2	Plot Area 813m^2	Wetted Area, 244 m^2	Plot Area 813m^2
29.05.2001	64	39	12	39	12	39	12	39	12
05.06.2001	65	39	12	59	18				
12.06.2001	62	37	11	56	17	37	11	56	17
19.06.2001	65	39	12	59	18				
26.06.2001	75	45	13	67	20	45	13	67	20
03.07.2001	73	44	13	66	20				
10.07.2001	75	45	13	67	20	45	13	67	20
17.07.2001	80	48	14	72	22				
24.07.2001	84	50	15	75	23	50	15	75	23
31.07.2001	77	46	14	69	21				
07.08.2001	64	38	11	57	17	38	11	57	17
14.08.2001	66	40	12	59	18				
21.08.2001	57	34	10	52	15	34	10	52	15
28.08.2001	63	38	11	56	17				
04.09.2001	60	36	11	54	16	36	11	54	16
Toplam	**1028**	**617**	**185**	**906**	**272**	**324**	**97**	**467**	**140**

Table 3. Amount of Irrigation Water Given to Treatments in 2002 Year

Irrigation Date	Evaporation (CAP) (mm)	Applied Irrigation Water Amount (mm)							
		If_1=7 days				If_2=14 days			
		Kcp_1=0.6		Kcp_2=0.9		Kcp_1=0.6		Kcp_2=0.9	
		Wetted Area, 244 m^2	Plot Area 813m^2	Wetted Area, 244 m^2	Plot Area 813m^2	Wetted Area, 244 m^2	Plot Area 813m^2	Wetted Area, 244 m^2	Plot Area 813m^2
04.06.2002	58.2	58.2	17.5	58.2	17.5	58.2	17.5	58.2	17.5
11.06.2002	53.9	32.3	9.7	48.5	14.6				
18.06.2002	60.9	36.5	11.0	54.8	16.4	36.5	11.0	54.8	16.4
25.06.2002	69.6	41.7	12.5	62.6	18.8				
02.07.2002	69.6	41.7	12.5	62.6	18.8	41.7	12.5	62.6	18.8
09.07.2002	73.0	43.8	13.1	65.7	19.7				
16.07.2002	57.4	34.4	10.3	51.6	15.5	34.4	10.3	51.6	15.5
23.07.2002	65.2	39.1	11.7	58.7	17.6				
30.07.2002	73.0	43.8	13.1	65.7	19.7	43.8	13.1	65.7	19.7
06.08.2002	69.6	41.7	12.5	62.6	18.8				
13.08.2002	60.9	36.5	11.0	54.8	16.4	36.5	11.0	54.8	16.4
20.08.2002	60.9	36.5	11.0	54.8	16.4				
27.08.2002	52.2	31.3	9.4	47.0	14.1	31.3	9.4	47.0	14.1
03.09.2002	52.2	31.3	9.4	47.0	14.1				
10.09.2002	47.0	28.2	8.5	42.3	12.7	28.2	8.5	42.3	12.7
Toplam	**876.6**	**549.0**	**165.0**	**794**	**238**	**282**	**85**	**395**	**118**

The minimum value were 324 and 282 mm for 14 days interval with coefficient of 0.60. The irrigation programs and drip irrigation allowed significant water saving. The highest water saving were calculated with 180% (in 2001) and 182% (2002) according to the treatment with 14 days interval and 0.60 K_{pc}. The lowest values were 47 and 45 percent for first and second years, respectively as the treatment with 7 days interval and 0.60 K_{pc}.

The wetted area by the drip lines under the trees was measured to control the irrigation effectiveness after events. It was determined that almost more than 30 percent of the surface area was wetted after irrigations.

Seasonal evapotranspiration results of some selected treatments, which have received high and low water amounts including traditional treatment, were calculated and given in Tables 4 for two experimental years. As calculating evapotranspiration, all rainfall amount received during growing season were accepted as effective to plant due to their quantities and frequencies were small during the growing season. Additionally, it is assumed that irrigation water given to the plots was hold in the root zone, and no deep percolation and no runoff occurred. The highest evapotranspiration value was in the treatment, which is frequently irrigated and received more water, such as $I_{f1}K_{cp2}$. In year of 2001, evapotranspiration varied from 518 (I_{f1} N_3Kpc_1) to 345mm ($I_{f2}N_3Kpc_1$) for plot area and 1152 to 572mm for the wetted area except in traditional treatments. Similarly, in 2002 the maximum evapotranspiration was calculated in treatment $I_{f1}N_3Kpc_1$ as 1227mm for wetted area and 641mm for whole plot area, contrary, minimum values were in $I_{f2}N_3K_{pc1}$ treatment with 700mm (wetted area) and 482mm (plot area).

Table 4. Seasonal Evapotranspiration for Some Treatments

Treatments	Soil Water S mm		Rainfall P mm		Irrigation Water IR mm		Etc mm (Wetted Area)		Etc mm (Plot Area)***	
	2001*	2002**	2001	2002	2001	2002	2001	2002	2001	2002
I_{f1} N_3Kpc_1	130	87	85	236	617	577	832	900	400	496
$I_{f1}N_3Kpc_2$	161	154	85	236	906	837	1152	1227	518	641
$I_{f2}N_3Kpc_1$	163	153	85	236	324	311	572	700	345	482
$I_{f2}N_3Kpc_2$	164	160	85	236	467	437	716	833	389	527
Traditional	135	155	85	236	0.0	0.0	-	-	220	391

* April 20-November 07/2001; ** March 18-November 26/ 2002; *** ETc in irrigated treatments was calculated by summation of rainfall, soil water and 30 percent of total irrigation water.

There are significant reductions of evapotranspiration between treatments. The reduction rate of ET for irrigated treatments according to $I_{f1}N_3K_{pc2}$ varied between 28 for $I_{f1}N_3K_{pc1}$ and 50 percent for $I_{f2}N_3K_{pc1.}$ Similar results were determined in experimental year of 2002. There are 64 and 36 percent reduction in treatment of $I_{f1}N_3K_{pc2}$ compared to $I_{f2}N_3K_{pc1}$ and $I_{f1}N_3K_{pc1}$, respectively.

The monthly variations of average crop water use (ET_c) calculations in two trial years for two extreme treatments which have received high water with most frequent irrigation ($I_{f1}K_{pc2}$) and low water amounts with longer interval irrigation ($I_{f2}K_{pc1}$) at the same nitrogen level of N_3, including grass reference evapotranspiration (ET_o) calculated by Penman-Monteith approach are presented in Figure 2. These calculations assume clean cultivated conditions; no cover or actively growing native weeds or grasses. Additionally, it is assumed in the estimation of ET_o that the soil covered by pistachio trees is about 35 percent. The average maximum monthly evapotranspiration was obtained in July with 96 mm for $I_{f1}K_{pc2}$. In this month ET in treatment of $I_{f2}K_{pc1}$ and grass reference evapotranspiration are also the highest among the others monthly values with 46 and 79 mm, respectively.

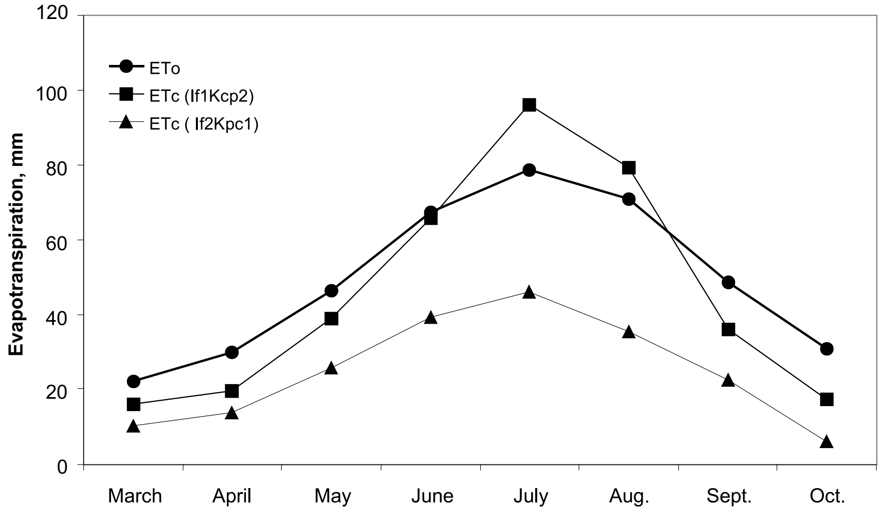

Fig. 2. The variation of ET_c for treatments of frequent irrigated with high water ($I_{f1}K_{pc2}$) and infrequent irrigated with low water ($I_{f2}K_{pc1}$) and ET_o values with time. ET_c values in November for treatments were small and they are not shoved in figure

At the beginning of the growing season and at harvesting, the crop evapotranspiration rates were found to be lower than those in irrigation season. The variation of measured ET for two irrigation treatments was similar to the change of ET_o. In the irrigation season, grass reference evapotranspiration are lower than those in frequent irrigated treatment. It can be reasoned by Penman-Monteith approach gives under estimation due to extra energy introduce by advection in this region (Steduto et al., 1996).

4. 2. Crop Coefficients (K_c)

The crop coefficient (K_c) values calculated using equation of Penman-Monteith, which were obtained from treatment of $I_{f1}N_3K_{pc2}$ for two years and average are shown in the Figure 3. The pistachio trees in this treatment are grown under completed irrigation condition compared to other treatments.

In general, K_c values gradually increase from March with very low values to July with maximum values in two years. Maximum K_c values start to decline from July towards to November due to leaf senescence. This behaviour is covered with what has been reported by Goldhamer et al. (1985) and Kanber et al. (1992). Maximum and minimum values of K_c were obtained in November and July, respectively. Monthly values of K_c were calculated between 0.21 and 1.32 for 2001 and 0.19 and 1.56 for 2002 as minimum and maximum. All the experimental years have the highest K_c values in July when the highest evapotranspiration was measured. The average values for two years varied between 0.2 and 1.44 for the months during the growing period.

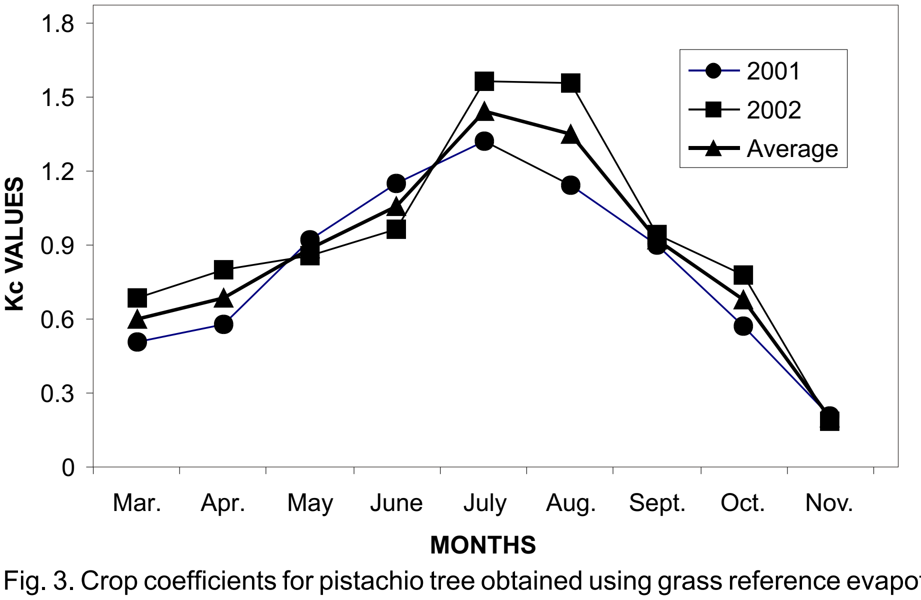

Fig. 3. Crop coefficients for pistachio tree obtained using grass reference evapotranspiration of Penman-Monteith equation

It can be seen from Figure 3, high crop coefficients were calculated during two years. In arid and semi-arid areas, high crop coefficient can be calculated due to excessive radiant energy, long day time, hot and dry air conditions (Doorenbos and Pruitt, 1984; Allen et al., 1998; Steduto, 1999). To our surprise, these K_c values for the treatment of $I_{f1}N_3K_{pc2}$ are very high. Goldhamer (1995) indicate that advective energy can cause ET_c rates to increase drastically if orchard is bordered upwind by bare ground. So, this situation can be assumed for this region where is border upwind by bare ground. Similar opinions were given by Allen et al. (1998) based on relation between energy entrance and crop evapotranspiration. On the other hand, Kanber et al. (1986) have found that K_c values, which were calculated with using SCS-Blaney-Criddle procedure, were lower than K_c values obtained by Penman-Monteith procedure in this experiment.

4.3 Fertilizers

Some results on fertilizer as a pure material, applied to the treatments during experimental years are shown in Table 5 and 6.

Table 5. The amount of fertilizers as a pure elements (N P and K) given to the treatments (2001)

Treatments	IR mm	N g/m^2	Wetted Area $g/244m^2$	P g/m^2	Wetted Area $g/244m^2$	K g/m^2	Wetted Area $g/244m^2$
$I_{f1}N_0Kpc_1$	617	0.0	0.0	4.9	1185.8	3.2	790.6
$I_{f1}N_0Kpc_2$	906	0.0	0.0	4.9	1185.8	3.2	790.6
$I_{f1}N_1Kpc_1$	617	6.2	1505.5	4.9	1185.8	3.2	790.6
$I_{f1}N_1Kpc_2$	906	9.1	2210.6	4.9	1185.8	3.2	790.6
$I_{f1}N_2Kpc_1$	617	9.3	2258.2	4.9	1185.8	3.2	790.6
$I_{f1}N_2Kpc_2$	906	13.6	3316.0	4.9	1185.8	3.2	790.6
$I_{f1}N_3Kpc_1$	617	12.3	3011.0	4.9	1185.8	3.2	790.6
$I_{f1}N_3Kpc_2$	906	18.1	4421.3	4.9	1185.8	3.2	790.6
$I_{f2}N_0Kpc_1$	324	0.0	0.0	4.9	1185.8	3.2	790.6
$I_{f2}N_0Kpc_2$	467	0.0	0.0	4.9	1185.8	3.2	790.6
$I_{f2}N_1Kpc_1$	324	3.2	790.6	4.9	1185.8	3.2	790.6
$I_{f2}N_1Kpc_2$	467	4.7	1139.5	4.9	1185.8	3.2	790.6
$I_{f2}N_2Kpc_1$	324	4.9	1185.8	4.9	1185.8	3.2	790.6
$I_{f2}N_2Kpc_2$	467	7.0	1709.2	4.9	1185.8	3.2	790.6
$I_{f2}N_3Kpc_1$	324	6.5	1581.1	4.9	1185.8	3.2	790.6
$I_{f2}N_3Kpc_2$	467	9.3	2279.0	4.9	1185.8	3.2	790.6
Traditional	0.0	-	500.0*	-	600.0*	-	400.0*

* Per tree

The fertilizers varied depending on irrigation interval and K_{cp} coefficients. Fertilizers (N P and K) amounts received by the treatments are higher than those in the traditional one. The maximum nitrogen amount was applied to treatment $I_{f1}N_3K_{pc2}$ with 18.1 $g.m^{-2}$ (in 2001) and 15.9 9 $g.m^{-2}$ (in 2002) among irrigated treatments. The same amounts of phosphorus and potassium fertilizers were applied to the all irrigated treatments except for the traditional. These chemicals are given via irrigation at two weeks interval when I_{f1} and I_{f2} treatments were irrigated together.

During the experimental years, the amount of P and K varied depended on irrigation water applied to the treatments. In 2001, all pistachio trees have received 4.9 and 3.2 gram per square meter phosphorous and potassium while in 2002 these values decreased to 4.2 and 2.8 gram per square meter.

The fertilizers were applied fixed dozes to traditional treatment according to project. Nitrogen, phosphorous and potassium that were 5, 6 and 4 grams per square meter were given beginning the February. The amounts of fertilizers given to traditional treatment are higher than those of irrigated treatments, except treatment, which has accepted maximum nitrogen.

Table 6. The amount of fertilizers as a pure elements (N, P and K) given to the treatments (2002)

Treatments	IR mm	N g/m^2	Wetted Area g/244 m^2	P g/m^2	Wetted Area g/244 m^2	K g/m^2	Wetted Area g/244 m^2
$I_{f1}N_0Kpc_1$	549	0.0	0.0	4.2	1033.9	2.8	689.3
$I_{f1}N_0Kpc_2$	794	0.0	0.0	4.2	1033.9	2.8	689.3
$I_{f1}N_1Kpc_1$	549	5.5	1339.6	4.2	1033.9	2.8	689.3
$I_{f1}N_1Kpc_2$	794	7.9	1938.5	4.2	1033.9	2.8	689.3
$I_{f1}N_2Kpc_1$	549	8.2	2009.4	4.2	1033.9	2.8	689.3
$I_{f1}N_2Kpc_2$	794	11.9	2907.7	4.2	1033.9	2.8	689.3
$I_{f1}N_3Kpc_1$	549	11.0	2679.3	4.2	1033.9	2.8	689.3
$I_{f1}N_3Kpc_2$	794	15.9	3876.9	4.2	1033.9	2.8	689.3
$I_{f2}N_0Kpc_1$	282	0.0	0.0	4.2	1033.9	2.8	689.3
$I_{f2}N_0Kpc_2$	395	0.0	0.0	4.2	1033.9	2.8	689.3
$I_{f2}N_1Kpc_1$	282	2.8	689.3	4.2	1033.9	2.8	689.3
$I_{f2}N_1Kpc_2$	395	3.9	963.0	4.2	1033.9	2.8	689.3
$I_{f2}N_2Kpc_1$	282	4.2	1033.9	4.2	1033.9	2.8	689.3
$I_{f2}N_2Kpc_2$	395	5.9	1444.4	4.2	1033.9	2.8	689.3
$I_{f2}N_3Kpc_1$	282	5.6	1378.6	4.2	1033.9	2.8	689.3
$I_{f2}N_3Kpc_2$	395	7.9	1925.9	4.2	1033.9	2.8	689.3
Traditional	0.0	-	500.0*	-	600.0*	-	400.0*

* per tree

4.4. Number of Black Buds

The number of black buds (fruit bud) that affected the pistachio yield was counted in June 2001 from the branches, which are randomly chosen from the four sides (east west north and south direction) of the labeled trees of the plots. The same counting procedure was repeated in autumn. The second counting was taken to obtain the number of buds remained on the branches and to quantify the shedding of the buds after falling of the leaves.

At the same time the shoot length on which buds were counted was measured. The highest numbers of buds in June were obtained from the treatments that had no or small yields in the last year. However the bud number for all treatments decreased in November (Figure 4). The maximum bud reduction (94%) was obtained in the treatment of $I_{f2}N_1K_{cp2}$. In treatments receiving high levels of water and nitrogen such as $I_{f1}N_3$ had 50% of buds reduction.

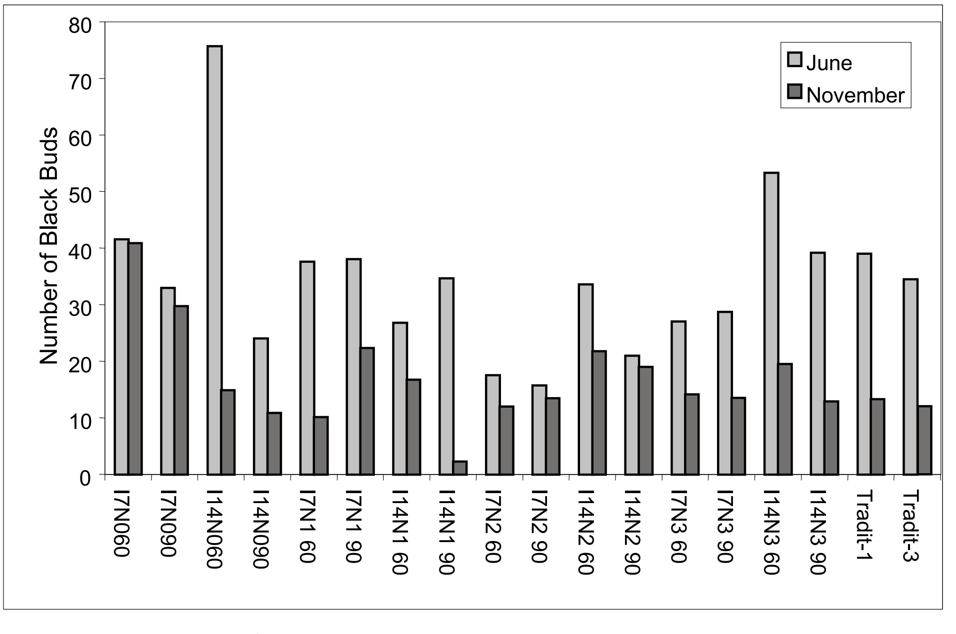

Fig. 4. The number of black bud on pistachio trees in June and November 2001

The traditional treatments had 66% bud reduction. The number and shedding of black buds can be caused by the fact that this year was off yielding year. However frequent irrigation and fertigation seems to decrease shading of black buds in off year too. The variations may indicate the expected yields in the forthcoming years. Almost the same results also were obtained in the year of 2002, as shown in Figure 5.

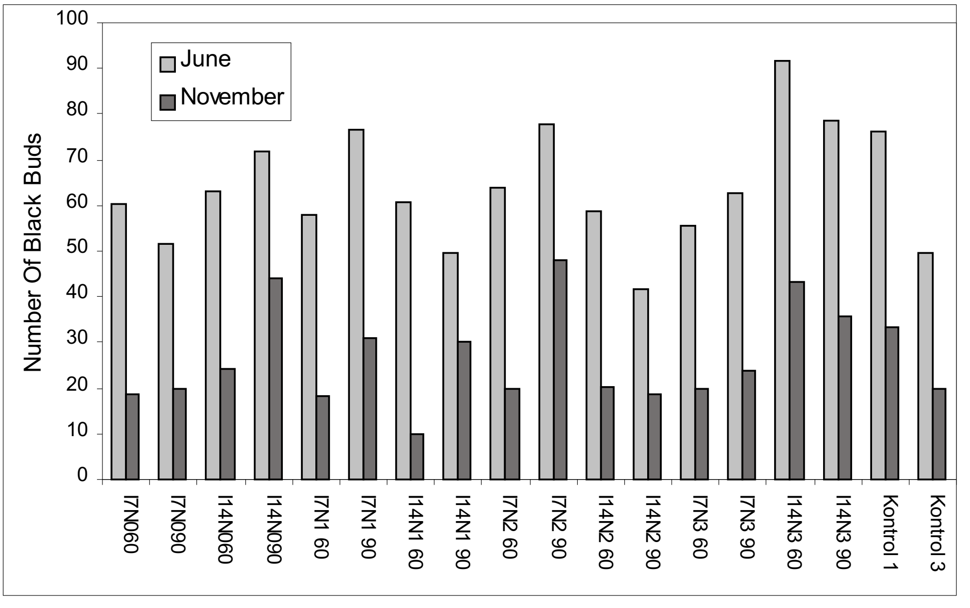

Fig. 5. The number of black bud on pistachio trees in June and November (2002)

4.5. Pistachio Leaf Gas-Exchange

Pistachio leaf gas-exchange response was carried out during summer periods at the experimental field in 2001. Five fully expanded and exposed leaves were measured for each treatment. Depending on the specific response to highlight measurements was taken either during noontime hours (i.e. the period of peak evaporative demand by the atmosphere) or diurnally at about 1.5-2 hr interval from pre-dawn to sunset. The measurements were repeated at various intervals including the days before and after irrigation applications.

The values of stomatal conductance (g_s) for the different treatments during the measurement period are shown in Figure 6. Although there was certain variability among trees it is possible to notice a trend of increase in g_s after irrigation as compared to the "Traditional" treatment.

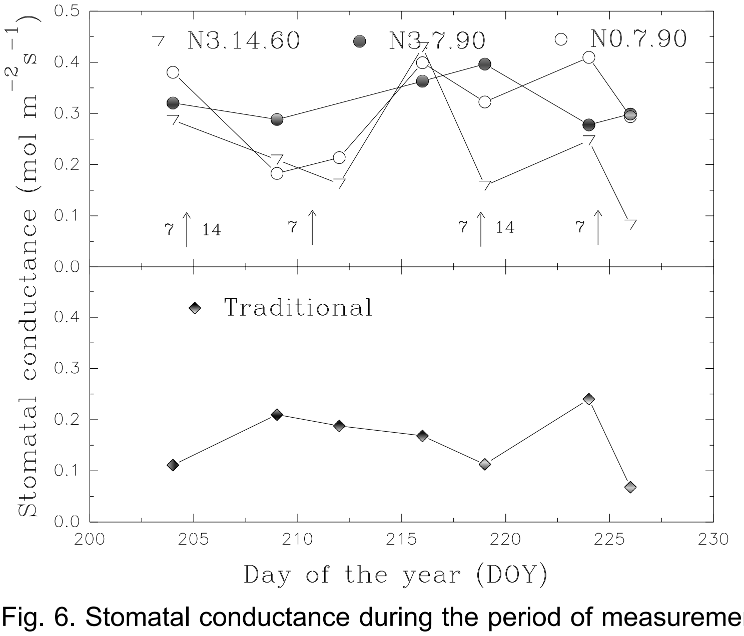

Fig. 6. Stomatal conductance during the period of measurements for the different treatments. Arrows indicate the time of irrigation. Numbers next to the arrows indicate the irrigation interval in days.

The g_s variation averagely ranged between about 0.2 and 0.4 mol m^{-2} s^{-1} for the irrigated treatments and between about 0.1 and 0.2 for the "Traditional" one. The treatment with high nitrogen and high water ($I_{f1}N_3$90) showed a tendency to maintain higher g_s values than the only irrigated treatments.

These tendencies are conserved when looking at the leaf net assimilation values or net photosynthesis (P_n) as reported in Figure 7 where the P_n variation averagely ranged between about 10 and 20 mol m^{-2} s^{-1} for the irrigated treatments and between about 5 and 15 mol $m^{-2}s^{-1}$ for the "Traditional" one.

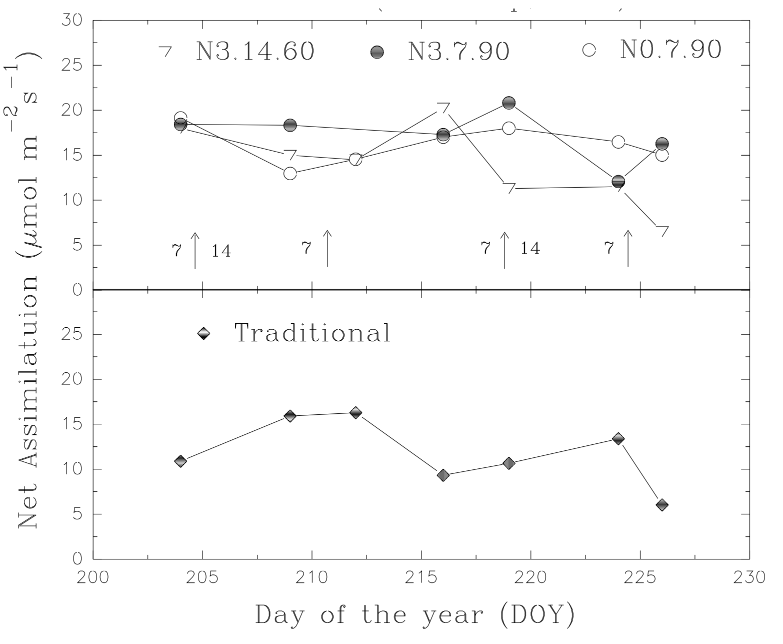

Fig. 7. Leaf net assimilation or net photosynthesis during the period of measurements for the different treatments. Arrows indicate the time of irrigation. Numbers next to the arrows indicate the irrigation interval in days.

This finding in turn is an indication of constant photosynthetic water use efficiency (WUE_{Pn}) as reported in Figure 8.

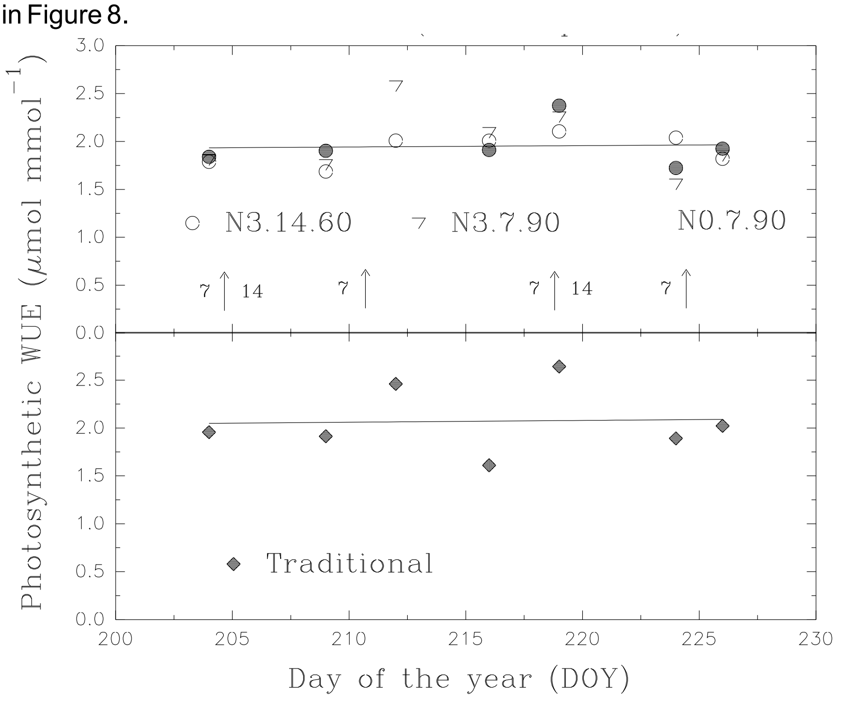

Fig. 8. Photosynthetic water use efficiency (WUE_{Pn}) during the period of measurements for the different treatments. Arrows indicate the time of irrigation. Numbers next to the arrows indicate the irrigation interval in days.

The WUE_{Pn} remained constant around 2 mol $_{(CO2)}$ mmol^{-1} $_{(H20)}$ regardless of the different treatments. This can be interpreted as an important feature of the *Pistachio* tree.

An additional response of photosynthesis and stomatal conductance was investigated in relation to leaf water potential. The major expression of the water status in the plant remains the water potential. A typical diurnal trend of photosynthesis and leaf water potential (LWP) is shown in Figure 9 for the well-irrigated and traditional (not irrigated) treatments. The corresponding diurnal trend of stomatal conductance and LWP is shown in Figure 10.

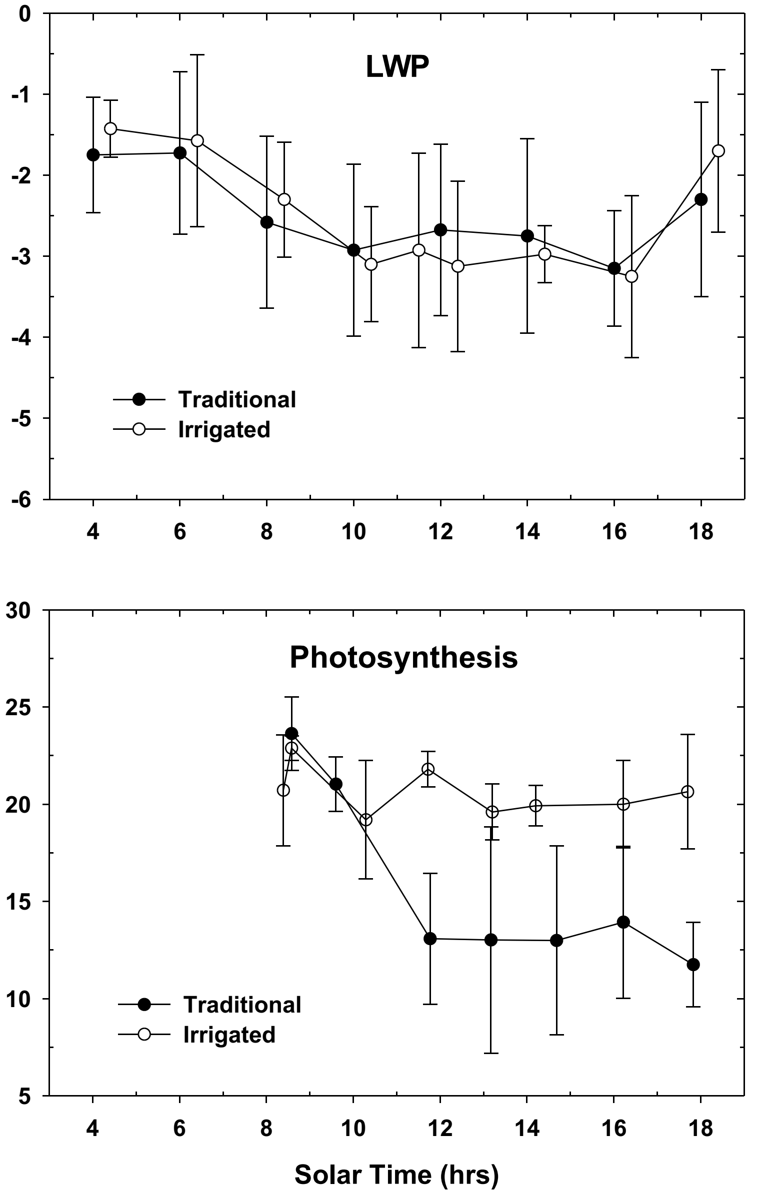

Fig. 9. Typical diurnal trend of leaf water potential (upper plot) and leaf photosynthesis (lower plot) of Pistachio for the traditional and irrigated treatments

It is worth noticing that leaf water potential can reach values as low as 4.0 MPa. This is of the same order of magnitude of what observed for olive trees and indicates the very low water status that *Pistachio* undergoes during his cycle.

Many other days were observed during the season of Pistachio with similar results. In summary the Pistachio seems responsive to the water status via the leaf water potential that affects the stomatal conductance (g_s). Stomatal conductance in turn is the major factor controlling photosynthesis.

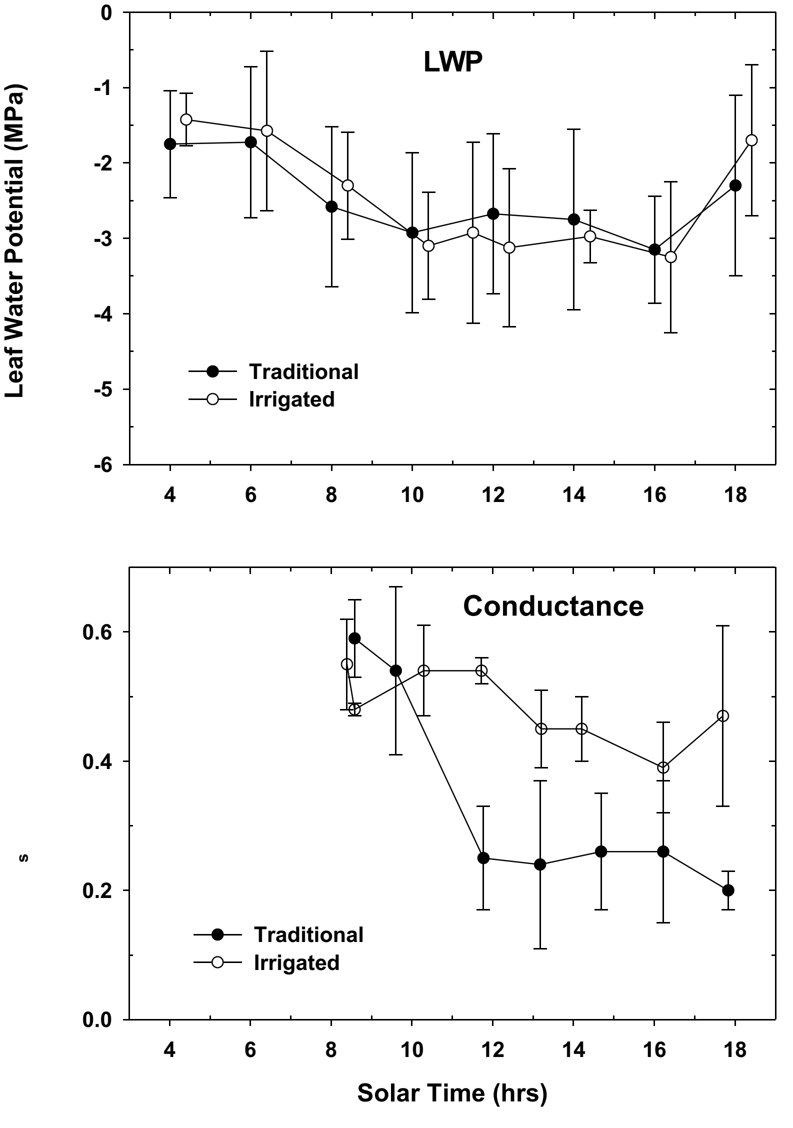

Fig. 10. Typical diurnal trend of leaf water potential (upper plot) and leaf stomatal conductance (lower plot) of Pistachio for the traditional and irrigated treatments

4.6. Yield

The average oven-dry yields for treatments for experimental two years are shown in Tables 7 and 8. Differences in yields from irrigation and nitrogen interaction are statistically significant at 0.05 levels. From the LSD test all treatments show 3 statistical yield groups (a, b, and c see Table 7). The maximum yields were taken from $I_{f2}N_3$ with average 11.7 kg per tree in 2001 and from $I_{f1}N_0$ with average 11.6 kg per tree in 2002.

Table 7. Pistachio Yield (Owen dry) From Treatments in 2001

Treatments	R1	R2	Average kg/tree	Groups*
$I_{f1}N_3K_{pc1}$	4.3	9.2	6.8	b
$I_{f1}N_3K_{pc2}$	4.1	7.1	5.6	b
$I_{f1}N_2K_{pc1}$	10.30	12.70	11.5	a
$I_{f1}N_2K_{pc2}$	8.66	13.04	10.9	a
$I_{f1}N_1K_{pc1}$	10.80	9.08	9.9	ab
$I_{f1}N_1K_{pc2}$	10.40	9.73	10.1	ab
$I_{f1}N_0K_{pc1}$	4.85	14.62	9.7	ab
$I_{f1}N_0K_{pc2}$	8.20	9.73	9.0	ab
$I_{f2}N_3K_{pc1}$	8.80	12.30	10.6	a
$I_{f2}N_3K_{pc2}$	11.00	14.70	12.9	a
$I_{f2}N_2K_{pc1}$	9.97	8.01	9.0	ab
$I_{f2}N_2K_{pc2}$	4.97	6.64	5.8	b
$I_{f2}N_1K_{pc1}$	6.96	14.46	10.7	a
$I_{f2}N_1K_{pc2}$	14.7	7.35	11.0	a
$I_{f2}N_0K_{pc1}$	8.10	10.90	9.5	ab
$I_{f2}N_0K_{pc2}$	7.30	9.70	8.5	ab
Sx_1	1.21			
Sx_2	1.51			
$I_{f2}N_3$			11.7	a
Traditional**			7.0	b
$t_{0.05}$ 2.26			t=3.3	

* Treatments marked with the same letter are in the same group at the P0.05 level.

** Mach analysis

Then traditional and $I_{f2}N_3$ treatments were compared using the *t* test. For this purpose 10 trees were used. There were statistically differences between two treatments at 0.05 significance level indicating that irrigation increased the pistachio yield of about 67% as compared to the traditional practice.

For year of 2002, pistachio oven-dry yield per tree was shown in Table 8. According to statistical analysis, there are no significant differences between treatments. The small differences between treatments obtained may be able to be coincidence.

In the on yielding year of 2002, irrigation has more effect on the yield than other such as nitrogen and irrigation intervals. The high yield was obtained from frequent irrigation with no nitrogen except phosphorous and potassium. Irrigation increased the pistachio yield of about 81% as compared to the traditional one, which is received all fertilizers without irrigation.

Table 8. Pistachio Yield (Owen dry) From Treatments in 2002 Year

Treatments	R1	R2	Average kg/tree	%Yield
$I_{f1}N_3K_{pc1}$	11.29	1.86	6.58	49
$I_{f1}N_3K_{pc2}$	14.38	2.73	8.56	64
$I_{f1}N_2K_{pc1}$	5.86	2.65	4.26	32
$I_{f1}N_2K_{pc2}$	2.68	3.75	3.22	24
$I_{f1}N_1K_{pc1}$	4.80	3.62	4.21	31
$I_{f1}N_1K_{pc2}$	2.62	4.52	3.57	27
$I_{f1}N_0K_{pc1}$	21.13	5.63	13.38	100
$I_{f1}N_0K_{pc2}$	14.74	5.06	9.90	74
$I_{f2}N_3K_{pc1}$	2.04	3.27	2.66	20
$I_{f2}N_3K_{pc2}$	4.41	2.59	3.50	26
$I_{f2}N_2K_{pc1}$	8.85	4.03	6.44	48
$I_{f2}N_2K_{pc2}$	11.41	2.44	6.93	52
$I_{f2}N_1K_{pc1}$	9.68	2.02	5.85	44
$I_{f2}N_1K_{pc2}$	4.61	1.23	2.92	22
$I_{f2}N_0K_{pc1}$	4.03	1.37	2.70	20
$I_{f2}N_0K_{pc2}$	4.64	2.15	3.40	25
Sx_1	4.14	For irrigation intervals at the same nitrogen content		
Sx_2	1.51	For irrigation intervals at the same and different nitrogen content		
Traditional			2.53	19

The cumulative yields of pistachio from treatments were analyzed according to irrigation and nitrogen factors used in this experiment. Generally, cumulative yield in all treatments increased as that in traditional measured beginning the experiment year of 2000 (Figure 11). The rate of increase of yield in irrigated treatments was quite higher than in traditional treatment, which has not been irrigated but been fertilized with nitrogen.

Nut yield at the end of two years-experiment increased nearly 5 times in I_{f1} and I_{f2} treatments according to the yield harvested in traditional treatment observed in 2000 as irrigation factors. Similarly, yield in the nitrogen factors increased 5, 6, 4.5 and 5 times in N_3, N_2, N_1 and N_0, respectively as the yield measured in traditional treatment in year of 2000. The rates of increase of yield according to irrigation factors were more than those in nitrogen factors. From this, it can be explained that irrigation has more effective for increasing the yield than nitrogen.

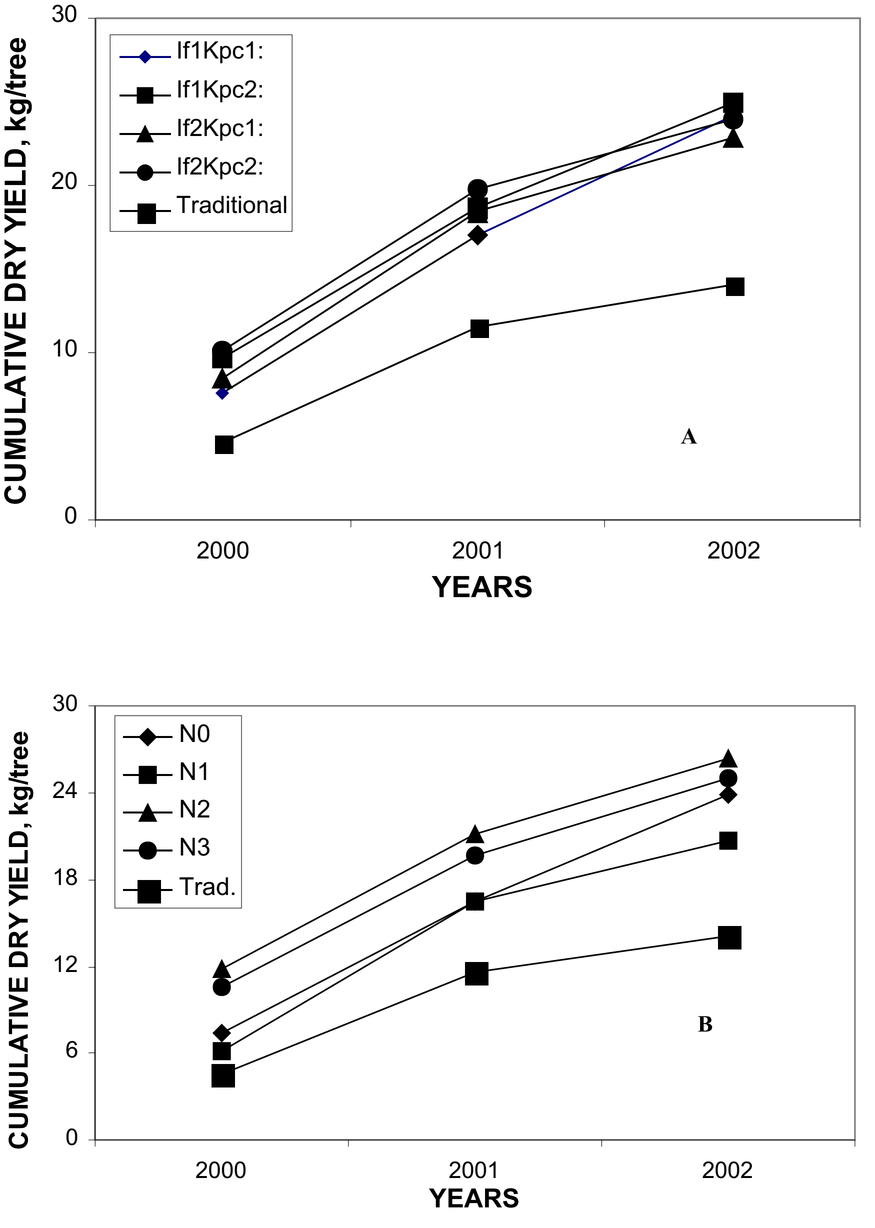

Fig. 11. Pistachio yield trend in trial years. Figure was designed according to factors determining water amount (A) and nitrogen dozes (B) in the treatments considered.

5. CONCLUSIONS

From results taken in the experimental years the following conclusions can be drawn:

(a) Pistachio trees seem to response to irrigation and nitrogen application. Although the year of 2001 was off-yielding year trees have given yield. This result is attributed to irrigation and fertigation. In 2002 (on-yielding year) there are no statistically significant differences between treatments but strong evidences were observed about the effects of irrigation on increasing the pistachio yield.

(b) The maximum nitrogen amount was applied to treatment $I_{f1}N_3K_{pc2}$ with 4.4 and 3.9 kg for wetted area among irrigated treatments in the experimental years, respectively.

(c) During the experimental years, the amount of P and K varied depended on irrigation water applied to the treatments. In 2001, all pistachio trees have received 4.9 and 3.2 gram per square meter phosphorous and potassium while in 2002 year these values decreased to 4.2 and 2.8 gram per square meter.

(d) In the traditional treatment, nitrogen, phosphorous and potassium that were 5, 6 and 4 grams per square meter were given beginning the February.

(e) The Pistachio seems responsive to the water status via the leaf water potential that affects the stomatal conductance (g_s). Stomatal conductance in turn is the major factor controlling photosynthesis.

(f) Water status (expressed by leaf water potential) represents the most relevant condition for *Pistachio* in order to achieve maximum rates of CO_2 assimilation.

(g) Although potential rates of net photosynthesis of 50 mol m^{-2} s^{-1} were observed under full CO_2 and light saturation actual values of no more than 20 mol m^{-2} s^{-1} were measured for the treatments receiving high nitrogen and high water applications ($I_{f1}N_3$90).

(h) The rate of photosynthesis was strictly linked to the stomatal conductance which ranged between about 0.1-0.2 mol m^{-2} s^{-1} of the "Traditional" treatment and about 0.4 mol m^{-2} s^{-1} of the $I_{f1}N_3$90 one.

(i) The photosynthetic water use efficiency of *Pistachio* was always held constant averagely around 2 mol $mmol^{-1}$ irrespective of treatments date of measurements and leaf sampled.

(j) Leaf water potential can reach values as low as 4.0 MPa. This is of the same order of magnitude of what observed for olive trees and indicates the very low water status that *Pistachio* undergoes during his cycle.

(k) The maximum yields were taken from $I_{f2}N_3$ with average 11.7 kg per tree in 2001 and from $I_{f1}N_0$ with average 11.6 kg per tree in 2002.

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DEFICIT IRRIGATION OF ORCHARDS

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ABSTRACT

Water scarcity has become a major constraint for economic development in many countries. To face the increasing demand, agriculture is required to increase its performance and probably to reduce its share for this resource. The pressure is particularly affecting fruit trees since they represent a sector of high irrigation water consumption particularly during the summer season. In many Mediterranean countries, waters of increasing salinity have been used to reduce the gap between the supply and demand. During droughts drastic cuts in supply have been observed. Because of chronic shortages, traditional management based on full irrigation and maximum yields is no longer appropriate. The concept of agricultural intensification needs probably to be reviewed. Adoption of Deficit Irrigation (DI) as a strategy in irrigation seems to be a relevant choice. This document explores the potential of this strategy to save water in orchards. Application to the peach species shows that irrigation water could be reduced by one third without affecting significantly yield (10 % reduction). Results obtained on apple show a similar potential. In both cases, appropriate scheduling seems to be a key element in water saving and in reducing risks of soil salinization.

INTRODUCTION

Many Countries have devised development plans on the basis of water mobilization. Important investments have been made for the construction of hydraulic infrastructure during the second half of the last century. Consequently, there has been an impressive expansion of the irrigated lands. But, because of the limitation in water supply, the need for management practices to save water became rapidely vital in many areas. Observed degradations of soils and contamination of aquifers stressed this need.

In the irrigated sector, this concern was expressed by a strong will to adopt practices that reduce water losses and protect the soil from degradation. During the 1990s, research showed a sharp shift from focussing on intensification towards integration and preservation of natural resources.

On the regional scale, many collaborative projects have been implemented in order to address the issue of water saving in agriculture. It is possible to list here, projects that have known a direct impact on the decision-making process and contributed to the increase of awareness at various levels in the Arab region.

For Tunisia, the supplemental irrigation national program is probably a land mark to a series of measures aimed at improving water productivity in the irrigated sector. It was launched in the 1980s following an active research on the irrigation of wheat that started fifteen years earlier. The objective was to adopt supplemental irrigation in a sector that was totally rainfed. Backstopping of this ambitious work was provided 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 Egypt and Tunisia. Its aim was to promote collaboration between Arab countries which have the potential to improve irrigation performance 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 ground water 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 WASIA project came at an essential moment to consolidate the available knowledge and to promote capacity building in the subject matter of water management. Within this context the Tunisian team had the opportunity to strengthen its ongoing research program concerning water saving through the adoption of deficit irrigation (D.I.).

Presently there is clearer ideas about the adoption of Deficit Irrigation instead of full irrigation as a strategic choice to handle severe problems of water shortages. This is essential in countries where the gap between supply and demand keeps growing.

At our level, research inline with 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.

The rationale of the research program, the objectives and the selection of the fruit species were based on the actual priorities. Peach and apple were selected because of their rapid expansion in the irrigated sector. By targeting these species we wanted to complement research findings about fruit trees.

RESEARCH ON IRRIGATION OF FRUIT TREES

Crop water requirement studies have been strongly implemented in Tunisia. Early investigations on annual crops started with the use of Lysimeters during the 1930s and then evolved to cover olive and citrus trees during the 1960s. A large body of information is available on water consumptive use of many crops. Knowledge is particularly important in the domain of using saline water for irrigation, due to the low quality of the water available in the country. A rapid review of relevant research about trees is presented in Table 1.

Table 1. Major experiments carried out in Tunisia on water consumptive use of trees

Species	Location	Period	Objective/exp. design
Olive	Tunis	1960-78	Yield response to three irrigation amounts with fresh (0.8 ds/m) and saline water (4.7 dS/m).
	Ksar Ghriss	1965-80	yield response to irrigation with saline waters (4.5 dS/m).
	Mornag	1998-pres.	Consumptive use of individual trees (sap flow).
Citrus	Tunis	1960-78	Yield response to three irrigation amounts with fresh (0.8 dS/m) and saline water (4.7 dS/m).
	Mornag	1974-76	Use of drip irrigation vs. surface irrigation
	Cap bon area	1974-76	Yield variability under drip irrigation .
Peach	Mornag	1996-2002	Deficit irrigation, its impact on vegetation, yield and fruit quality.
Apple	Mornag	1996 2000	Deficit irrigation applicability.

Major results have showed the quantitative relationships between production and water supply. Thus on olives the work carried out in Tunis was intended to evaluate the potential of using different irrigation doses to complement rainfall. Results showed that olive production was almost unchanged when water supply increased from 300 to 650 mm/year in addition to the 450 mm of rainfall. The use of saline water (4.7 dS/m) in this experiment gave similar conclusions.

In the central zone of the country (Ksar Ghriss), results showed that with an annual rainfall of 200 mm, irrigation amounts ranging from 450 to 950 mm/ year produced the same yield on young olive trees (Bouaziz, 1983). Furrow irrigation gave satisfactory results in terms of productivity and salinity control . Adoption of drip systems to deliver 400 mm/ year resulted in small increase of yield (15%) although two surface applications were provided : one at the beginning of the irrigation season for good moisture setting under the drippers and a second at the end to wash salts downward.

The experiment concerning citrus growing showed that the crop coefficient for this species when conducted under intensive systems was about 0.75. With saline waters (ECw = 4.7 dS/m), good yields were obtained over many years. The most serious problem observed in this orchard was chlorosis. Corrective soil measures for iron deficiencies were relatively costly and the profitability of the whole operation was a serious question. Nevertheless, trees that received saline water amounts equivalent to rainfall (450 mm) suffered less from iron chlorosis.

Concerning leaching, precipitation of about 500 mm helped remove salts from the 0-125 cm soil profile whereas amounts higher than 600 mm were needed for the leaching processes to reach the 125-200 cm stratum.

From these results it seemed that adding waters having total dissolved solids of about 3 g/l to tree crops can improve agricultural productivity without being detrimental to the environment provided that the rainfall regime and the soil structure allow for natural leaching of salts.

The recent research work is addressing the issue of purposly reducing the supply below the crop requirements. It is different from studies concerned by physiological response of plant to water stress. It considers D.I. as a strategy that could be used to save water with the cost of reducing yield.

RATIONALE OF DEFICIT IRRIGATION

D.I. strategy is based on the concept that water supply can be reduced to control vegetation growth during specific times of the growing season, while fruit growth remains unaffected. The idea is very attractive because of its simplicity and because of its large implication on water saving opportunities. Furthermore, DI may help reduce the cost of pruning by controlling the whole vigor of trees.

As a choice, deficit irrigation is particularly important for orchards which are frequently subject to chronic water shortages during the dry season. For the Maghreb countries, orchards represent an important part of the irrigated sector and are using the highest share of irrigation water (Table 2). For instance, in Tunisia fruit trees cover more than 40% of irrigated lands and represent an important component of the productive farming system in the country. However productivity is usually low and irrigation with waters having more than 1.5 g/l of TDS is commonly practiced without provision of drainage. Moreover during years of drought water supply could be seriously reduced.

Table 2. Share of orchards in the irrigated sector for the Maghreb countries (Source : Medagri-FAO).

	Irrigated area (1000 ha)	Irr. Fruit trees (1000 ha)	Ratio (%)
Algeria	560	293	52
Morocco	1291	301	23
Tunisia	380	182	48
Maghreb	2231	776	35

In Tunisia, various water management strategies based on reduced water supply have been the subject of active investigation during the last ten years. More recently, and within the framework of the national federative project on water requirements and cropping systems a particular effort has been devoted to means to increase water marginal productivity. WASIA Project helped probe deeper into the long-term impact of DI. The potential of using saline waters under restrictive conditions has been also tackled.

Unlike research carried out during the 1960s and 1970s on citrus and olives, the work conducted on peach and apple trees was intended to explore the potential of DI for water saving.

Experiments on these species started in 1996. The objective was to reduce the amount of water supply during the less sensitive periods without substantially affecting yields. Thus, various deficit irrigation strategies have been tested.

In relation to our work, many interesting results have been obtained under Mediterranean type climate around the world with application of a wide variety of methodologies. In Australia, Mitchell et al. (1984) applied, on pears, water amounts to replace 92%, 47% and 23% of the evaporation rate during times of rapid vegetative growth; whereas, during the period of rapid fruit growth all trees were irrigated at the rate of 150%.

Girona et al. (1993) used Pennman equation and estimated crop coefficients to apply full crop water requirements (ETc) to the control. Trees under DI received 25% of the control during fruit growth stages I and II and post harvest and 100% to 130% of ETc during stage III. In their study on prune trees, McCutchan and Shackel (1992) irrigated daily their wet plots and used soil moisture contents as a reference for irrigation scheduling. In another work, a lysimeter was used to measure hourly ET from two peach trees and soil surface in order to investigate the irrigation treatments that are normally used by the industry (Crisosto et al., 1994).

CLIMATE, SOIL AND WATER OF THE EXPERIMENTAL SITE

The experimental work has been conducted in a commercial orchard located in the plain of Mornag, at 15 km South-East of Tunis (Latitude 32,7° N, longitude 10°14 E).

Climatic data of Tunis, supposed to represent the region, have been analyzed. Time series for 20 years of climatic data for each 10 days have been used to characterize evapotranspiration (Fig. 1) and rainfall (Fig. 2).

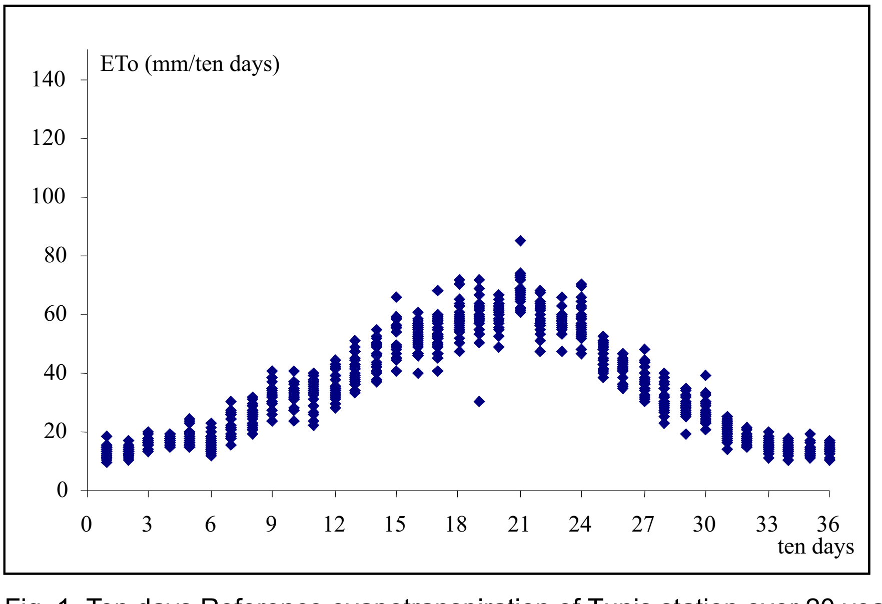

Fig. 1. Ten days Reference evapotranspiration of Tunis station over 20 years.

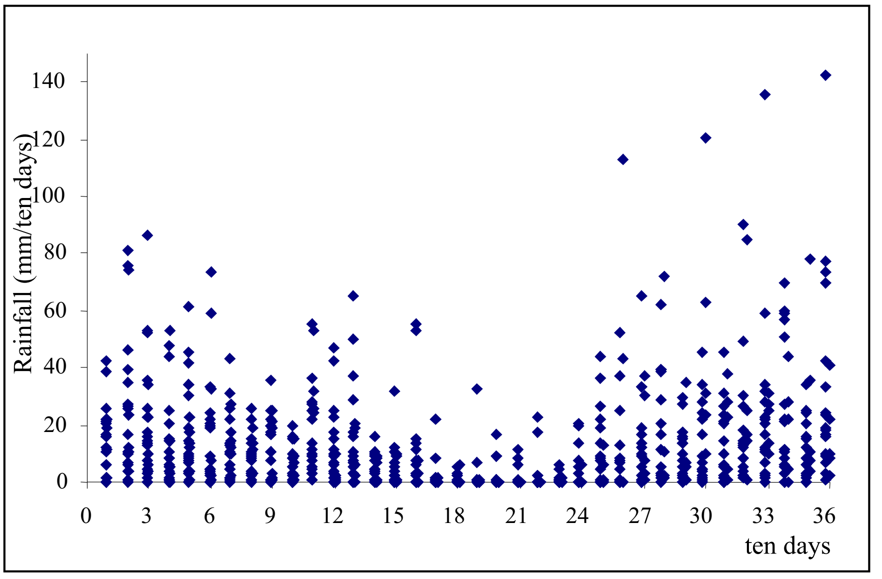

Fig. 2. Ten days rainfall amounts recorded at Tunis weather station over 20 years.

The Mornag plain is characterized by an alluvial soil, its physical properties at the experimental site are shown in Figure 3.

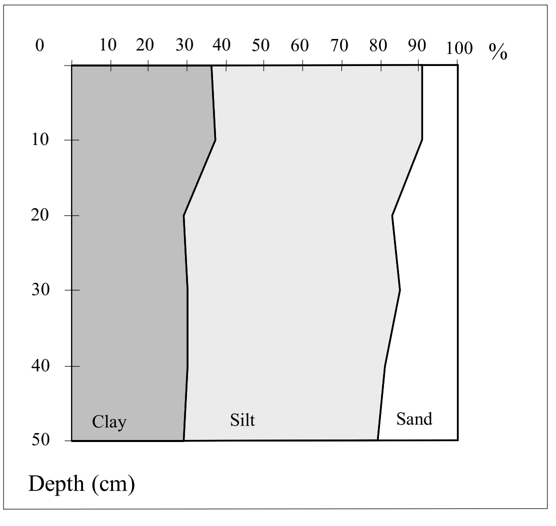

Fig. 3. Properties of Mornag experimental station soil.

The water related properties of the soil are presented in table 3. The important storage capacity of the root zone is a determinant factor in the valorization of water coming from natural precipitation.

Table 3. Water related soil properties of the experimental station.

Soil layer (cm)	0-20	20-40	40-60	60-80
Bulk density (g/cm^3)	1.41	1.62	1.42	1.31
Moisture at field capacity (cm^3/cm^3)	0.39	0.46	0.39	0.37
Moisture at wilting point (cm^3/cm^3)	0.24	0.29	0.25	0.22

Irrigation water is supplied from deep acquifers with ECi=1.88 dS/m or 1.31g/l TDS.

DEFICIT IRRIGATION OF PEACHES

Experimental setting

Experiments have been conducted in a drip irrigated commercial orchard of Carnival, a late peach cultivar (Prunus persica (L.) Batsch). The trees were planted in 1992 with a density of 555 trees/ha (3m x 6m), using GF677 rootstock. For the experiment, four irrigation treatments were applied at different fruit growth stages:

T0: is the grower's conventional irrigation program, taken as a control
Res. I-II: irrigation restriction during stages I and II
Res. III: irrigation restriction during stage III
Res. I-II-III: irrigation restriction during all phases I-II-III.

Irrigation reduction, when applied, consisted in 33% less water than the control. From 1999 and on, only the two extreme treatments have been maintained i.e. the control (T0) and the treatment with restriction during all stages (Res. I-II-III). Daily meteorological data have been used to estimate the Penman-Monteith reference evapotranspiration (ETo). These data were used to scale watering conditions by a coefficient K_s defined as (Irrigation+precipitation)/ETo.

The four irrigation strategies have been evaluated according to their impact on the amount of irrigation water saving, yield, fruit size, dry matter, total soluble solids (°Brix) and soil salinity.

yield response to water reduction at different stages

The average value of annual Penman-Monteith reference evapotranspiration (ETo) for the five years (1996-2000) was 1233 mm. The climatic demand of water was compensated by rainfall and irrigation. The average value of annual rainfall for this period was 471 mm, with no substantial precipitation during the third phase of fruit growth. Almost the all precipitation was concentrated during the autumn to early spring season. During the period 1996-2000, the average annual amount of irrigation water was 690 mm and 460 mm respectively for the Control (T0) and treatment (Res. I-II-III). The restriction of 1/3 of irrigation during the entire season (Res. I-II-III) saved 33% of total irrigation water, while treatment (Res. I-II) and (Res.III) saved respectively only 10% and 22% of water (table 4).

Table 4. Irrigation, total water supply (I+P) and irrigation water saving (IWS) for different water restriction treatments applied at different fruit growth stages of the peach variety '*Carnival*'. Mornag, 1996-1998. (source : Ben Mechlia et al 2002).

1996-1998	Irrigation (mm)	I+P (mm)	IWS (mm)	IWS (%)
Control (T0)	740	1268	-	-
Res. I-II	661	1189	79	10
Res. III	573	1101	167	22
Res. I-II-III	494	1022	246	33

Precipitation: 528 mm/year
Eto: 1295 mm/year

Variable fruit yields were obtained under the different irrigation treatments (table 5). The relationship between yield (Kg/tree) and the average K_s corresponding to the fruit-set-harvest period was not linear.

Table 5. Irrigation water saving (IWS), yield and yield loss for different water restriction treatments applied at different fruit growth stages to the peach variety '*Carnival*'. Mornag-Tunis, 1996-1998. (source: Ben Mechlia et al 2002).

1996-1998	IWS (%)	Yield (Kg/tree)	Yield loss (%)
Control (0)	-	85.0	-
Res. I-II (1)	10	71.8	15
Res. III (2)	22	66.1	22
Res. I-II-III (3)	33	76.1	10

Precipitation: 528 mm/year
Eto: 1295 mm/year

The highest yield was obtained for the unrestricted treatment control (T0). However, while receiving less water, trees under the most severe treatment (Res. I-II-III) gave better yields than those of treatment (Res. I-II) and (Res. III) (table 2). Under our experimental conditions, a continuous water restriction seemed to give a better yield than restrictions during just the vegetative growth phase or during the final fruit growth stage.

Long term impact on yield

Year to year variation of yield was quite large (Fig. 4) and seemed to be linked more to climatic conditions and to a changing tree load rather than watering conditions. The difference between the two extreme treatments i.e. the most watered (T0) and the least watered regime (Res. I-II-III) was quite stable for the entire period 1996-2000.

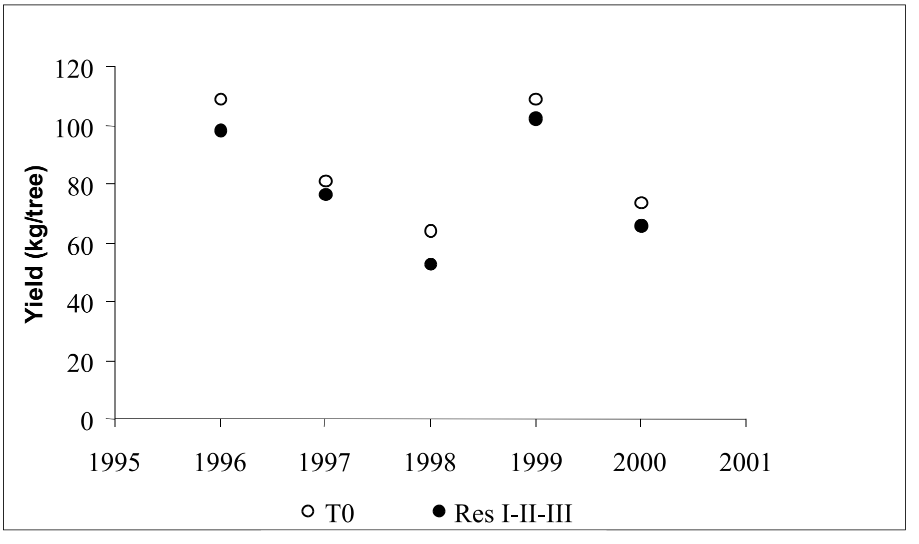

Fig. 4. Peach yield (kg/tree) of the Control (T0) and the D.I. treatment Res. I-II-III over the 1996-2000 period. (Ben Mechlia et al 2002).

Impact on fruit quality

Fruits picked at commercial maturity were weighted and sized separately. The classification according to the fruit size resulted in a high percentage of large fruits (diameter >67 mm) for both extreme treatments (T0) and (Res. I-II-III) (Table 6). Water restriction during the whole growing season seemed to improve the dry weight of fruits for the five years of experimentation (Table 6).

Table 6. Dry weight (g/fruit) variation and percentage of fruits having a diameter larger than 67 mm for the control (T0) and the least irrigated treatment (Res. I-II-III).

	Dry weight (g/fruit)		% fruits having a diameter > 67 mm	
Year	Control	Res. I-II-III	Control	Res. I-II-III
1996	13.0	14.0	95	95
1997	15.3	16.1	91	75
1998	-	-	99	97
1999	15.6	15.0	99	97
2000	16.7	17.7	98	98
2001	14.28	14.68	-	-
Average	**14.97**	**15.50**	**96**	**92**

Fruit sugar content seemed to be well related to watering regimes (Figure 5). The total soluble solids in °Brix was higher for low water supply treatments. In fact, its value increased linearly from 10.7 to 13.5 as the water supply coefficient, K_s decreased from 0.99 to 0.54 (Ben Mechlia et al 2002).

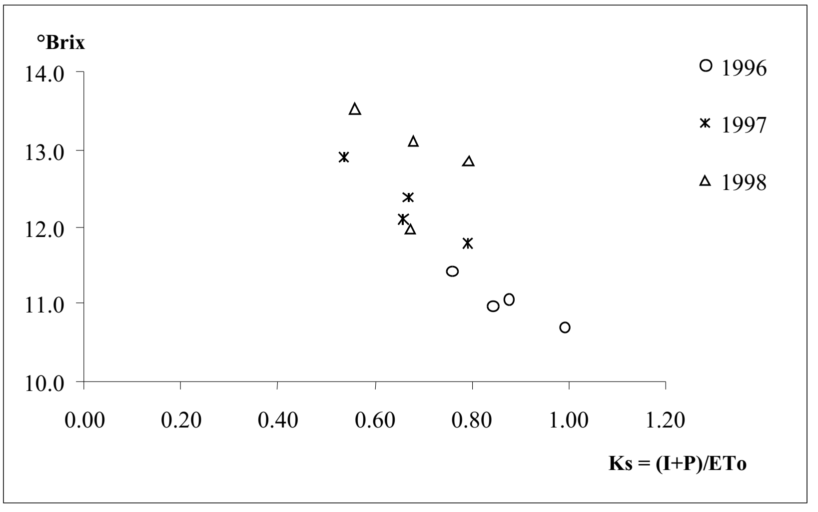

Fig. 5. Total soluble solids (°Brix) of peach fruits at mid - harvest stage in relation to K_s of the fruit set-harvest period. (source Ben Mechlia et al 2002).

Impact on Vegetative Growth

Measurements of the shoot length have been performed during two successive years. An active vegetative growth was observed during phases I an II of fruit growth for both years (Fig. 6 and 7). However no substantial difference was observed between the two extreme treatments T0 and Res. I-II-III during the second year of experiment (Ghrab et al, 1998).

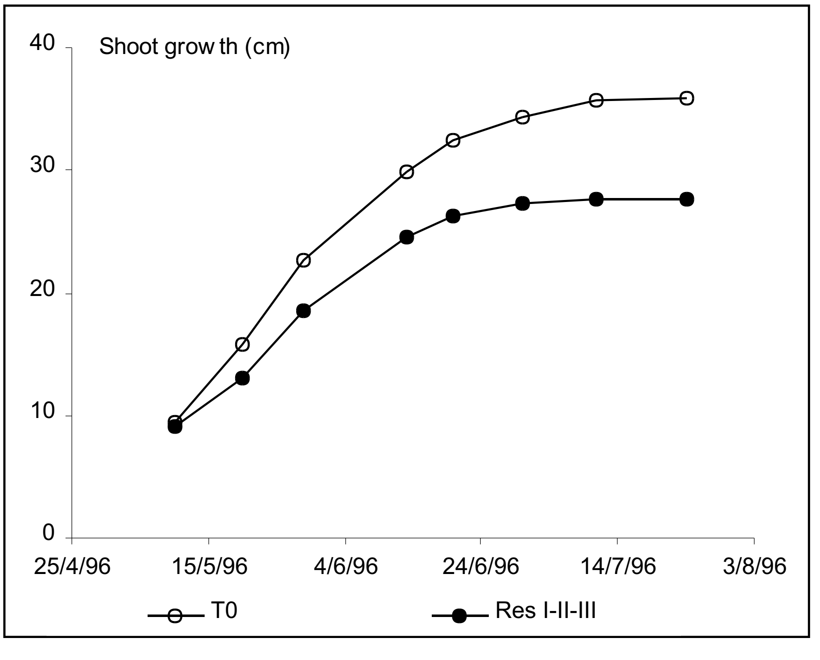

Fig. 6. Shoot growth during the first year of DI application.

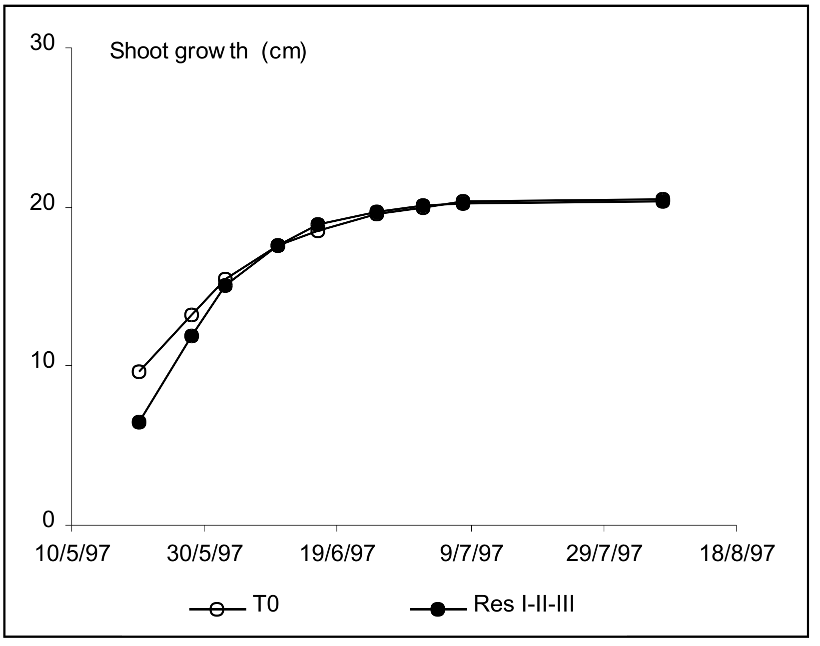

Fig. 7. Shoot growth during the first year of applying DI..

DEFICIT IRRIGATION OF APPLE TREES

Experimental set up

The experimental works on deficit irrigation of apple tree was carried out on ten-year-old Golden Delicious cultivar planted at the density of 1250 trees/ha. With reference to the control (T0), water reductions of 50% were applied at phase I (Res. I, flowering to end of cell division), phase II (Res. II, fruit growth) and at both stages (Res. I-II). Monitoring concerned fruit and shoot growth, climatic factors and water supplies. Final yields and fruits total sugar contents expressed in °Brix were measured at harvest.

Impact on fruit quality

For all DI treatments, apple diameter ranked between 60 to 66 mm, whereas for T0 it varied between 62-69 mm. Reduction of irrigation during the entire growing season resulted in better total sugar contents (Table 7).

Table 7. Total soluble solids (°Brix) of apple fruit for full and deficit irrigation regimes. (source : Nasr and Ben Mechlia, 2002)

	Full Irrigation	Deficit Irrigation		
		Res. I	Res. II	Res. I-II
1996	13.0	13.4	13.6	13.2
1997	11.8	12.5	11.9	12.8
1998	14.6	15.2	14.7	15.8
average	**13.1**	**13.7**	**13.4**	**13.9**

Impact on yield

The limited number of trees used during the 1996-99 period didn't allow for clean cut conclusions although there is an indication that water supply reduction during phase II (Res. I-II and Res. II) could decrease yield in a significant way (Nasr and Ben Mechlia, 2002). During the year 2000, the number of trees was increased to 10 for each irrigation regime (To, Res. 1, Res. 2, and Res. 3). A modified strategy with adjustments concerning the period of D.I. application was used. Results are summarized in table 8.

Table 8. Effect of D.I. applied at different developmental stages on growth and yield of apple trees (cv Golden Delicious), Mornag-Tunis (year 2000).

	Full Irrigation	Deficit Irrigation		
		Res. 1	Res. 2	Res. 3
Period of DI applicat°.	None	20/03-20/06	21/06-15/07	20/03-15/07
Rainfall (mm)	446			
ETo (mm)	1300			
Irrigation (mm)	541	401	482	342
Shoot length (cm)	20	24	21	26
Fruit diameter (cm)	73.2	72.4	70.6	69.5
Fruit weight(g/fruit)	179.9	164.9	177.8	144.3
Fruit number (frt./tree)	372.9	274.1	273.4	268.1
Yield (Kg/tree)	67.1	45.2	48.6	38.7

Source: Master Thesis of Ben Mrad M.R. (INAT 2002)

PHYSIOLOGICAL INDICATORS FOR THE ADOPTION OF D.I.

Extrapolation of results obtained at Mornag to other Mediterranean regions is possible on the basis of measurement of tree water status. To this end, predawn and midday leaf and xylem water potential were measured on peach for the two extreme treatments at different stages.

Predawn water potential showed an increasing difference between the control and Res. I-II-III treatments. During the period June-July its value varied from 0.21 to 0.27 MPa for the control while it dropped from 0.25 to 0.53 MPa for the less watered regime (Fig. 8). Midday xylem water potential, minimums were around 1.0 and 1.5 MPa respectively for the control and Res. I-II-III treatments.

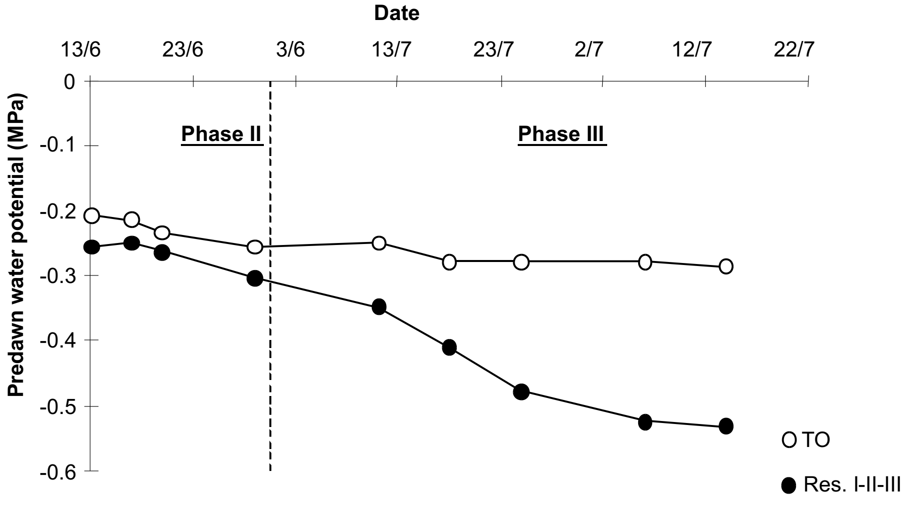

Fig. 8. Predawn water potential of peach during phase I and II for full (T0) and deficit (Res. I-II-III) irrigation regimes. (Source : Ghrab et al, 1998)

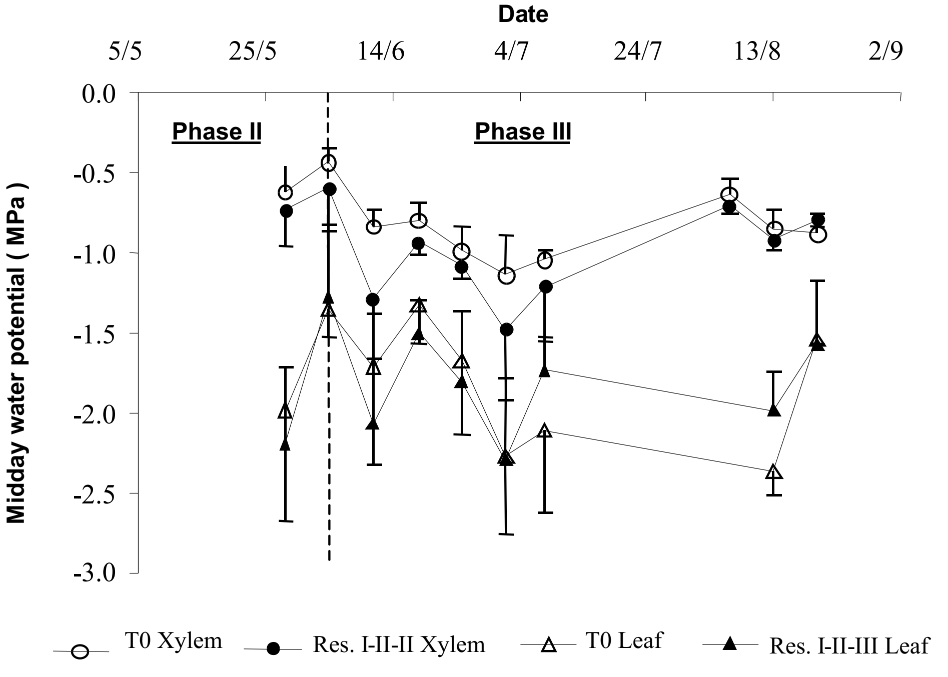

Fig. 9. Midday leaf and xylem water potential of peach tree during phase II and III for full and restricted irrigation regimes.

SALT ACCUMULATION IN THE SOIL

Measurements of soil salinity under full irrigation and deficit irrigation treatments in the apple orchard didn't show significant differences (Nasr et Ben Mechlia, 2002). Values of 3.0 and 2.9 dS/m were obtained for 12 samples taken under the drippers respectively for the control and the restricted treatment. For peaches more precise measurements with intensive sampling were carried out.

Electrical conductivity of saturated paste (ECe) measurements in the peach orchard started in august 2001 in order to evaluate the effect of the highest and lowest irrigation regimes (control T0 and Res. I-II-III) on soil salinity in the first 80 cm layer. Soil samples were taken for every 20 cm layer in 14 sampling points situated at different distances from the drippers.

Conductivity of the extract of saturated paste was determined at four dates during the growing season (09/08/2001, 23/10/2001, 12/02/2002 and 13/05/2002). A weighted average of soil salinity have been performed using the kriging interpolation method (Fig. 10 and 11).

Results show that salts were mainly concentrated near the trunk and that soil salinity distribution pattern varies in the same manner for both treatments. Under the control T0 and Res. I-II-III, the largest values of soil salinity were observed during periods of high evaporative demand in the absence of rainfall.

Soil salinity decreased during wet periods as a result of natural leaching. The experimental results obtained for 2000-2001 indicated that natural leaching is possible even during years with below normal precipitation. During the winter season, the contribution of rainfall to salt removal from the root zone could be enhanced by adding small amounts of irrigation waters.

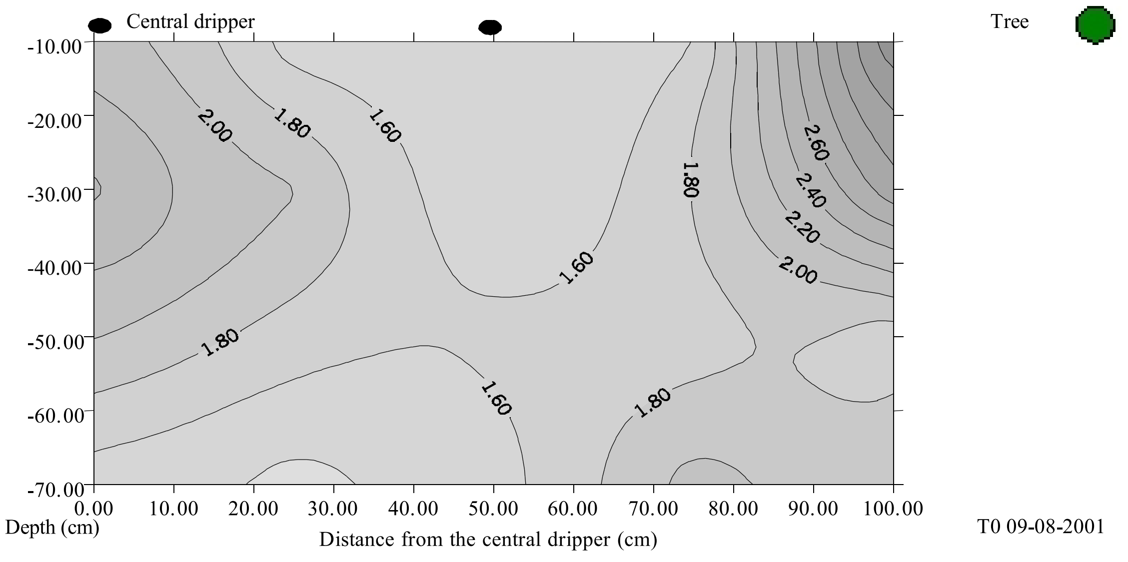

Fig. 10. Salt distribution (g/l) along the line of drippers for trees under full irrigation.

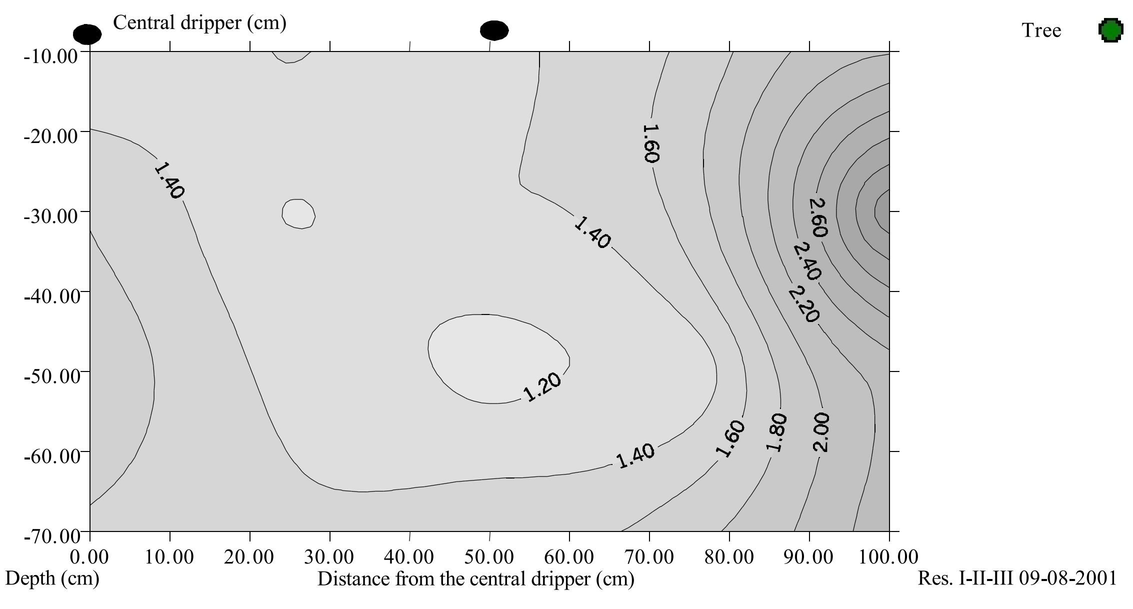

Fig. 11. Salt distribution (g/l) along the line of drippers for trees under D.I.

Apparently D.I. strategy can be applied in a way that allows substantial irrigation water savings without contributing to additional salt accumulation in the root zone.

PERSPECTIVES

Reducing the amount of total salts in addition to saving water with little impact on the yield makes D.I. a very valuable technique when no drainage systems are used, as it is the case of many arid regions.

However it is important to investigate the quantitative relationships between irrigation restrictions, trees growth, yield and quality of fruit production under conditions of relatively severe water shortages, high ETo and saline waters. The objective should be the development of guidelines for D.I. practices suitable for conditions of chronic water shortages and salt control with natural leaching.

In this line, the project team initiated a research work in Mornag which aims at the integration of deficit irrigation management, the variety and cultivation techniques.

An orchard of peach trees of 1.4 ha has been planted in march 2001 at the INAT station. Two rootstocks (GF 677 and Cadaman) and two planting densities have been used. The trees were grafted in September 2001 with two varieties having different growing cycle and thus water requirement.

The station has been equipped with an automatic weather station and a drip irrigation system using water with two qualities. This infrastructure allows fundamental research work on the relationships between main production factors in relation to the environment. The adopted experimental design and irrigation system allow the use of different irrigation amounts and/or water qualities.

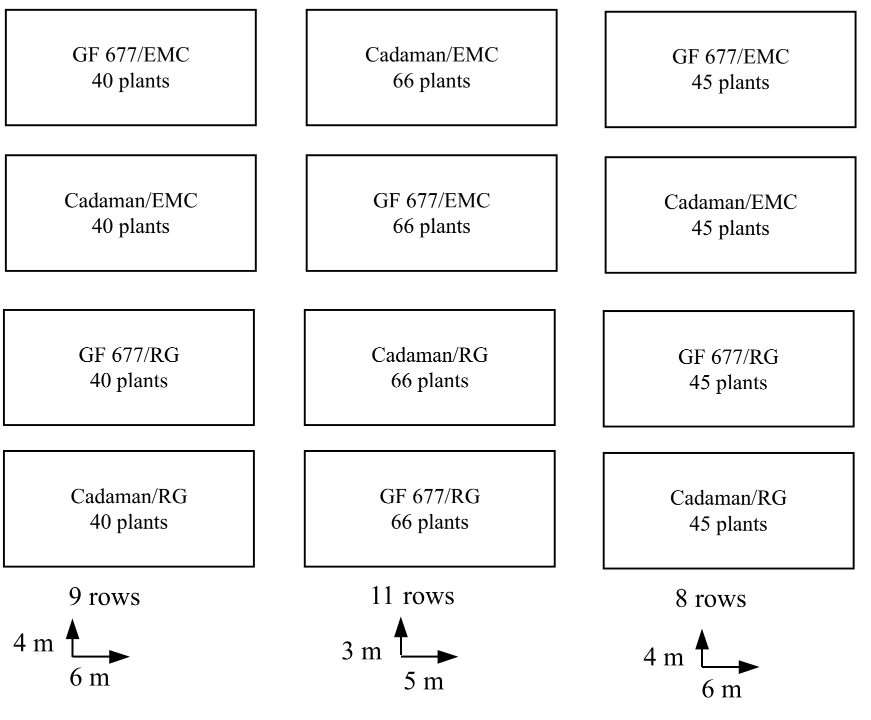

Fig. 12. Experimental layout adopted at the INAT-Mornag station to investigate D.I. in relation to the variety, the rootstock and the planting density.

CONCLUSIONS

Innovative methods and techniques that ensure the best use of water coming from natural precipitation need to be developed for semi-arid environments. Traditional options based on full irrigation with intensive cropping systems are not probably relevant choices anymore, when considering chronic water shortages. Whereas practices such as supplemental irrigation, deficit irrigation, conjunctive use of rainfall and saline ground-waters have the potential to save water and to increase choices for non-conventional water utilization in the dry areas.

Under environments characterized by alternating wet and dry seasons, addition of small amounts of water during the growing season can increase water productivity many times. This potential must be explored for a better use of saline waters for deficit irrigation particularly in the semi arid Mediterranean where natural leaching of salts out of the root zone is possible.

Application of D.I., however, requires scaling of the restriction to be applied. It needs precise knowledge on the grown species, the local environment and soil conditions. A wide range of scaling techniques of D.I. is needed to suit the many Mediterranean microclimates.

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Collective Irrigation System Network

PROJET WATER SAVING IN IRRIGATED AGRICULTURE (WASIA)
RAPPORT FINAL

Fethi LEBDI et Nicola LAMADDALENA

PREAMBULE

Le projet WASIA a été le couronnement d'un ensemble de travaux initiés entre l'IAMBari et l'IRESA, dans le cadre de la recherche de méthodes de gestion des ressources en eau et de modernisation des réseaux hydrauliques sous pression.

La Tunisie , pays semi-aride à aride, a développé depuis trois plus de trois décennies, une politique de l'eau appuyée sur l'évaluation de la ressource, sa mobilisation, son emploi dans l 'agriculture irriguée d'une part et dans l'eau potable urbaine et rurale d'autre part, ainsi que sa gestion et son économie, eu égard à l'évolution des besoins en eau parallèlement à l'évolution démographique maîtrisée et économique.

La surface irriguée potentielle actuelle est de l'ordre de 400000ha, soit 8% de la surface agricole utile. Cette surface est aménagée en partie par des périmètres irrigués publics qui commencent à céder la place aux associations d'irrigants (GIC : Groupements d'intérêt collectif) et des investissements privés de petite hydraulique, qui concernent le captage de sources ou puits de surface.

A l'aube du 21ème siècle, le pays s'est préoccupé de plus en plus de la gestion de l'eau et de son économie, tout particulièrement dans le secteur de l'irrigation, qui utilise prés de 80% de la ressource mobilisée.

C'est dans ce contexte que ces actions du projet WASIA interviennent, dans un cadre de partenariat entre l'IAMBari et l'IRESA (Institution de la recherche et de l'enseignement supérieur agricoles). L'IRESA est appelée de par ses prérogatives, à accompagner le développement et les projets sur le terrain, d'actions de recherche et de formation, dans le domaine agricole en général et de l'eau en particulier. La recherche avec l'IAMBari s'articule autour du développement d'outils pour l'analyse diagnostic des réseaux hydrauliques, en vue soit de leur réhabilitation soit de leur modernisation, d'outils de gestion des données au niveau des GIC et de méthodes de gestion optimale de la ressource à l'amont. Ce sont ces dernières actions qui ont fait l'objet de développement dans le cadre du projet WASIA.

Les résultats confirment le choix de continuer à mettre en place, à partir des outils de base de données développées dans ce cadre de WASIA, et sur plusieurs campagnes de mesures des consommations en eau, relatives aux spéculations correspondantes, des courbes de demande en eau à des pas de temps faible (quelques jours, selon le tour d'eau ou journalier si c'est une irrigation à la demande). Ceci permettra de mieux affiner les modèles de gestion d'une part des réseaux hydrauliques (mieux apprécier les régimes de débit) et d'autre part de la ressource en en eau, en employant les demandes en eau variables et réelles.

A l'occasion de ce projet, une base de données de suivi des consommations en eau des GIC a été développée, permettant de suivre et de générer les courbes de la demande, pour chaque agriculteur et pour chaque spéculation. Deux articles ont été conjointement publié avec Dr. Lamaddalena et concernent la méthode d'analyse diagnostic des réseaux sous pression avec le cas tunisien du périmètre de Ghézala et l'autre sur l'analyse diagnostic des GIC, avec cas tunisien de Bir Bel Kemla.

De même, un site web a été produit, contenant les différentes activités du projet WASIA, actions en Tunisie..

A - Problématique

Les aménagements hydro-agricoles réalisés jusqu'aujourd'hui en Tunisie, ou ceux prévus, ont mobilisé des ressources humaines et matérielles importantes, que ce soit en infrastructure de stockage, de transfert de l'eau ou en aménagement et de mise en valeur des périmètres irrigués. L'étape actuelle du développement du pays exige, dans un objectif d'économie d'eau, une gestion rigoureuse des ressources hydrauliques, un suivi dynamique de l'évolution du système des périmètres irrigués et par suite de la demande en eau.

Le contexte du projet WASIA (1998-2002) financé par l'EU/CIHEAM dans le cadre de l'action RAP (Regional Action Programme) "Water Resource Management" est orienté à l'usage optimal et participatif des ressources en eau dans le secteur de l'irrigation avec des questions techniques majeures (ci-dessous détaillées) qui sont étudiées, dans le cadre du projet WASIA et de l'activité prévue entre l'équipe de recherche de l'IAM-Bari et l'équipe de recherche de l'INAT/IRESA.

B - Objectifs du projet

Les objectifs du projet WASIA sont principalement les suivants :

- Efficience de l'utilisation des ressources en eau en irrigation ;
- Etude, gestion et optimisation du service hydraulique délivré à l'usager, à travers l'analyse de la performance et la réhabilitation de systèmes collectifs irrigation ;
- Gestion du risque et optimisation stochastique des règles de gestion d'un barrage ;
- Gestion participative des ressources en eau en irrigation, dans le cas de réseaux collectifs sous pression.

Les objectifs spécifiques des actions élaborées par l'équipe de recherche conjointe de l'IRESA et de l'IAMBari sont les suivants:

1. Compréhension du comportement de l'agriculteur, par une confrontation entre les courbes de la demande objective (besoin en eau) et la demande affichée à la borne : installation des 20 bornes à carte électrique dans le gouvernorat de Bizerte, acquis par l'équipe tunisienne.
2. Suivi, analyse de performance et réhabilitation des réseaux hydrauliques sous pression pour une irrigation à la demande : Cas de périmètre *Ghezala* dans le Gouvernorat de Bizerte.
3. Optimisation d'un barrage par programmation dynamique stochastique afin de déterminer les lâchures optimums ainsi que la gestion de risque pour le choix de la règle de gestion : cas de barrage *Ghezala* dans le Gouvernorat de Bizerte.
4. L'aménagement et l'introduction des techniques économes en eau et la gestion participative dans l'irrigation , sur deux cas et deux sites d'étude:
   Cas d'un nouveau périmètre public irrigué (*Nefza)* dans le gouvernorat de Béja : introduction de techniques économes en eau, pour l'essai de culture de la mangue ;
   Cas d'un ancien périmètre public irrigué (Bir ben Kamla) dans le gouvernorat de Mahdia : analyse de la gestion participative à partir d'un réseau collectif sous pression et poids de l'eau dans le bilan des exploitations.

Le travail dans le cadre de ce projet a donné lieu à l'encadrement d'étudiants de Mastère et à la production de mémoires de fin d'études.

C - Les réalisations et les résultats produits

Afin de parvenir aux objectifs du projet plusieurs actions ont été entreprises :

1. Installation des bornes à carte électronique *AcquaCard,*
2. Etude des besoins en eau des cultures et comparaison besoin lâchure au niveau du périmètre.
3. Suivi, analyse de performance et réhabilitation des réseaux hydrauliques sous pression pour une irrigation à la demande : Cas de périmètre *Ghezala* dans le Gouvernorat de Bizerte.
4. Optimisation d'un barrage par programmation dynamique stochastique afin de déterminer les lâchures optimums ainsi que la gestion de risque pour le choix de la règle de gestion : cas de barrage *Ghézala* dans le Gouvernorat de Bizerte.
5. Publications scientifiques sur le diagnostic des systèmes collectifs sous pression opérant à la demande : Cas de périmètre Ghézala et sur la gestion participative dans le PPI de Bir Ben Kamla
6. Les aménagements et la gestion participative des périmètres irrigués :
   Cas du PPI de *Nefza* dans le gouvernorat de Béja ;
   Cas du PPI Bir ben kamla dans le gouvernorat de Mahdia.
7. Système de base de données de suivi des GIC (Associations d'irrigants)
8. Site web des actions du projet

Analyse Diagnostic du Périmètre irrigué de Ghézala : Réseau de distribution et adéquation demande en eau- lachure du barrage

L'objectif de ce chapitre est de distinguer, à partir des mesures effectuées sur le terrain :

- installation d'un débitmètre à ultra son en vue de mesurer instantanément les volumes d'eau desservis dans le périmètre
- enquêtes en vue de préciser les cultures en place et leur superficie ainsi que les données climatiques

Les interprétations de la comparaison entre les besoins en eau avec les lachures peuvent démontrer un besoin, soit de réhabilitation du réseau sous pression (chapitre 1), soit de recherche de règles de gestion optimale à échéance inter-annuelle (chapitre 2).

Le périmètre de ghézala (cas de notre étude) a une superficie de 1060 ha (SAU), répartie en grandes cultures (à peu près 590 ha), arboricultures (à peu près 363 ha) et cultures maraîchères (à peu près 220 ha).

1. Cultures existantes et leur répartition

Dans le cadre de ce projet on a fait une étude sur trois années (de1998 à 2000). Pour les cultures existantes, on les présente dans le tableau ci-dessous et pour l'année 1999-2000.

Tableau 1. Occupation culturale du périmètre irrigué de Ghézala

Spéculations	**sec**	**irrigué**
ARBORICULTURE	**0**	**363**
olives de tables	0	0
olives à l'huile	0	0
agrumes	0	0
vignes à tables	0	110
vignes de cuve	0	0
pommier et poirier	0	218
espèces à noyaux	0	35
GRANDES CULTURES	**70**	**520**
blé dur	0	250
blé tendre	0	30
orge	0	0
triticale	0	0
avoine fourrage	70	0
fenu grec fourrage	0	0
ensilage	0	0
orge en vert	0	0
Bersim	0	120
Betterave forager	0	0
fourrage d'été	0	90
sorgho	0	70
mais	0	0
luzerne	0	20
cultures industrielles	0	30
CULTURES MARAICHERES	**0**	**220**
P.T saison	0	60
P.T arrière saison	0	25
P.T primeurs	0	0
C.M d'hivers	0	50
artichaut	0	0
légumes feuilles	0	0
choux et chou-fleur	0	0
fenouillet	0	0
carotte et navet	0	0
légumineuses d'hivers	0	20
ail	0	20
oignon	0	10
divers	0	0
C.M d'été	0	85
tomate	0	30
piment	0	20
cucurbitacées	0	10
oignon	0	20
légumineuses de printemps	0	5
Divers	0	0
TOTAL	**70**	**1103**
TOTAL GENERAL	**1173**	
TAUX D'INTENSIFICATION	**104.05**	
TAUX D'OCCUPATION	**110.66**	

2. Année 1998 et 1999

Pour ces deux années, on a remarqué que les volumes d'eaux qui sont nuls ne correspondent pas à des mesures mais à une panne survenue au niveau de débitmètre. Pour cette raison, on a étudié la comparaison des demandes et des lâchures pour toute l'année et pour les périodes où le débitmètre a fonctionné.

a- Année 1998 :

On remarque pour les 13 premières décades ainsi que pour les 10 dernières décades (figure 1.) que les lâchures sont nulles (problème de panne sur le débitmètre)

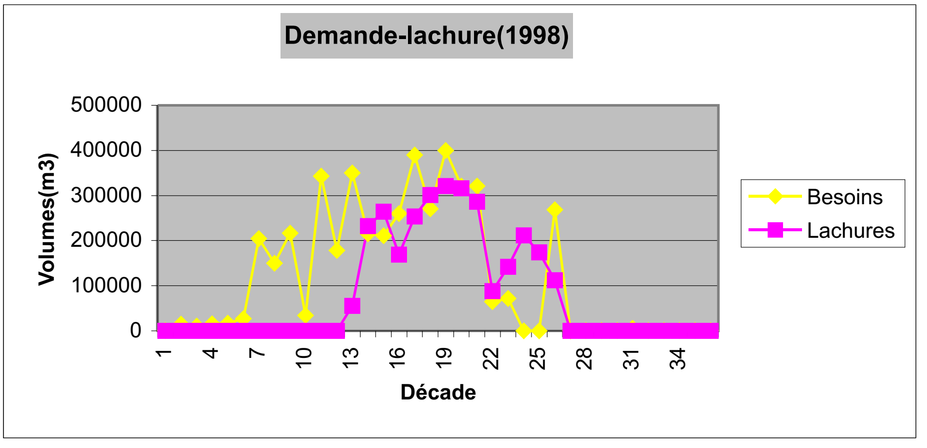

Fig. 1. Comparaison demande - lâchures (1998.)

Pour ces raisons on va étudier pour cette année seulement les périodes où on a enregistré des lâchures.

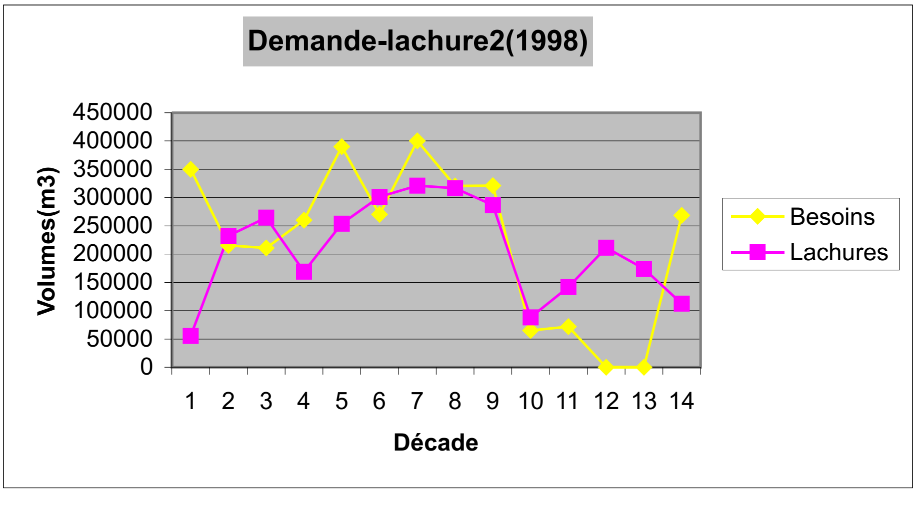

Fig. 2. Comparaison demande- lâchures (1998.)

Pour mieux expliciter la comparaison entre les demandes et les lâchures, on a représenté la différence demande lâchures indiqués dans la figure 3.

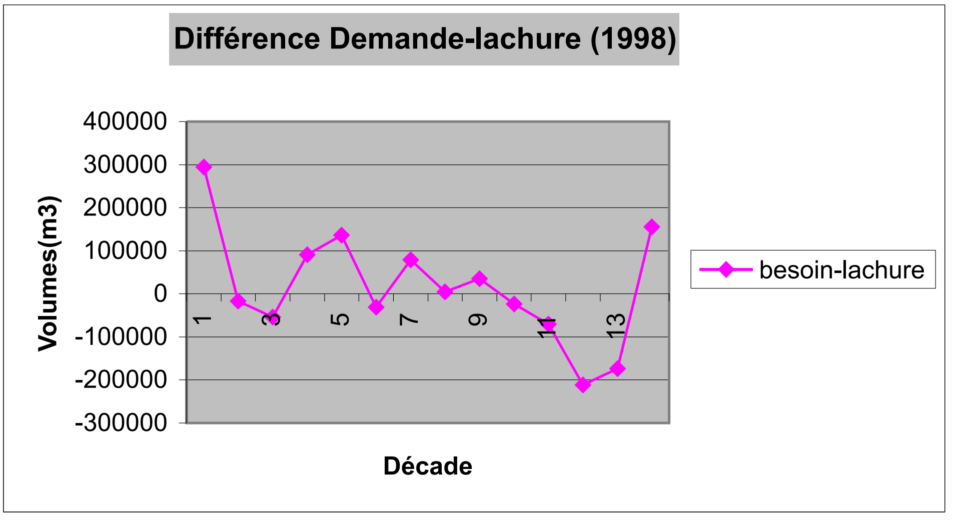

Fig. 3. Différences besoin lâchures (1998.)

On remarque qu'il y a une grande différence entre les besoins et les lâchures sauf pour quelques décades où on a donné exactement l'eau qui arrive à satisfaire ces besoins.

b- Année 1999 :

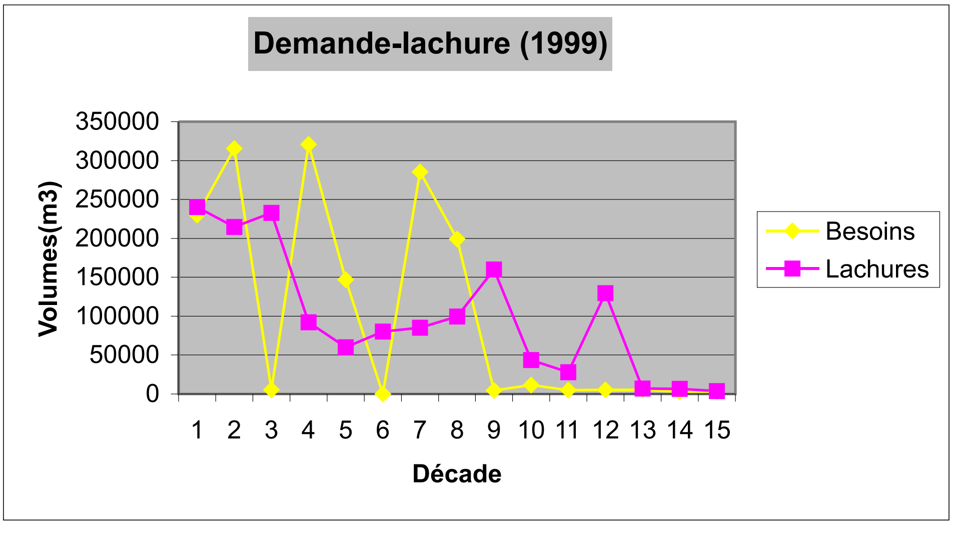

Fig. 4. Comparaison demande- lâchures (1999.)

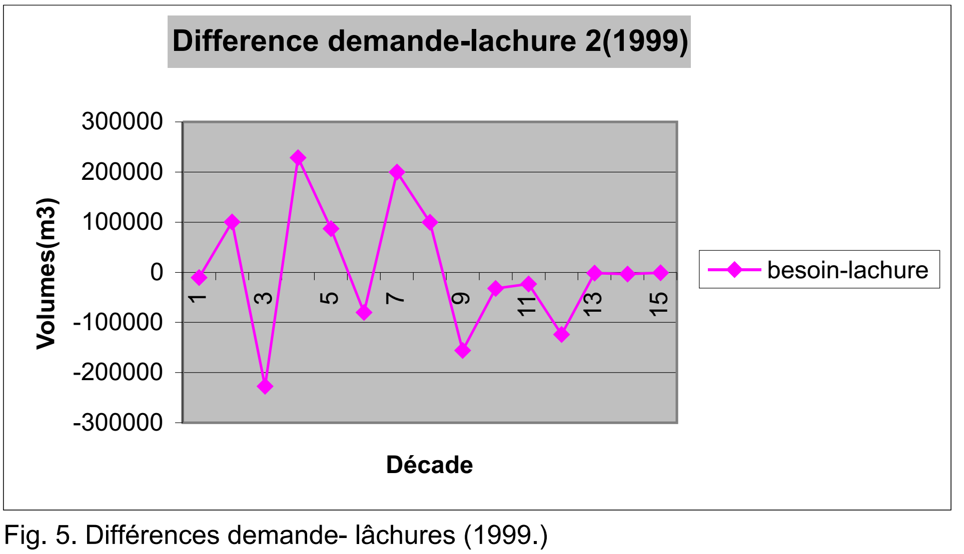

Fig. 5. Différences demande- lâchures (1999.)

c- Année 2000

Cette année est considérée comme la meilleure année où le débitmètre a fonctionné sans qu'il y ait de panne. Pour cette année on remarque qu'il n'y a pas de grandes différences entre les lâchues et les demandes sauf pour quelques-unes.

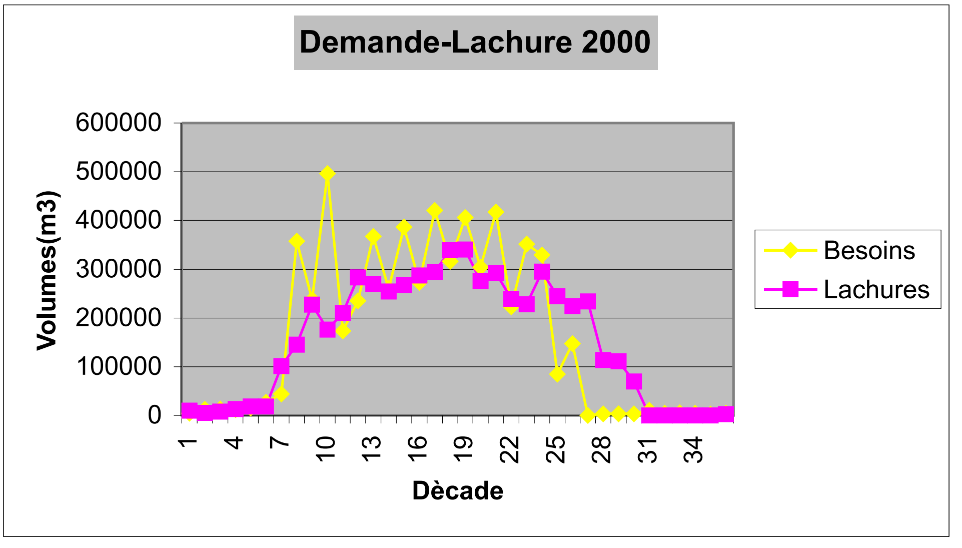

Fig. 6.Comparaison demande- lâchures (2000.)

Au niveau des 6 premières ainsi que 6 dernières décades ces différences sont presque nulles. Le grand déficit ou excès d'eau sont constaté surtout au niveau de la 8ième,10ième et la 27ième décades. Les mois mars, avril, mai, juin et juillet présentent des besoins supérieurs aux lâchures

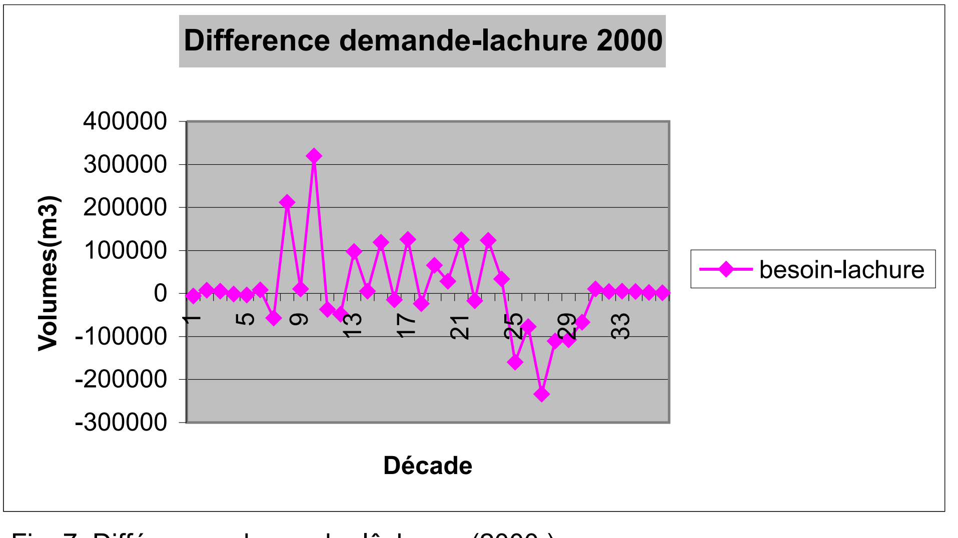

Fig. 7. Différences demande- lâchures (2000.)

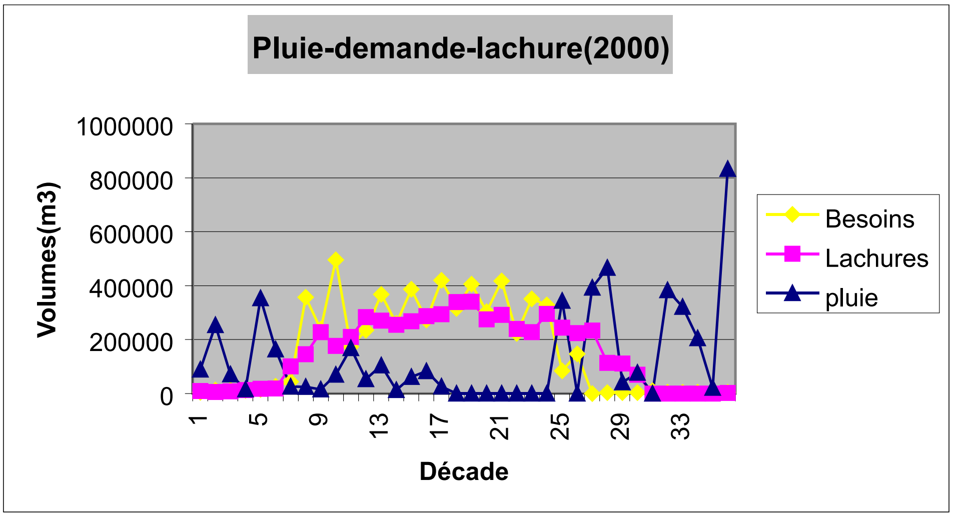

Fig. 8. Pluie-demande-lâchure (2000.)

Conclusion

Les résultats obtenus nous montrent au niveau de ces trois années d'étude une différence faible généralemet, entre les demandes en eau et les lâchures; Le réservoir barrage arrive à satisfaire sans trop de risque cette demande, tant que les besoins sont figés.

Les chapitres qui suivent vont s'intéresser d'une part (chapitre 1) à mettre en place une méthode d'analyse des réseaux et du service hydraulique fourni à la borne et le chapitre 2 concernera les règles de lâchure selon la demande en eau, au niveau du barrage Ghézala.

1- Analyse de performances et réhabilitation : périmètre Ghézala

1.1 Présentation du périmètre Ghézala

Le site de Ghézala se situe dans la zone sub-humide de la tunisie. Ce périmètre se trouve dans la partie Sud-Ouest de la pleine de mateur, à environ 60 Km au Nord-ouest de Tunis. La superficie du périmètre est de 1031 ha et découpée en quatre secteurs comprenant respectivement 471, 134, 300, et 180 ha. La zone du projet se situe dans l'étage bioclimatique humide à hiver doux caractérisé par une pluviométrie relativement abondante et des températures hivernales modérées. La station climatique la plus proche se situe à Mateur. Le barrage de l'oued Ghézala à une capacité utile de 8.9 millions de m3 et un volume régularisé de 5.9 millions de m3. La qualité de l'eau est bonne (moins de 1 g/l comme résidu sec). Le volume disponible dans le barrage varie d'une année sur l'autre, pour atteindre certaines périodes moins de 2 millions de m3

1.2 Analyse des performances du réseau Ghézala

1.2.1 description des méthodes d'analyse des performances hydrauliques du réseau

Aprdès l'installation de débitmètre à ultrason en tête de réseau au niveau du barrage Ghézala, nous avons pu avoir les courbes de demande en eau, à des périodes différentes pour les trois dernières années (1999,2000,2001).

A partir es ces enregistrements des débits, on a pu analyser les performances hydrauliques du réseau, à travers deux méthodes :

i. **Méthode des courbes indicées** par la probabilité de satisfaction des prises en pression (comportement du réseau face à un ensemble des régimes de débits, générés par des configurations de prise ouvertes simultanément).
ii. **Méthode de l'analyse du réseau** au niveau des bornes par le logiciel **COPAM (Combined optimization analysis model**)

Le logiciel **COPAM** se base sur deux indicateurs de performances à savoir :

La fiabilité des bornes du réseau, définie comme le rapport entre le temps pendant lequel la borne est satisfaite en pression et le temps de fonctionnement de cette borne

La fiabilité est calculée comme suit :

$$_j = \frac{\sum_{r=1}^{C} Ih_{j,r} \; Ip_{j,r}}{\sum_{r=1}^{C} Ih_{j,r}}$$

Avec $_j$ = fiabilité de la borne j.

$Ih_{j,r}$ = 1, si la borne j est ouverte dans la configuration r.

$Ih_{j,r}$ = 0, si la borne j est fermée dans la configuration r.

$Ih_{j,r}$ = 1, si la pression dans la borne j ouverte dans la configuration r, est plus grande que la pression minimale requise dans la borne.

$Ih_{j,r}$ = 0, si la pression dans la borne j ouverte dans la configuration r, est plus faible que la pression minimale requise dans la borne.

C : c'est le nombre total des configurations générées.

Le déficit relatif de pression des bornes du réseau est défini comme le rapport entre la pression à la borne j dans la configuration r diminué par la pression minimale exigée divisé par pression minimale exigée :

$$H_{j,r} \quad \frac{H_{j,r} \quad H_{min}}{H_{min}}$$

Avec $H_{j,r}$ Le déficit relatif de pression de la borne j ;

$H_{j,r}$ [m], si la hauteur de la prise d'eau de la borne j ouverte dans la configuration r ;

H_{min} [m], le minimum à exiger de hauteur d'eau dans la borne ;

1.2.2 Résultats de l'analyse des performances hydrauliques du réseau Ghézala

a) Analyse des performances hydrauliques par la méthode des courbes indicées

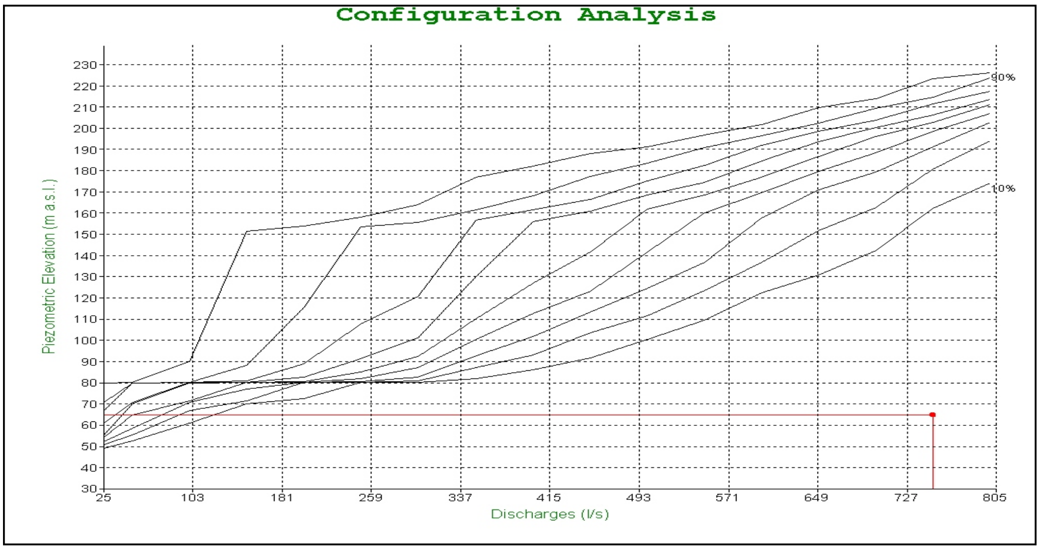

Fig.1. Les courbes caractéristiques indicées

D'après les courbes caractéristiques indicées Fig.1, on observe que le set-point (point de fonctionnement) P_0 (750 l/s, 65 m) se trouve en dessous de la courbe caractéristique indicée de 10% ; Ce qui veut dire que moins de 10% des configurations exploitées sont satisfaits. Ce résultat montre une très grande défaillance dans le réseau. Mais en faite cette méthode s'avère trop sévère puisque une configuration est supposé défaillante lorsque seulement une borne où plus présente une pression de service $H_{j,r}$ inférieure , à la pression minimale exigée H_{min} quelque soit les nombres des bornes ouvertes simultanément, ce qui nous a amené à utilisé la méthode de l'analyse des performances hydrauliques du réseau par le logiciel **COPAM** qui permet d'estimer les défaillances du réseau par borne ouvert dans tous les configurations gérées , et non pas par configuration des bornes ouverts simultanément , cette méthode permet de détecter exactement les bornes défaillantes dans le réseau en période pointe. Les résultats de l'analyse sont dans les paragraphes suivants.

b) Analyse des performances hydrauliques du réseau Ghézala par le logiciel COPAM

b-1 Graphique de Déficit relatif de pression des bornes

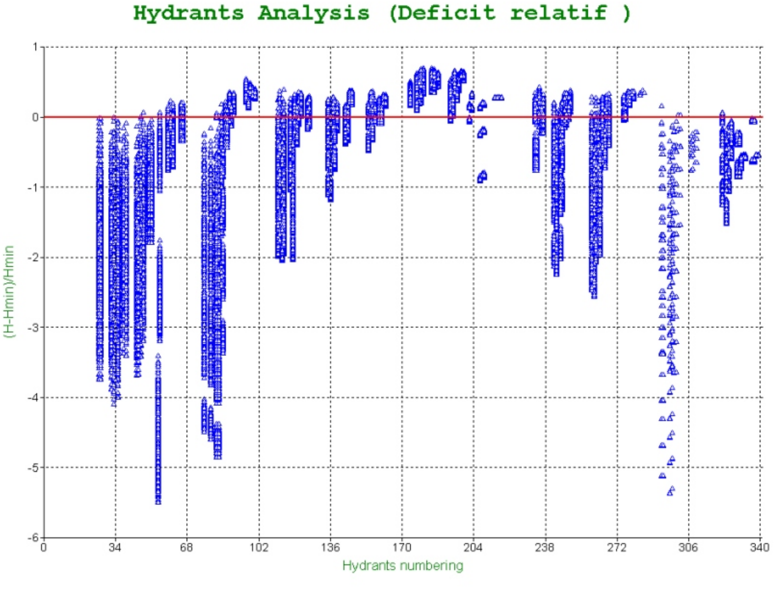

Fig. 2. Déficit relatif de pression des bornes (Q=750 l/s

D'après la fig.2, on peut identifier les bornes qui présentent de déficit de pression et évaluer l'ordre de variation de cette insuffisance.

Sachant que selon l'ordre d'insuffisance on peut interpréter les anomalies de dysfonctionnement du réseau :

- o H>0 Pas de défaillance ;
- o -1< H <0 Risque de défaillance au niveau de la parcelle ;
- o H <-1 Risque de défaillance au niveau du réseau ;

b-2 Graphique de la fiabilité des bornes

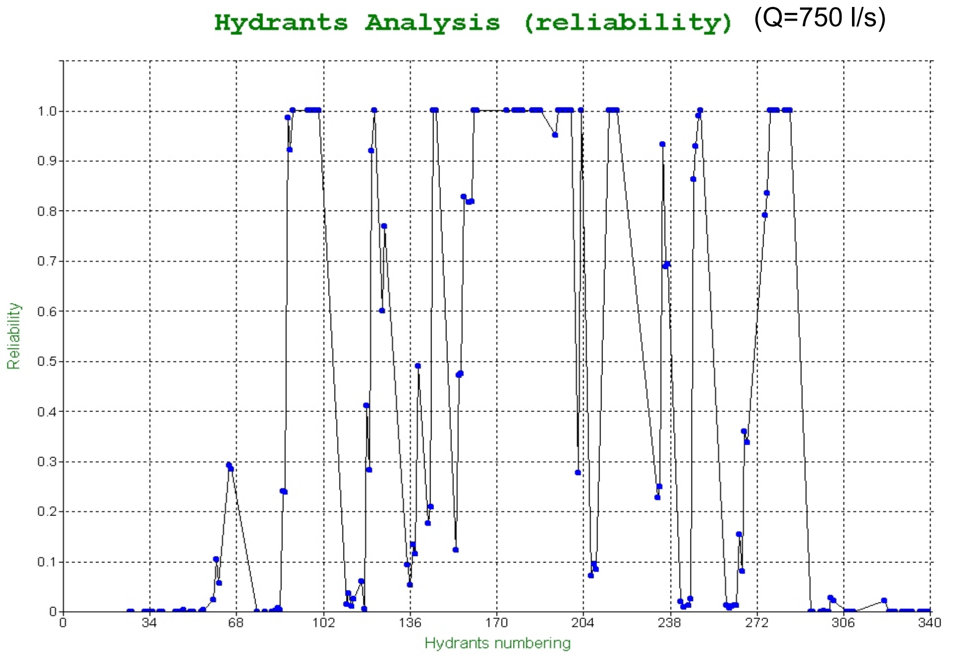

Fig. 3. Fiabilité des bornes

D'après la fig.3, on peut identifier avec précision les bornes non performantes.

Sachant que selon la valeur de fiabilité, on peut interpréter les anomalies de dysfonctionnement du réseau :

- o $_j$ > 90% Pas de défaillance ;
- o 80 %< $_j$ <90% Risque de défaillance au niveau de la parcelle ;
- o $_j$ < 80% Risque de défaillance au niveau du réseau ;

1.2.3 Elaboration d'un outil d'aide à la décision : interfaçage entre Modèle hydraulique (COPAM) et le système d'information géographique (GIS-arcview)

La conception d'un réseau d'irrigation requiert la disponibilité d'un système d'aide à la décision accessible, flexible, de façon à manipuler les grandes quantités de données de projection.

a) Méthodologie de l'interfaçage

Tous les résultats obtenus par l'analyse des critères de performances du système nous ont permis de déterminer les principaux problèmes des réseaux en termes de déficit relatif de pression, de fiabilité et de localisation de bornes défaillances existantes. La visualisation et la transposition de couches d'informations permettent d'interpréter au mieux les voisinages physiques des bornes défaillantes et leur situation géographique, en vue d'une meilleure réhabilitation hydraulique :

- Thème polygone limite du périmètre;
- Thème polyline oued Ghezala;
- Thème point barrage;
- Thème polyline système de distribution : tronçon par tronçon;
- Thème point bornes;

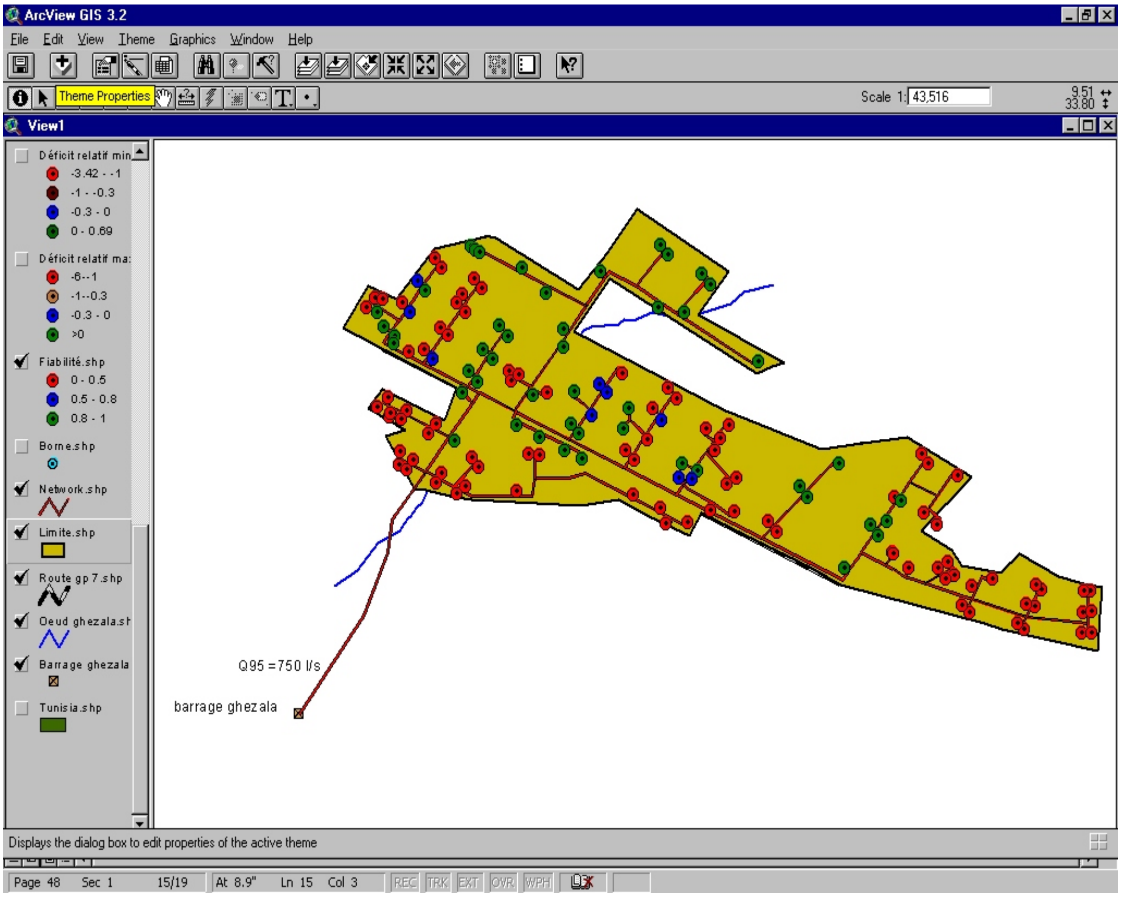

Fig. 4. Thèmes cités dans le système d'information géographique SIG-arcview

L'interfaçage des résultats de calculs hydrauliques s'appuie sur les critères :

- Thème de fiabilité
- Thème de déficit relatif maximum de pression

Pour mieux identifier les zones défaillances du réseau on a classé les résultats selon le tableau ci-dessous :

Tableau 1. Les intervalles de classification des critères de déficit relatif de pression et de fiabilité

	Pas de défaillance ●	**Risque de défaillance au niveau de la parcelle** ● **et** ●	**Risque de défaillance au niveau des réseaux** ●
Déficit relatif De pression	>0	-1 -0,3 et –0,3 0	<-1
Fiabilité	>90%	80% 90%	<80%

b) Résultats de l'interfaçage COPAM et SIG-arview

b-1 résultats de l'interfaçage des résultats de fiabilité et SIG-arcview (Q=750 l/s)

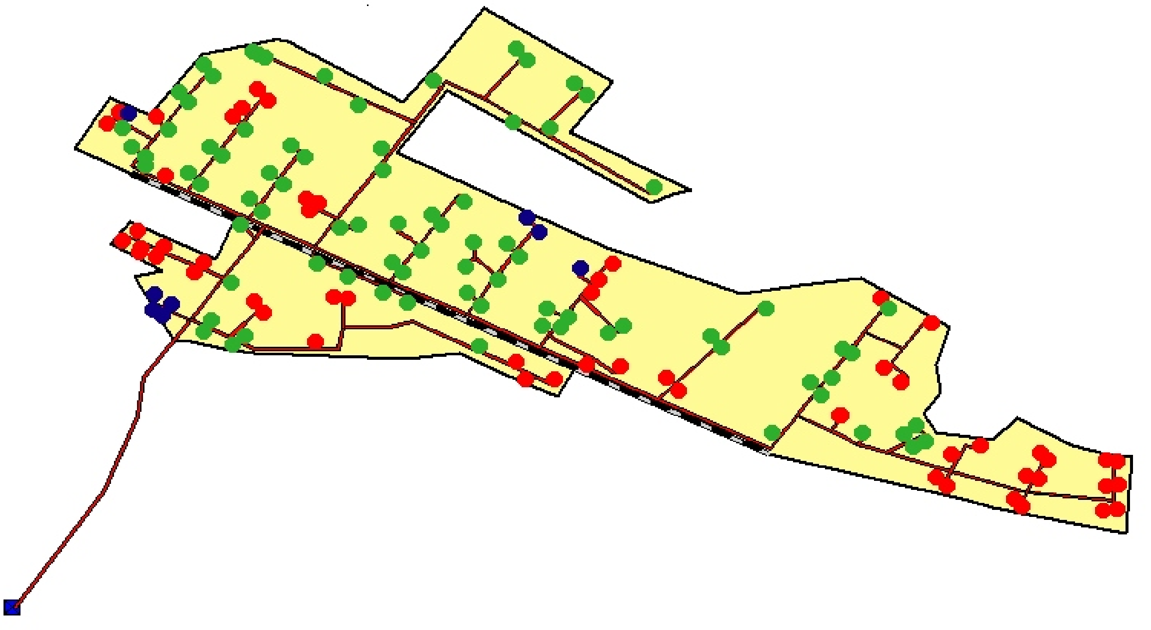

Fig. 5. Distribution spatiale de fiabilité des bornes d'irrigations

b-2 Résultats de l'interfaçage des résultats de déficit relatif maximum et SIG-arcview (Q=750 l/s)

Fig. 6. Distribution spatiale du déficit relatif maximum des bornes d'irrigations

Pour le cas d'étude, la confrontation entre fig.5 et fig.6 concernant le déficit relatif de pression montre des zones en couleurs rouges, ces zones de réseau ont des bornes dont la limite inférieure de la valeur de H est inférieure à 1. Ceci veut dire que les pressions de service sont négatives pour toutes les configurations générées pour ces derniers. Les zones présentant la couleur rouge pour la fiabilité indiquent que les bornes ont une probabilité de défaillance inférieure ou égale à 0.5 pour toutes les configurations générées ; Ceci signifie que dans ces aires, la défaillance dans le service hydraulique rendu se vérifie spatio-temporellement.

Pour le cas d'étude, le système nécessite des interventions de réhabilitation que ce soit par des actions de réhabilitation physique, là où les défaillances sont maximum (changement des diamètres des conduites, installation de surpresseurs..), ou bien par changement dans le mode de gestion (par exemple en imposant un système tour d'eau pendant l'heure de pointe de la demande en eau ou l'installation de bornes équipées d'**ACQUACARD** pour la régulation automatique des ouvertures des bornes, donc une gestion plus rigide du système), ou par changement des techniques d'irrigation et donc des exigences de pression et du débit (contraintes plus souples)

1.3- Etude de réhabilitation du réseau Ghezala

1.3.1 Optimisation des diamètres des conduites

Lors de l'optimisation on a deux régimes d'écoulement.

* Le régime de l'écoulement ; singulier si le débit est calculé par la méthode de Clément, plusieurs régimes si le débit est calculé aléatoirement à l'aide de la commande Random.
* Si on choisit les régimes aléatoires, on doit imposer le débit en tête du réseau et le nombre de régimes à générer.

La méthode d'optimisation considère fixes les débits qui coulent dans les conduites du réseau. Elle s'appuie sur l'algorithme de Labye (Cemagref, 1981), employant les contraintes hydrauliques, un bordereau de prix commercial et une minimisation du coût du réseau.

1.3.2 Réhabilitation du réseau

1.3.2.1 Optimisation selon un régime d'écoulement singulier (Sa)

a- Hypothèses:

Avec ce régime d'écoulement, une borne de 5 l/s n'irrigue que 2.5ha, c'est à dire que l'agriculteur n'irrigue pas la totalité de ces cultures en une seule fois mais il l'irrigue en deux fois.

Le débit spécifique continu est 0.681 l/s*ha ;

Le nombre des bornes terminales ouvertes est 4 ;

La surface non cultivée est 0 ;

Le coefficient de clément est 0.660 ;

La qualité de fonction est 1.645 ;

La hauteur piézomètrique amont est 73 m ;

Le débit amont est 750 l/s ;

La pression exigée aux bornes est 20 m ;

Une étude des performances du réseau, optimisé avec les hypothèses ci-dessus est effectuée :

Les résultats seront présentés dans les figures 7 et 8.

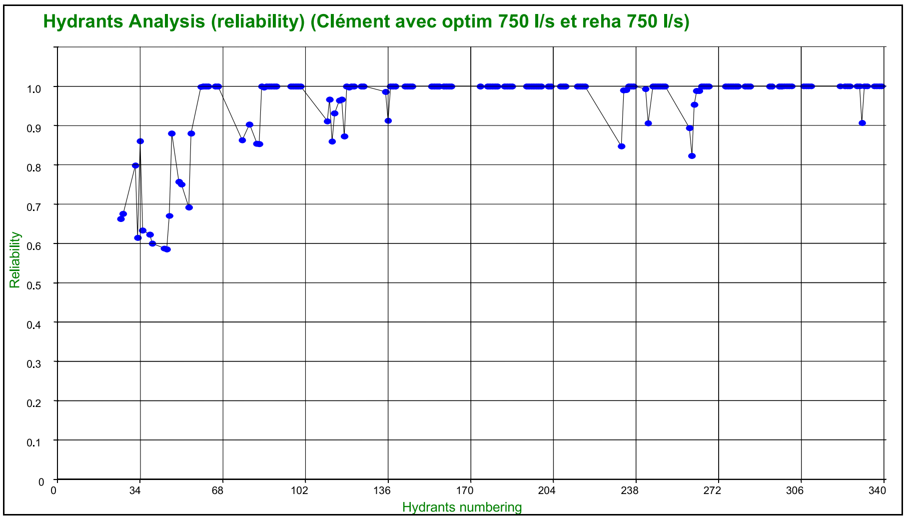

Fig. 7. Fiabilité avec Qopt=750 l/s et Qclément=750 l/s.

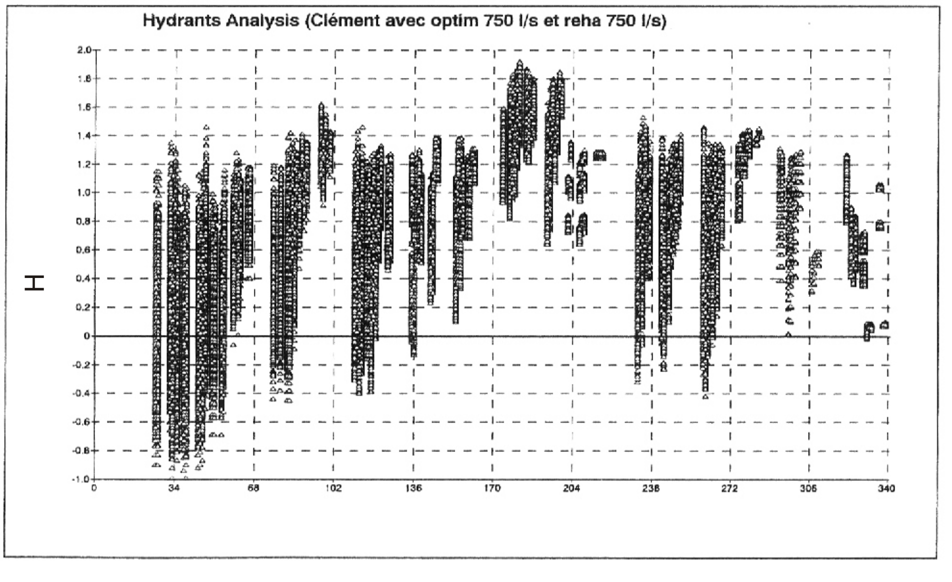

Fig.8. Déficit relatif de pression (H) avec Qopt=750 l/s et Qclément =750 l/s

3. Représentation de la solution proposée sous SIG-arcview

Les résultats seront classifier selon des critères de déficit relatif de pression et de fiabilité

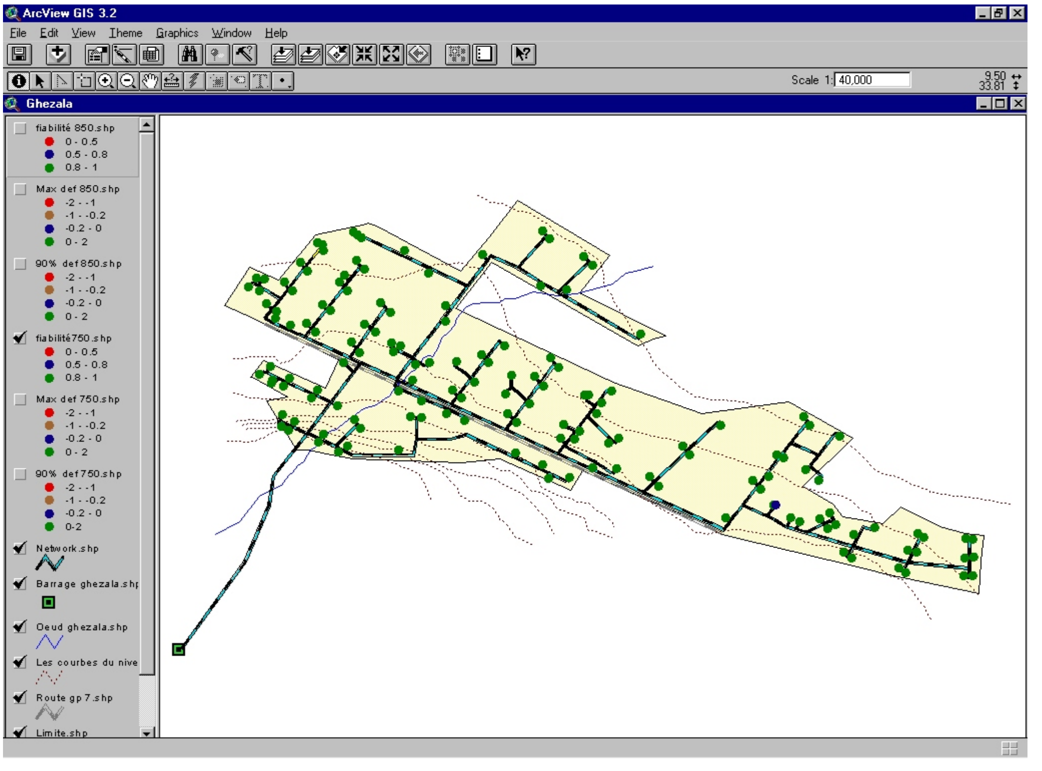

Figure 9. Représentation de la fiabilité sous SIG-arcview de la solution S1 (Q=750 l/s).

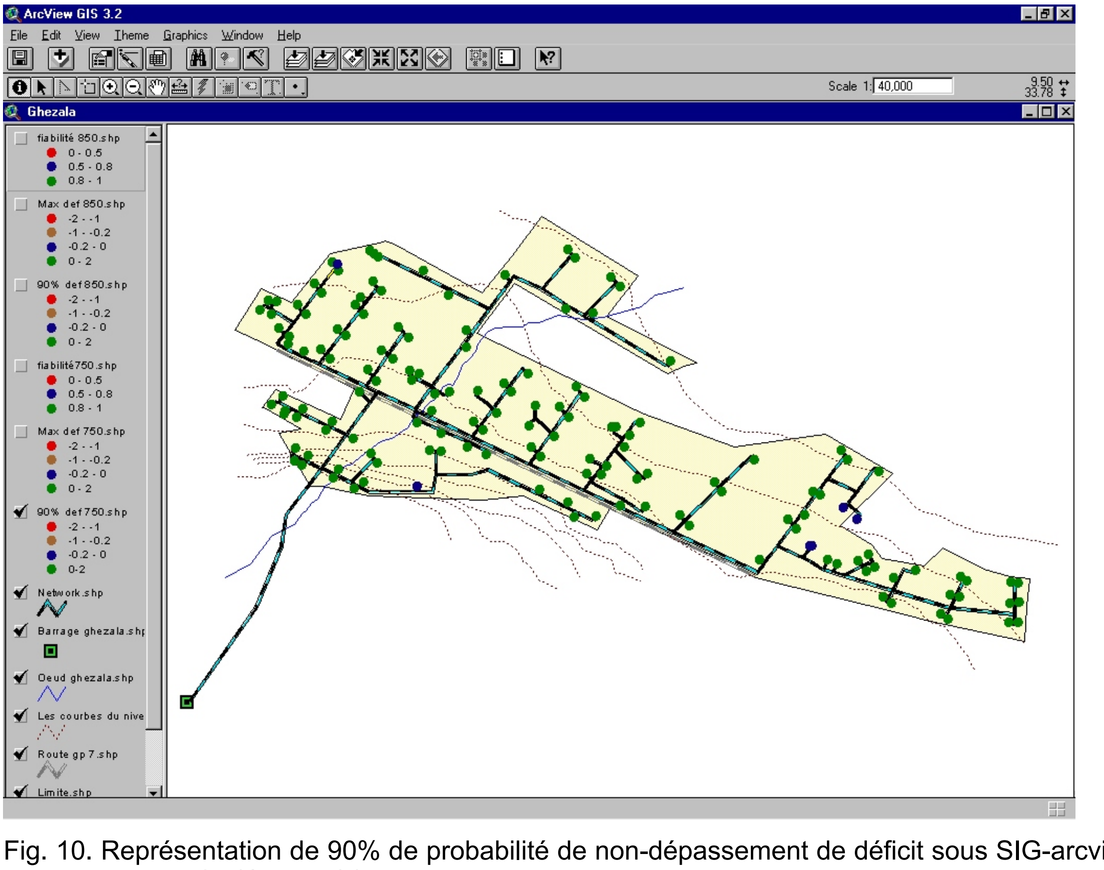

Fig. 10. Représentation de 90% de probabilité de non-dépassement de déficit sous SIG-arcview de la solution S1 (Q=750 l/s).

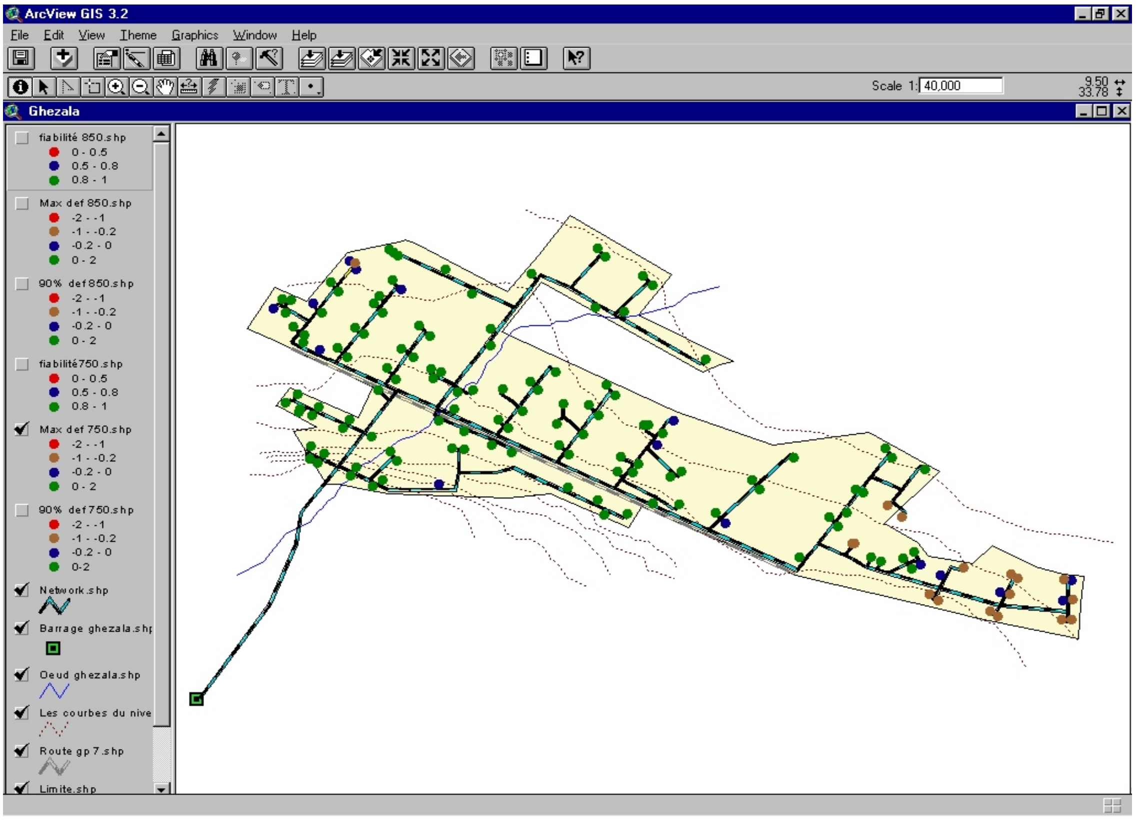

Fig. 11. Représentation de max déficit sous SIG-arcview de la solution S1(Q=750 l/s).

2. Gestion du risque et optimisation stochastique des règles de gestion d'un barrage : cas de barrage *Ghézala*

La gestion optimale du réservoir barrage de Ghézala, consiste à établir les lachures optimales en vue de satisfaire au mieux les besoins d'irrigation, **selon un service hydraulique pré-établi (cf. première partie),** en fonction des observations du stock d'eau à un instant donné, la prévision des apports et la demande en eau affichée.

2.1- Algorithme de résolution

La procédure d'optimisation par P.D.S nécessite la discrétisation des variables d'états et leur représentation par un nombre fini des valeurs caractéristiques. Les variables stock et apport sont les plus utilisées en matière des ressources hydrauliques comme variables d'états.

2.2- Discrétisation des stocks et d'apports

L'ensemble des stocks de la retenue est rendu discret par la théorie des réservoirs de Moran qui consiste à subdiviser l'état du réservoir en n classes égales. Le nombre de discrétisation n'est pas évident à choisir. Plus il est grand, meilleure sera la gestion. Cependant le nombre de cas à traiter par l'algorithme augmente très vite et il faut tenir compte des limites de puissance de calcul disponible. D'autre part, c'est la demande qui réglemente la discrétisation. Les lâchures d'eau déduites de la règle de gestion suivent l'unité de discrétisation. Il faut donc éviter les incohérences du type "le barrage est discrétisé en 100 niveaux de 80000 m^3 tandis que la demande décadaire n'est que de 40000 m^3".

Dans le cas de l'étude, c'est la limitation de la demande qui nous fera choisir la classe de discrétisation. En effet, une gestion au pas de temps décadaire entraîne de faibles demandes par décades. Le barrage est discrétisé en 110 niveaux de manière à avoir des classes de 80000 m^3 les lâchés seront donc des multiples de 80000. Comment satisfaire les demandes décadaires entre octobre et mars, où les demandes sont inférieures à 40000 m^3 sans gaspiller trop d'eau? Une discrétisation par 40000 m^3 semble plus adaptée. Quant aux apports, le découpage en classes ne peut se faire que de façon arbitraire tout en veillant à ne pas dénaturer e profil des chroniques par un découpage très grossier. Afin de faciliter la procédure d'optimisation, les apports seront discrétisés de la même manière que les stocks.

2.3- Détermination de la distribution de probabilités des apports

Etant donné que les apports sont établis d'après des réalisations historiques reconstituées, en plus les apports des périodes de retour supérieures à la période d'étude (15 ans) ne sont pas pris en compte (événements supposés exceptionnels), nous supposerons en dehors d'un ajustement statistique de la série, que la probabilité d'apports n'est autre que la fréquence empirique d'apparition des réalisations observées appartenant à une classe déterminée (ce travail devra être corrigé selon les résultats des hydrologues). Cette méthode appliquée à chaque classe d'apports par décade, permet de construire une matrice de dimension (nombre d'années-décades) contenant les probabilités d'apparition (matrice (Stock - Apports - Probabilité)).

Remarque: on peut parler de probabilité d'occurrence ou d'apparition car l'indépendance des apports est justifiée d'une décade à l'autre.

2.4- Détermination des sorties : lâchures, besoins et évaporation

L'unité des lâchures d'eau correspond à l'unité de discrétisation (40000m^3). L'erreur due à la grossièreté de la discrétisation est inévitable. En outre, pour améliorer la règle de gestion, une lâchure maximale décadaire en concordance avec les objectifs, peut être imposée. Cette hypothèse dans l'algorithme d'optimisation permet de rejeter les règles entraînant une vidange très rapide du barrage. Si l'on fait abstraction de cette contrainte, la gestion n'est plus dans une logique de pénurie d'eau mais une gestion en mode normal. En effet, quelle logique y aurait-il à lâcher plus de 10% du réservoir (890000 m^3) sachant que la demande décadaire maximale est de 406 617m^3 . Ainsi, pour répondre à une gestion annuelle sous un climat semi-aride, les lâchures décadaires seront limités à 440000 m^3 (11 unités de 40000 m^3), presque égal à la demande maximale décadaire.

Les évaporations décadaires sont liées au volume de la retenue par la relation

Vev = a (V) + b

Avec : a et b sont deux coefficients décadaires;
V= volume de la retenue tel que V=0 se trouve à la hauteur du radier

2.5- objectifs de gestion

Un des objectifs principaux est bien entendu d'optimiser la satisfaction de la demande. En contre partie, il est intéressant de garder le niveau d'eau proche d'un niveau de consigne, permettant de ne pas vider le barrage et de pouvoir assurer une irrigation pour le pas de temps suivant, en espérant un apport d'eau futur probable.

De plus, même en gestion annuelle, il est intéressant de ne pas finir sa période de gestion sur un stock inférieur à un minimum garantissant un volume d'eau initial pour la période suivante (semis d'automne). Pour répondre à l'ensemble de ces attentes, nous allons emprunter le critère d'optimisation suivant, avec C^t comme fonction objective:

$$C(t) \qquad {}_{j}^{M} P_j \left(\frac{V_{t\ 1} \quad V_{consigne}}{V_{max}} \right)^2 \qquad 1 \qquad \left(\frac{L_t \quad D_t}{D_{max}} \right)^2$$

Où :

V^{t+1} : volume du réservoir au temps t+1 ;
P_j : probabilité d'apparition de l'apport j ;
L : volume d'eau lâché à l'aval du barrage ;
D : besoin en eau ou demande en eau par le périmètre ;
: facteur de pondération donnant un poids aux deux termes de l'expression "critère”.

$V_{consigne}$ est un niveau du réservoir minimal jugé rassurant pour pouvoir démarrer la gestion du stock en plus. Au-dessus de ce niveau, on considère qu'il y a suffisamment d'eau et que l'on peut lâcher de l'eau pour l'irrigation. En dessous, il est préférable de demeurer prudent, quitte à ne satisfaire qu'une partie de la demande pour rester proche de ce niveau. Ce stock immobilise l'eau dans la retenue pour les pas de temps suivants mais il permet d'éviter une pénurie due à des événements de sécheresse exceptionnels qui peuvent être pris en compte dans l'aléa hydrologique.

Ce niveau de consigne peut faire l'objet d'une étude de sensibilité de la règle de gestion. L'apport médian annuel étant égal à 5 % de la capacité de la retenue, le barrage se remplit et se vide en une année. On le définit à 50 % de la médiane des apports annuels, soit 240000 m^3 (6 niveaux de discrétisation).

2.6- Evolution décision-hasard et calcul des coûts de transition appliquée au barrage

Conditions initiales :

- Les apports sont associés à une probabilité d'apparition.
- Le réservoir est discrétisé en 224 niveaux (de O à 8900000 m^3).
- La gestion se fait sur 36 décades.

Pour chaque décade, on considère tous les niveaux du barrage. Pour un niveau d'eau i, on teste tous les lâchures envisageables variant entre i et max (i,i-19) et faisant aboutir le système au niveau j. Le processus est celui de Décision-Hasard **(Décider sur la valeur de la demande et considérer les probabilités des apports, en donnant comme hypothèse que la demande est plus stable et que son écart type est faible)**. La première étape est donc d'effectuer une lâchure. Pour cette décision de lâcher, on détermine:

1. le coût instantané dû à la décision de lâchure. Il est basé sur la satisfaction de la demande en eau :

   $(1- \quad)[(L-D)/D_{max}]$

   Où:

L : volume d'eau lâchée pour l'irrigation.
D : demande en eau par le périmètre.
: paramètre de gestion

2. On fait évoluer le système par un apport aléatoire. Pour cela on considère tous les apports probables possibles. Pour chaque apport, le nouveau niveau d'eau dans Le barrage est calculé.

3. Calcul du coût espéré: il traduit la garantie d'un stock consigne. Pour avoir une valeur unique du coût espéré qui tient compte de toutes les évolutions possibles, on associe chaque transition à son espérance mathématique. Le coût espéré sera donc la somme des espérances des évolutions possibles du système:

Avec:
Vt±I :Volume du réservoir au temps t+ i.
$V_{consigne}$:240000 m^3 (6 niveaux de discrétisation).
:paramètre de gestion.
Pj :probabilité d'apparition de l'apport j.
Ainsi, au coût espéré associé au stock consigne, il faut ajouter l'espérance du coût de la transition précédente (correspondant à une transition ultérieure dans le temps).

$$^{n}_{j\ \ 1} P_j f_{vf/Apj} \quad t \quad 1,T$$

le coût optimal de transition est alors déterminé par :

C_{opt} =$Min_{(\text{sur l'ensemble des décisions})}$ {Coût instantané +coût espéré consigne+coût espéré ultérieur).

Le lâcher optimal sera alors le lâcher correspondant à la transition qui aura le coût optimal. Cette boucle est réitérée pour chaque niveau du barrage et pour chaque pas de temps. Le résultat de l'optimisation est un couple (lâchure-coût) optimum pour chaque niveau du réservoir et pour chaque pas de temps.

2.7- Présentation des termes du bilan

Sur un intervalle de temps donné, l'équation générale du bilan hydrique d'une retenue découle de l'application du principe de la conservation des volumes d'eau. Elle peut s'écrire :

$$V = (Vr + Vecs + Vp)\ (Vev + Vd + Vinfi + Vu)$$

avec:

V : La variation du stock.

Vp : sont les apports dus aux précipitations directes sur la retenue. Ils se déduisent des enregistrements pluviographiques et la courbe hauteur/surface de la retenue.

Vev : correspondant à l'évaporation. Elle est estimée d'après les mesures journalières et la surface moyenne du même jour. L'évaporation est forte dans toute la zone semi-aride tunisienne. Le passage entre l'évaporation du bac et l'évaporation de la retenue reste délicate.
En effet le bac surestime l'évaporation du barrage en étant soumis à une demande climatique plus importante (effet oasis). Le coefficient de passage choisi Arbitrairement est "0,80 ". On le considère constant malgré sa corrélation avec la surface de la retenue, le vent, la température … etc.

Vd : Déversement.

Vvi : vidange. Connues d'après les côtes lues avant et après la manœuvre.

Vu : eau prélevée directement. Elles se déduisent du temps de pompage par les agriculteurs.

Vr : apports ruissellement des versants.

Vinfi : volume infiltré. Il est du à la charge hydraulique de la retenue, et est donc fonction du volume stocké.

Vecs: apports par écoulement souterrain. C'est un terme difficile à déterminer.

2.8- Critique du bilan journalier

Plus le pas de temps est petit, plus les valeurs entrant en considération sont faibles. Si ces valeurs sont des valeurs mesurées, alors il faut que les appareils de mesures soit précis. Par exemple, l'évaporation est difficilement appréciable à l'échelle journalière: la mesure et la précision sont du même ordre (mm). En augmentant le pas de temps d'étude, les erreurs sur chaque terme se compensent: la mesure est de l'ordre de dizaine de mm tant disque l'erreur reste de quelques mm. Parallèlement, d'un point de vue agronomique le manque d'eau se ressent sur la plante au bout d'une semaine (bien entendu il s'agit d'une moyenne, il existe différentes phases de sensibilité variant selon le stade végétatif de la plante).

Ainsi, un pas de temps décadaire semble répondre à la fois à une modélisation correcte du fonctionnement de la retenue et à une analyse cohérente des défaillances de fourniture en eau au périmètre irrigué.

2.9- Gestion des risques par simulation

L'optimisation précédente permet d'établir les lâchures les moins pénalisants par rapport à un critère choisi. Ce dernier dépend d'un paramètre de gestion alpha. Même si la règle de gestion est optimale, le stock d'eau peut rentrer dans un état de défaillance. Selon la valeur d'alpha, le système entre plus ou moins souvent dans des états de défaillances et avec des amplitudes différentes. L'idée est donc de calculer la règle de gestion optimisée pour plusieurs valeurs d'alpha, définir les incidents possibles au niveau de la retenue, puis étudier ces incidents en fonction du paramètre alpha par une simulation du fonctionnement du barrage. Les incidents pourront être quantifies à l'aide de performance préalablement définis.

2.10- Incidents et indices de performance

2.10.1- Les événements dommageables

Trois types d'incidents peuvent être envisagés :

- La défaillance du stock : l'eau atteint un niveau inférieur alarmant: le radier d'irrigation (il ne reste que la tranche morte de la retenue).
- La déverse : l'eau se trouve au niveau du réservoir.
- La non satisfaction de la demande : les lâchures d'eau n'arrivent pas à satisfaire les demandes.

Ainsi les deux premiers indices sont décris par des comparaisons à des niveaux de consignes (radier d'irrigation et déversoir) tant dis que le dernier est une comparaison à la demande réelle affichée.

2.10.2- Quantification des événements dommageables

Un événement ne peut pas être décrit à l'aide d'un seul paramètre. Par analogie à la description des précipitations, les incidents vont être décrits selon trois indices de performance caractérisant l'intensité, la durée et la fréquence du phénomène.

- **Le risque** (fréquence) : correspond à la probabilité d'avoir une défaillance, une déversé ou une demande non satisfaite.
- **La vulnérabilité** (intensité) : correspond au volume perdu ou manquant à l'origine de l'incident.
- **La résilience** (durée) : temps moyen entre l'entrée du système dans un état dommageable et son retour à un état satisfaisant.

2.10.3- Quantification de la défaillance du stock et de la déversé

La figure ci après illustre une défaillance et une déversé. Ces deux incidents pourront être caractérisés par leur vulnérabilité (V) et leur résilience (T).

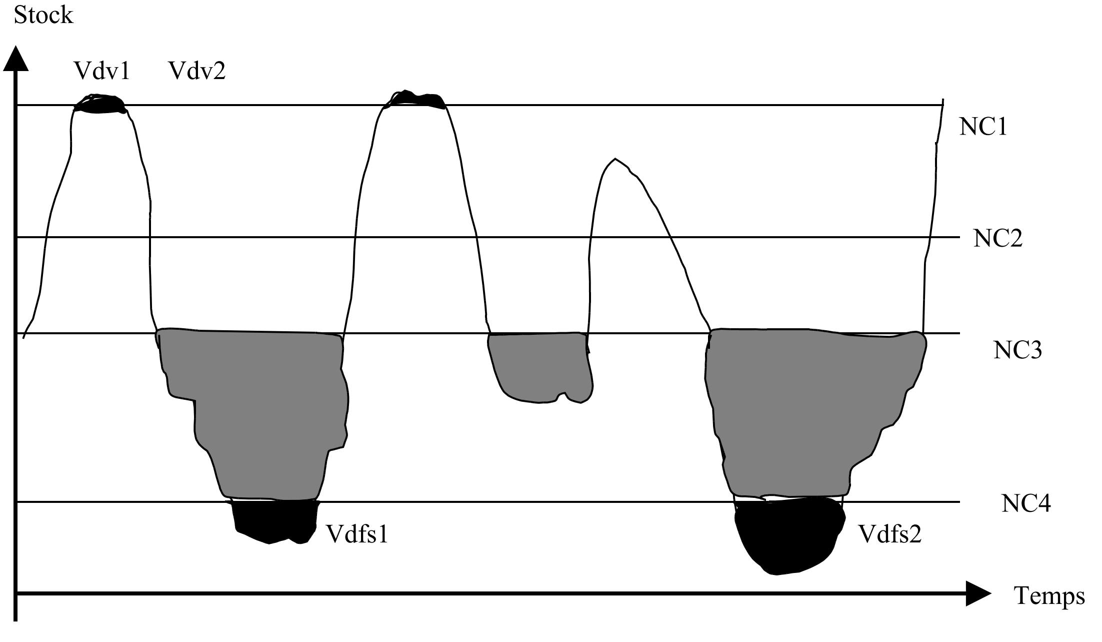

Fig. 12. niveau de satisfaction du stock en fonction du temps.

Nc4 : Niveau de consigne au-delà duquel il y a un incident.
Nc2 : Niveau de consigne jugé satisfaisant par rapport à un incident.
Nc3 : représente des niveaux du réservoir jugé satisfaisant, permettant d'éviter des incidents. Ils servent à définir la résilience de chaque événement dommageable. Ainsi on fixe:
Nc2 déverse = NC1 déverse-apport maximal des valeurs médianes (correspond à l'apport des décades de mars) =8900000-33866 = 88661336
Nc2 défaillance=NC1 défaillance + demande lors de la campagne de pointe (juin-août) ; (dépend du scénario de la demande) = 3 442 004 m^3

- NC1 déverse : NCdvris : 8900000 m^3
- NC2 déverse : Ncdvres : 8866133m^3
- Sconsigne : 240 000 m^3
- NC2 défaillance: Ncdfres : 3442000m^3
- NC1 défaillance: NCdfris : 0m^3

Ces deux indices de performances ne permettent pas de juger de la répétition des incidents, c'est pourquoi la notion de risque (temps au-delà d'un niveau NC1/temps de simulation) est introduite.

2.10.4- Quantification de la demande non satisfaite

Elle ne se fait plus par rapport à des niveaux de consigne, mais par rapport à la demande réelle. On définit un taux de non-satisfaction de la demande(fourniture <60% de la demande) en dessous duquel on considère le système en incidence. Nous pouvons justifier cette hypothèse de non-satisfaction par les observations faites sur le terrain. En effet, même si l'eau est disponible, les agriculteurs ont tendance à moins irriguer par rapport aux besoins en eau des plantes. Ainsi, une valeur assez faible de ce taux a été prise.

Risque de non-satisfaction = (temps lorsque (demande/fourniture)<0,6)/(temps de simulation.

Vulnérabilité de non-satisfaction = moyenne des volumes d'eau annuels qui n'ont pas satisfait la demande.

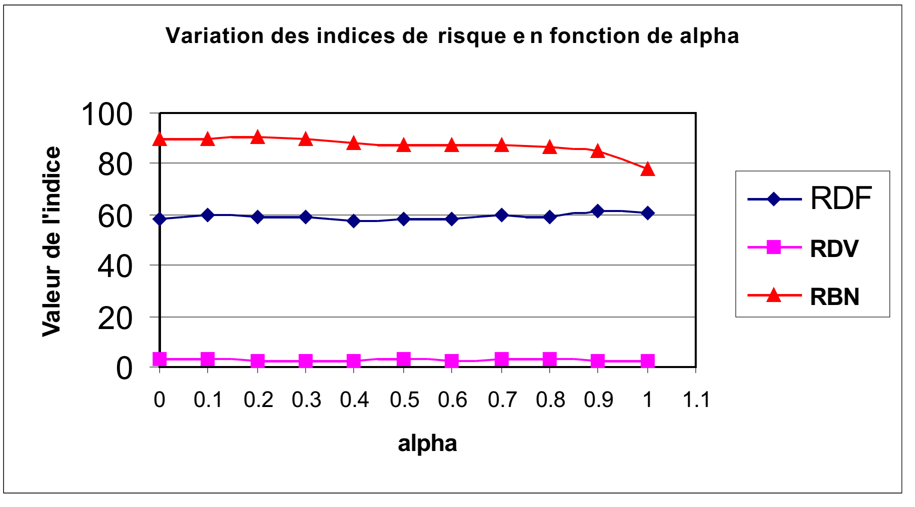

Fig. 13. Variation des indices de risque en fonction d'alpha.

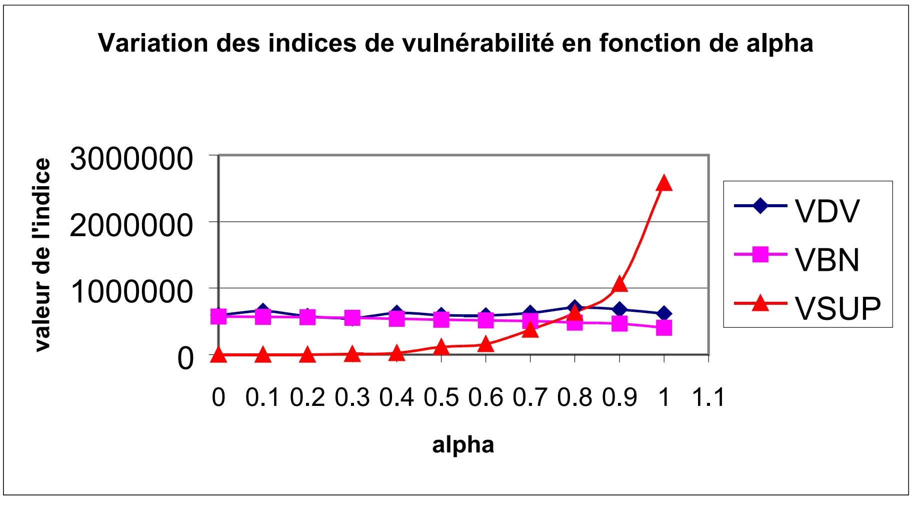

Fig. 14. Variation des indices de vulnérabilité en fonction d'alpha.

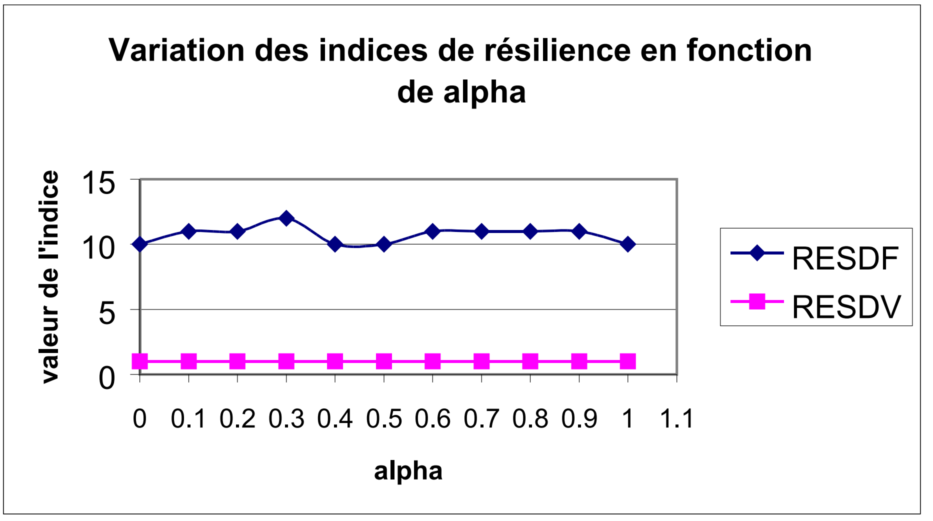

Fig. 15. Variation des indices de résilience en fonction d'alpha.

Dans le cas de la satisfaction de la demande c'est à dire pour des petites valeurs d'alpha, les défaillances sont rares. Donc avec un faible pénalité, le réservoir a tendance à être rempli et son niveau d'eau évolue lentement.

On rappelle que RBN est le risque que la fourniture soit inférieure à 60 % de la demande (hypothèse de non-satisfaction de la demande). Ce risque est supérieur à ce pourcentage pour toutes les valeurs d'alpha (de 77.92 % à 90.04%) ce qui est trop élevé. Donc on peut donner une valeur de 27% à RBN tout en notant que cet indice ne va pas être pris en considération lors du choix.

La figure 14 montre qu'un seuil de 565987 m^3 de la vulnérabilité, rejette les règles non satisfaisantes. Le risque maximal de déverse (2.96 % pour alpha =0.1) est faible, donc on accepte la déverse de la règle la plus pénalisante (655827 m3) qui correspondrait à un seul écrêtement de crue. Pour rester dans des objectifs de gestion en pénurie d'eau, l'eau lâchée ne servant pas à l'agriculture sera limitée à 10% de l'apport médian annuel (445000 m3), soit VSUP = 44000 m3.

Le tableau suivant nous donne une idée sur les indices qui sont à l'origine du choix de la règle optimale de gestion.

Tableau 4 - Indices de performance normalisés.

alpha	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
RDF	0.98	1.01	0.99	1	0.97	0.98	0.98	1.01	0.99	1.03	1.02
RDV	0.94	1	0.83	0.82	0.91	0.92	0.84	0.97	0.99	0.91	0.88
RBN	3.3	3.3	3.3	3.3	3.24	3.21	3.22	3.19	3.17	3.10	2.86
VDV	0.9	1	0.88	0.84	0.96	0.9	0.89	0.95	1.07	1.04	0.94
VBN	1.01	1	0.99	0.98	0.95	0.93	0.91	0.89	0.85	0.82	0.72
Vsup	0	0	0	0.25	0.59	2.65	3.61	8.52	14.31	24.17	58.61
RESDF	0.9	1	1	1.09	0.91	0.9	1	1	1	1	0.91
RESDV	1	1	1	1	1	1	1	1	1	1	1

Il est à noter que le choix des limites d'acceptabilité d'une règle à partir de ses indices de performance permet d'en tirer les règles optimisées acceptables ou réalisables. Elles ont été choisies de façon plus ou moins arbitraire à cause du manque de données.

Elles doivent obéir à des considérations agronomiques, hydrauliques ou socio-économique. Ces limites sont les véritables contraintes de gestion. Les indices sont ensuite normalisés entre 0 et 1 pour simplifier l'interprétation.

La règle sera rejetée, lorsqu'elle a un indice normalisé au-delà de 1 pour chaque valeur des indices déjà cités.

Donc d'après les valeurs de ces indices on peut déduire que la règle alpha égale à 0.2 est la règle optimale.

RDF rejette les règles pour alpha 0.1 ; 0.7 ; 0.9 et 1
RDV ne rejette aucune règle
VDV rejette la règle pour alpha 0.8 et 0.9
VBN rejette les règles pour alpha 0 et 0.1
VSUP rejette les règles pour alpha 0.5 à 1
RESDF rejette les règles pour alpha 0.3

La règle optimisée donc acceptable par rapport aux seuils imposé est alpha=0,2

3. Les aménagements et la gestion participative des réseaux collectifs sous pression

3.1- Premier Cas : Nouveau périmètre public irrigué (PPI) de Nefza dans le gouvernorat de Béja

C'est dans le cadre du projet WASIA et pour ce nouveau périmètre irrigué, qu'une introduction des systèmes d'irrigation localisée est faite sur l'arboriculture, sur sol léger. Il s'agit d'une action qui, dans l'avenir, devra être poursuivie pour évaluer le degré d'efficience du système mis en place.

Le périmètre irrigué de Nefza a une superficie de 2461 ha, répartie en quatre zones, Bouzenna sur une superficie de 1086 ha, Jmila sur une superficie 375 ha, Touila sur une superficie de 470 ha et Ouechtata sur une superficie de 530 ha.

Le projet concernant ce périmètre a commencé au mois mai 2000, à ce stade il est arrivé à un taux de réalisation de 70 %. Le périmètre va entrer en phase de production agricole au début de 2003. Le projet prévoit la construction d'une station de pompage, de deux réservoirs de régulation, et un réseau d'irrigation sur une longueur de 30 Km, il va bénéficier environ 600 agriculteurs.

3.1.1- Présentation de la région de Nefza

La région de Nefza, se situe au Nord ouest de la Tunisie dans le gouvernorat de Béja faisant partie de l'atlas Télien (Afrique du Nord). La superficie du périmètre est de 2260 ha, la zone du projet se situe dans l'étage bioclimatique humide de type méditerranée tempéré à hiver pluvieux et humide et un été sec et chaud. La pluviométrie dans la région se caractérise par une irrégularité inter-annuelle et saisonnière avec une moyenne annuelle sur 50 ans est de 906 mm. Le barrage de Sidi Barrak a une capacité utile 264 millions de m3 et un volume régularise de 188 millions de m3. La qualité de l'eau est bonne (moins de 1 g/l comme résidu sec), avec un pH varie de 7.4 à 8.6.

a- Système d'irrigation

Le mode d'irrigation choisie, pour la mise en valeur des périmètres publics irrigués de Nefza est un système mixte à base d'aspersion mais qui s'adapte à l'irrigation au goutte à goutte. Ainsi les cultures céréalières, fourragères et maraîchères sont irrigués par aspersion alors que les cultures arboricoles sont prévues irriguées au goutte à goutte.

b- Les infrastructure dans les différents périmètres :

- Périmètre de Bouzenna et jmila
  - Un ouvrage de piquage sur la conduite des eaux du barrage Sidi El Barrak au barrage sejnane.
  - Un réservoir de régulation.
  - Un réseau d'adduction
  - Un réseau de distribution

- o Périmètre de Touila Ouechtata
  - Station de pompage
  - Réservoir de régulation
  - Réseau d'adduction
  - Réseau distribution

3.1.2- La synthèse des résultats produits

La création des PPI a permis d'améliorer la production agricole à l'échelle nationale et régionale dont les modes d'accès à la terre sont un peu différents de ceux sec. Cette particularité se traduit par le choix des cultures à installer au niveau de la parcelle, tout en prenant en considération les facteurs terres, l'eau et la localisation par rapport aux marchés. Dans le cas de PPI de Nefza, est-ce qu'on a tenu compte de ces facteurs lors de l'élaboration du projet ?

- o Quant au mode de gestion de la demande en eau est ce que le périmètre de Nefza, va subir une gestion de type dirigiste (la gestion du périmètre est attribuée au CRDA) ou une gestion participative dont les irriguants participent à la gestion de l'eau (groupe à intérêt collectif GIC) ?

- o Pour assurer une utilisation rationnelle et plus économique de l'eau quelle sera la tarification appliquée à l'eau ? : une tarification en vigueur ou une tarification binôme(basée sur une formule qui tient compte de la superficie en irriguée).

- o Au niveau du PPI de Nefza il y a des terres qui ont été perdues suite aux aménagements hydraulique (Barrage de Sidi El Barrak) quel serait l'impact de ces mutations sur le système de production ? Est-ce que les agriculteurs vont faire recours à un système de production très intensif (augmenter le taux d'utilisation du sol) dans le but de récupérer ces terres perdues?

- o Quels sont les principaux objectifs des exploitants et quel serait le système de production à choisir par les agriculteurs pour atteindre leurs objectifs ?

- o Quel serait la relation entre le système de production et les choix des activités agricoles au niveau PPI de Nefza ?

- o Quel sera le comportement des exploitants vis a vis de la gestion de leur exploitation dans ces nouveaux conditions (introduction de l'agriculture en irriguée) ?

- o D'après l'analyse de l'enquête on a remarqué la dominance des exploitations de petite taille (50.3% des exploitations ont une superficie inférieure à 2 ha) cette taille aura-elle des répercussions sur le développement du secteur agricole ?
  D'un autre côté, on remarque que la plupart des exploitations enquêtés ont une superficie utile hors périmètre (en sec) supérieure à celle trouvée dans le périmètre. Quelle serait l'influence de cette superficie sur l'avenir du périmètre ? Et est ce que ses exploitations ont intérêt à exploiter dans ou hors périmètre ?

3.2- Second cas : Analyse de la gestion participative de l'eau dans un réseau collectif sous pression géré par une association d'agriculteurs Cas de périmètre Bir Ben Kamla

La présente contribution dans le projet WASIA concerne en première partie l'analyse du fonctionnement hydraulique et de la gestion de l'eau dans un réseau collectif sous pression, géré et administré par une association d'agriculteurs en Tunisie (GIC : groupement d'intérêt collectifs).

Le cas d'étude concerne le GIC de "Bir Ben Kemla", situé dans le Sahel Tunisien. Il exploite un périmètre de 124 hectares avec une vocation arboricole et maraîchère et compte 76 agriculteurs présents sur le périmètre. Le périmètre a été crée en 1970 et géré par l'administration jusqu'en 1994, date de la passation des pouvoirs de l'administration vers l'association d'agriculteurs. Le nombre d'adhérents du GIC Bir Ben Kamla est en évolution constante. D'après les fiches de consommation journalière de l'eau des campagnes 1998-1999, 1999-2000 et 2000-2001 du GIC, le nombre des agriculteurs et des adhérents a évolué de la façon suivante (graphique n°1).

3.2.1- Performances et contraintes de la gestion hydraulique

La ressource en eau du périmètre irrigué provient d'un forage situé sur le même périmètre et qui débite 50l/s. Les analyses de l'eau effectuées montrent un résidu sec supérieur à 3g/l. L'eau disponible à la parcelle nécessite une utilisation délicate et une surveillance des effets néfastes dus à un mauvais lessivage et à une augmentation de la salinisation du sol.

3.2.1.1-Le réseau hydraulique

La distribution de l'eau se fait par refoulement du forage vers un ouvrage partiteur placé en tête du périmètre et permet le partage du débit entre deux secteurs, ainsi qu'une pression de 3 m au moins à l'entrée des parcelles . Ces dernières sont en passe d'être équipées totalement en bassins de stockage, en béton, de 40 à 100 m^3 de capacité. Le réseau a été évalué selon plusieurs critères :

les pertes en eau qu'il occasionne ;
l'adaptation des conduites qui le constituent au fonctionnement exigé du réseau ;
la satisfaction de la demande à chaque borne , en termes de pression et débit pour quelques parcelles encore dépourvues de bassins de stockage et en terme de volume pour la majorité des parcelles équipées de bassins.

D'après les bilans financiers de l'association, on peut disposer des volumes pompés (mesurés par un compteur à la sortie de la station de pompage) et des volumes vendus. Puisque les bornes remplissent des bassins chez la grande majorité des exploitants, les volumes vendus par l'association évaluent assez précisément les quantités fournies à l'ensemble des bornes. On dispose ainsi des volumes entrés et sortis dans le réseau ainsi que des pertes globales, assimilées en même temps à un manque à gagner de l'association :

Tableau 4. Pertes en eau globales dans le réseau

Année	**1998**	**1999**	**2000**
Volume pompé (m^3)	280732	249659	316956
Volume vendu (m^3)	273633	244470	311969
Pertes globales ou manque à gagner	2.53%	2.08%	1.57%

L'évaluation des pertes en eau globales montre une bonne efficience de ce dernier. Néanmoins, l'évaluation des pertes aurait pu être affinée par une mesure des pertes partielles des différents tronçons du réseau, ce qui aurait permis de connaître l'état de ce dernier tronçon par tronçon et de séparer ce qui peut être un manque à gagner et ce qui peut être des pertes réelles de quantités d'eau.

3.2.1.2- la gestion de l'eau au niveau du GIC

Le réseau d'irrigation fonctionne au tour d'eau et une durée d'arrosage est impartie à chaque borne en fonction de la surface qu'elle dessert. Toutefois, actuellement et suite au développement des bassins individuels à l'entrée des parcelles, il y'a eu plusieurs avantages qui ont amélioré la gestion hydraulique :

assouplissement du tour d'eau : les bassins sont remplis tour à tour mais les exploitants gèrent les volumes disponibles comme ils le souhaitent. Le mode de gestion de l'eau est passé de la disponibilité d'un service (débit, pression, temps) à un service de volume ;
les volumes consommés sont connus assez précisément, à la différence de la gestion d'un débit au tour d'eau. La maîtrise des volumes a eu pour conséquence une considérable économie d'eau ;
les volumes connus règlent les conflits habituels entre les exploitants et le gestionnaire de l'eau. La responsabilité d'un service défaillant est précisée et localisée. Le volume qui sort du forage est connu et le volume de remplissage du bassin aussi. Il est dés lors possible à l'agriculteur de séparer ce qu'il paye comme volume disponible dans le bassin, à l'entrée de la parcelle et sa contribution dans la facture, aux différentes pertes d'eau qui s'opèrent entre le forage et son bassin individuel. C'est une comptabilité analytique de la desserte de l'eau, depuis sa production jusqu'à son usage ;

la gestion des volumes d'eau à travers les bassins individuels ont eu un fort impact psychologique de la ré-appropriation de l'eau chez les exploitants ;
de même, le système hydraulique à l'intérieur de la parcelle a été amélioré, par l'adoption de l'irrigation localisée, tout en veillant sur la durabilité du système (suivi et surveillance de la salinisation des sols). Ces techniques visent principalement une meilleure économie d'eau et un allègement du travail, par l'automatisation des tâches d'arrosage et de fertilisation.

3.2.1.3- Indicateurs de l'évolution du périmètre irrigué

3.2.1.3.1- taux d'exploitation

C'est le rapport entre superficie cultivée (en sec et irriguée) et superficie totale. Ce taux traduit le stade du développement du périmètre et le dynamisme des exploitants. Le tableau 4 ci-dessous montre que le taux d'exploitation atteint 100% en 1998/99, c'est à dire que le périmètre a atteint sa maturité complète. La baisse enregistrée en 2000/2001 est due à la stagnation des superficies maraîchères et à la récession qui concerne les grandes cultures en année sèche.

3.2.1.3.2- taux d'utilisation de l'irrigation

Correspond au rapport de la superficie couverte par des cultures irriguées et de la superficie totale. Ce taux indique la part du périmètre qui est effectivement exploitée en irrigué. Lors de l'étude du périmètre, ce taux d'utilisation est prévu égal à 100%. Or, ce taux d'utilisation de l'irrigation reste faible puisque la pratique de l'irrigation concerne seulement la moitié de la superficie équipée (cf. tab 4). Ce taux met en évidence une forte contrainte structurelle puisqu'il n'évolue pas dans le temps. La cause est la forte salinité de l'eau d'irrigation, qui impose de pratiquer une rotation de cultures, où la superficie irriguée pour cette année doit être laissée sous l'influence des pluies l'année suivante, en vue d'un lessivage des sels accumulés.

3.2.1.3.4- taux d'intensification

Il prend en compte la totalité des cultures irriguées, et montre la maîtrise des exploitants du calendrier cultural, du pilotage de l'irrigation, en conformité avec les soucis du marché. Le taux d'intensification a atteint une bonne valeur de 173% lors de la campagne 1999/2000.

Tableau 5. Indicateurs d'évolution du périmètre

Compagne	**Taux d'exploitation**	**Taux d'utilisation**	**Taux d'intensification**
1997/1998	97,2	45,9	131,8
1998/1999	100	45,9	135,9
1999/2000	100	50,7	172,9
2000/2001	89,5	56,5	136,4

Conclusion

La passation progressive des pouvoirs de gestion et d'exploitation de la ressource en eau et des réseaux hydrauliques aux associations d'agriculteurs, est étudiée en partie, à travers les performances hydrauliques des périmètres irrigués, les indicateurs d'évolution de ce dernier et l'analyse du budget de l'association et du coût de l'eau. L'étude de cas et les enquêtes ont été réalisées à partir de l'association d'agriculteurs de Bir Ben Kemla (Mahdia) en Tunisie.

Il apparaît que le passage à la gestion des volumes au lieu d'un tour d'eau au débit, en installant des bassins individuels à l'entrée des parcelles, a amélioré la gestion du système (règlement de conflits, comptabilisation des volumes délivrés) et a apporté à l'agriculteur, une plus grande liberté de gestion et un sentiment de ré-appropriation de l'eau. De ce fait, les indicateurs d'exploitation, d'utilisation de l'irrigation et d'intensification cultural ont atteint de bonnes valeurs et dénotent d'une maîtrise de la gestion du système hydro-agricole.

REGIONAL ACTION PROGRAMME (RAP)-WATER RESOURCES MANAGEMENT: WATER SAVING IN IRRIGATED AGRICULTURE *(WASIA PROJECT)*

EXECUTIVE SUMMARY

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I. PRIORITY SETTING JUSTIFICATION AND OBJECTIVES

At the beginning of the new century, agriculture faces the challenges to produce more food for inexhaustible population growth, while maintaining almost unchanged land and water input. This challenge becomes particularly important for arid and semi-arid areas of the Mediterranean, where agricultural production is strictly related to irrigation and where, in many places, the maximum employment of resources has already achieved.

The Southern Mediterranean, comprehending the Northern African and Near East countries, is the poorest region in the world in terms of water resources, globally and per inhabitant. In many countries of the region, annual water withdrawal has reached or already exceeded total annual renewable water resources (e.g. Egypt, Libya, Palestine, Israel, Jordan, Syria, Malta, Tunisia) and further employment of resources is unrealistic from both technical, environmental and socio-economic point of view. In the region, population growth is among the greatest in the world (3% per year) and agricultural production relies heavily on irrigation: in the Northern African region, irrigated agriculture consumes in average about 85% of total annual water withdrawal (FAO, 1997), and, in some countries, water use for irrigation approaches even 90% (e.g. Egypt, Morocco, Cyprus). At the same time, average losses of water diverted to agriculture are extremely high and accounts to about 50% (FAO, 2000) due to inefficient use of water at on-farm scale, poor performance of irrigation distribution systems caused by inadequate maintenance and operation, improper irrigation and drainage infrastructures, etc.

The projections of food and water demand in the Mediterranean indicate, for the period 1990-2025, a population increase in the Southern Mediterranean countries of almost 100% with the corresponding increase of water demand of approximately 50%. Irrigated agriculture holds the key to feeding the growing population in the region since irrigated land produces two to three times more crops than rainfed agriculture. At present, the irrigated areas in the Mediterranean account for more than 16 million hectares with a growth rate stabilized, at the beginning of the nineties, to around 200,000 hectares per year. This requires an additional supply of water for agriculture by a rate of 2 km^3/year. However, regardless of these specific causes, existing situation is not amenable to cope with the spiraling increases in food and water demand due to water and land shortage in the region.

Therefore, the solution should be searched not in the increase of land and water input for agricultural use but in better employment of already existing natural resources, i.e. in water saving in irrigated agriculture, and increased use of non-conventional water resources (saline and treated wastewater) which may have adverse impacts on both the environmental and public health.

In the Phase I of the RAP, great efforts had been carried out to cope the above cited problems locally and at the regional Mediterranean scale and, through the collaborative research network, these efforts have resulted in numerous publications, organizations of conferences and workshops as well as the realization of several research projects. That is the time to translate the ideas, conclusions and recommendations developed through these researches to actions on the ground in the Mediterranean region. This is what had been exactly formulated in the Research Project WASIA ("Water Saving in Irrigated Agriculture") which aims at the development of sustainable agricultural production and food security in the Mediterranean region.

The main objective of the WASIA research project is to develop a conceptual framework for ***water saving in irrigated agriculture*** of the Mediterranean region through the integration of the activities which represent major topics of the three Collaborative "Water Resources Management" Research Networks and aim to:

Improve water use efficiency in irrigation practices (WUE_Net),
Improve performances of irrigation distribution systems (CIS_Net), and
Promote safe and sustainable use of non-conventional water resources (NWRM_Net),

Specific objectives of the project are addressed to the development of 8 (eight) research themes to be carried out at eight different locations in the Mediterranean Region:

1. Deficit Irrigation of orchards with low quality water, (Tunis, Tunisia)
2. Deficit Irrigation of pistachio with different fertigation practices (Southeast Anatolian Region, Turkey)
3. Hydraulics performances of irrigation systems under different irrigation practices (Ghezala-Teskraya, Tunisia)
4. Innovative approach for energy saving in irrigation systems (Souss Massa, Morocco)
5. Reuse of treated wastewater for irrigation of cereals, forage and vegetables by means of different irrigation methods (Agadir, Morocco)
6. Re-cycling of drainage water for sustainable irrigated agriculture (Nile Delta, Egypt)
7. Sustainable use of highly saline water for irrigation of crops under arid and semi-arid conditions: new strategies (Tarsus, Turkey)
8. Development of screening legumes and forage nursery for salinity tolerance (Aleppo, Syria)

The proposed research themes cover some of the most important aspect of water saving in the Mediterranean agriculture and represent the continuation of the collaborative research network activities carried out during the first phase of the RAP. Therefore, it is expected that the outputs of the project should provide a substantial contribution in achieving sustainable agricultural production and food security in the Mediterranean region.

II. METHODOLOGY

In the realization of the WASIA project, 8 local institutions (one for each experimental site) were involved along with the CIHEAM-IAMB and the National Water Research Center (Cairo, Egypt). The programmed duration of the project was 24 months, while the approved budget was Euro 300,000.

According to the Working plan, four Work Packages are established. Three of them are tightly related to the three Collaborative Irrigation Networks of IAMB (WUE, CIS and NWRM) with the task of coordinating and carrying out the major activities under specific research themes, while the fourth is related to the overall scientific and administrative coordination of the Project, the exchange of information and interactions between the first three Work Packages.

Two meetings, related to preparation of activities and organizational aspects of the WASIA project, were carried out in the 1st year of the Phase II of RAP, while the third and fourth meeting, related to the monitoring of activities and presentation of results, were held in the 2nd phase of the RAP. The last meeting is scheduled for the end of the program in May 2003.

The first meeting was organized at IAMB, in October 2000, before the initiation of the experimental work at eight selected pilot sites included in the WASIA project. The scientific coordination of the Project is assigned to the Chairperson of the National Water Research Center (NWRC), Cairo (Egypt), in cooperation with the CIHEAM-IAMB Research Network coordinators and local coordinators of different pilot sites. It is agreed that the Project should be financially administrated, along the whole duration, by the Administration Division of the CIHEAM-IAMB in cooperation with the person nominated by the NWRC, Cairo (Egypt). In this occasion, the working plan of WASIA project was fully discussed between the local coordinators and IAMB scientific coordinators. A part of discussion was dedicated to the definition of the way of communication among the partners, the contribution of each local site and the division of the EU budget among the sites, to be allocated to the equipment and consumable material needed to improve the experimental work on the fields and in laboratories and to facilitate the communication between the partners.

The second meeting was held at Bari Institute from 23 to 25 February 2001 with the participation of the representatives from NWRC (Cairo, Egypt), local coordinators and IAMB staff included in the project. In this meeting, the working plan was revised and approved. Moreover, it was agreed to distribute equally among the experimental sites the EU budget allocated for the project, with the exception of ICARDA site which had to receive only a part of budget for travel expenses and consumable material.

The third meeting of the local co-ordinators and scientific co-ordinators of work packages was held at the National Water Research Center (Cairo, Egypt) from 13 to 15 January 2002 following the invitation of the Chairperson Dr. Mona El Kady. In that occasion, the local co-ordinators presented the activities related to each pilot site and agreed the completion of the program with the scientific co-ordinators. It was decided to interrupt the activities at the Souss Massa experimental site in Morocco due to difficulties to establish the contacts with the coordinators of the pilot area.

The fourth meeting was held in Cairo (Egypt) at the NWRC from 10 to 11 October 2002, where the complete presentation of the outcomes and research findings from 7 experimental sites was done. Moreover, the way of preparation of the final report and other deliverables of the project are discussed and agreed according to the formulated working plan for each site.

The last meeting is scheduled for the end of May 2003 when the research results of the project will be presented and discussed during a regional seminar with the participation of numerous irrigation experts and researchers from the Mediterranean region. In that occasion, the level of exchange of information and interaction between different themes and working packages will be assessed. Furthermore, this meeting should trace the guidelines for the further actions on water saving in agricultural sector to be taken in the Mediterranean region.

III. RESULTS AND OUTPUTS

Detailed reports related to the eight research themes, describing the experimental site, measurements methods and procedures, and giving the results and outputs are presented as separate documents, while a summary of the activities with results and conclusions is reported here bellow.

Research theme 1: "Deficit irrigation of orchards with low quality water"
Pilot area: Mornag-Tunis, Tunisia
Partner: Institut National Agronomique de Tunisie (INAT), Tunisia
Objectives:

- save water in irrigated agriculture through deficit irrigation practices,
- monitor and reduce salt input to the soil and consequently diminish environmental degradation
- improve irrigation water productivity in orchards.

Programmed Activities:

- Meteorological data collection and regional climate characterisation: rainfall frequency distribution, ten-days T°C averages and ETo
- Characterization of the soil of the selected region: sampling of typical soil, determination of Field Capacity, Permanent Wilting Point (PWP), Soil Moisture Release Curve
- Surveys on irrigation practices in representative orchards
- Collection and analysis of existing research data and development of phenological calendars for the selected tree species.
- Implementation of demonstration plots (amount of water usually delivered by the farmer will be used for reference). Restrictive treatments consist in irrigation water cuts of 33% at selected growth stages.
- Quantification of saved water volumes and salt-input reductions
- Preparation of “Deficit Irrigation Guidelines”
- Dissemination of results

Deliverables:

- Deficit irrigation guidelines for peach growers to save water
- Indications on irrigation criteria to control excessive salt accumulation in the root zone

Results and Conclusions:

- A continuous water restriction seems to give a better yield than restrictions during just the vegetative growth phase or during the final fruit growth stage: 1) irrigation water saving during the whole season of 33% has resulted in the yield losses of 10%; 2) irrigation water saving of 33% during the vegetative growth stage (10% saving over the whole season) has resulted in the yield reduction of 15%; 3) irrigation water saving of 33% during the final growth stage (22% saving over the whole season) has resulted in yield reduction of 22%.
- Water restriction during the whole growing season seems to improve sugar content and the dry weight of fruits.
- Salts are mainly concentrated near the trunk and that soil salinity evolves in the same manner for different treatments.

Predawn water potential showed an increasing difference between the control treatment and restriction treatments. During the period June-July its value varied from 0.21 to 0.27 MPa for the control while it dropped from 0.25 to 0.53 for the less watered regime. Midday xylem water potential was respectively 1.0 and 1.5 MPa for the control and restriction (I-II-III) treatments.
The extrapolation of the results obtained at the Mornag region to other Mediterranean regions is possible through the measurement of the water status of trees.
At Mornag-INAT, a reference station is established for the continuation of experimental work on deficit irrigation practices.

<u>Research theme 2:</u> "Deficit irrigation of pistachio with different fertigation practices"
<u>Pilot area:</u> Southeast Anatolian Region, Turkey
<u>Partner:</u> Çukurova University, Faculty of Agriculture, Adana, Turkey
<u>Objectives:</u>
save water in irrigated agriculture through deficit irrigation practices,
optimize nitrogen use and fertigation practices
improve irrigation water productivity of pistachio.

<u>Programmed Activities:</u>
Collection of available climatic data
Characterization of the soil of the selected region
Experiment on a pistachio orchard with restrictive irrigation treatments, having water cuts down to 30% and different fertigation programs
Monitoring of the soil-water status, plant growth, morphology, phenology and gas-exchange
Quantification of water savings
Preparation of “Deficit Irrigation Guidelines"
Dissemination of results and “Guidelines” and meetings with pistachio growers held by the “Pistachio Research Institute” Extension-Service of the Region

<u>Deliverables:</u>
Project Reports
Deficit Irrigation Guidelines related to Fertigation Practices

<u>Results and Conclusions:</u>
Although pistachio is traditionally cultivated under rainfed conditions, it significantly increases yield even under deficit irrigation. The response to deficit irrigation is enhanced by the use of fertilizers in the irrigation water (fertigation).
Irrigation and fertigation decreased the shedding of reproductive bud compared to traditional practice in 2001. It can be expected that higher yields can be obtained in the irrigated treatments in the following year.
There were significant statistical interaction between irrigation and nitrogen both affecting yield in 2001. The maximum yield was taken from $I_{f2}N_3$ treatment. In 2002 it could not be found significant relation between yield and nitrogen amount.
Stomatal conductance of *Pistachio* does not respond to VPD of the atmosphere while shows a response related to leaf water potential;
Although potential rates of net photosynthesis of 50 mol m^{-2} s^{-1} were observed under full CO_2 and light saturation, actual values of no more than 20 mol m^{-2} s^{-1} were measured for the treatments receiving high nitrogen and high water applications ($I_{f1}N_3$90);
the net photosynthesis of the “Traditional” leaves was at least 32% lower than $I_{f1}N_3$90;
the rate of photosynthesis was strictly linked to the stomatal conductance which ranged between about 0.1-0.2 mol m^{-2} s^{-1} of the “Traditional” treatment and about 0.4 mol m^{-2} s^{-1} of the $I_{f1}N_3$90 one;
irrespective of the treatments date of measurement and leaf sampled the sub-stomatal CO_2 partial pressure remained significantly constant around 200-220 mol mol^{-1}. This is an indication of the *Pistachio* ability to maintain an optimum balance between stomatal opening and photosynthetic rate;
Due to the inference reported in the previous two points, the photosynthetic WUE of *Pistachio* was always held constant in average around 2 mol $mmol^{-1}$ irrespective of treatments date of measurements and leaf sampled.
The results of this experiment highlighted that pistachio can achieve the maximum yield with 30% less water than the full irrigation requirements provided that fertigation is applied.

<u>Research theme 3:</u> "Hydraulics performances of irrigation systems under different irrigation practices"
<u>Pilot area:</u> Ghezala - Teskraya Irrigation District, Tunisia

Partner: Institution de la Recherche et de l'Einsegnement Supérior Agricoles (IRESA)

Objectives:

to understand the farmers behaviour by monitoring the irrigation system and by applying models able to simulate different scenarios;
to develop a tool aiming at identifying the failure areas in the system and the importance of such a failure;
to improve the capabilities of managers and operators of irrigation systems in identifying the problems and related solutions for improving the irrigation system performance.

Programmed Activities:

Data collection on climate, hydrology, irrigation network characteristics, demand hydrograph, cropping pattern.
Analysis of data and realization of relevant thematic maps.
Development of models for the performance analysis of the irrigation scheme.
Application of models for performance analysis of the irrigation scheme
Identification of possible improvement of the system performance
Development of criteria for improving management of irrigation system.
Dissemination of results.

Deliverables:

Quantify the degree of performance of the irrigation system.
Define criteria for the identification of critical zones
Developed criteria for management of irrigation system.

Results and Conclusions:

The degree of performance of the Ghezala system has been defined in respect to the relative pressure deficit and reliability. The following criteria for identification of the critical zones were adopted: no risk when relative pressure deficit > 0 and reliability >90%; failure risk at the farm level when relative pressure deficit is between -1 and 0 and reliability between 50 and 90%; failure risk at the water distribution network level when relative pressure deficit <-1 and reliability<50%.
1000 demand hydrographs flowing through the network have been analyzed corresponding to the discharges from 200 to 750 l/s. The best performances were observed with the discharge of 200 l/s when 20 hydrants out of 147 had reliability lower than 50% and 61 out of 147 had relative pressure deficit lower than -1 indicating permanent dangerous failure of the system. The worst performances were observed with the discharge of 750 l/s when about 50% of hydrants had reliability lower than 50% and almost all hydrants (139 out of 147) had permanent pressure deficit problems.
In order to improve the performances of the water distribution network, new technology for the delivery system can be used ("ACQUACARD") allowing irrigation only during the night when discharges are lower than 200 l/s. Also, the rehabilitation of the network (by increasing pipe diameters) may be considered.
The application of the software "Analyse du reseau" for the analysis of pressurized irrigation systems (developed during the realization of the project) and the integration of the results of software analysis in GIS demonstrated the usefulness of these tools in the performance analysis of irrigation systems with large number of data.

Research theme 4: "Innovative approach for energy saving in irrigation systems"
Pilot area: Souss-Massa Irrigation District, Morocco
Partner: Ministère de l'Agriculture, du Développement Rural, des Eaux et Forets (MADREF - Morocco)

Objectives:

set up an innovative methodology for reducing energy cost for the operation of the system;
quantify the energy saving; and
improve the social conditions of farmers by reducing the water price.

Programmed Activities:

Data collection on the demand hydrograph, on the energy consumption and on the physical characteristic of the network
Set up a data-base on the demand hydrograph, on the energy consumption and on the physical characteristic of the network
Development of a methodology (including a software package) for the energy saving in irrigation districts serving by pumping station

Application of such a methodology to the "Ait Amira" irrigation scheme
Quantification of the energy saving
Dissemination of results.

Deliverables:
A software package
Data-base on energy consumption and on the physical characteristic of the network
Quantification of energy saving

Results and Conclusions:
Unfortunately, during the Cairo meeting in January 2002, it was decided to interrupt the activities at this site due to difficulties to establish the contacts with the coordinators of the pilot area Souss-Massa in Morocco.

Research theme 5: "Reuse of treated wastewater for irrigation of cereals, forage and vegetables by means of different irrigation methods"
Pilot area: Drarga, Agadir, Morocco
Partner: Institut Agronomique et Vétérinaire Hassan II, Agadir, Morocco
Objectives:
To promote the use of treated waste effluents as an additional water source for irrigation;
To set new strategies for management to reduce risks for degradation of environment;
To establish an association of users of treated wastewater;
To establish an irrigation network to supply each farmer or a group of farmers with treated effluent;
To demonstrate water and nutrient saving and productivity of irrigated forage, vegetables and cereals crops and to convince the farmers on the safety of treated water.

Programmed Activities:
Collection of meteorological data (rainfall, temperature, ETo)
Plant productivity and product quality
Monitoring of nitrogen balance for each crop.
Evaluation on the performance of the different irrigation systems (water distribution efficiency, clogging, etc.)
Quantification of water and nutrient saved for each cropping system.
Evaluation of alternated use of freshwater and treated effluent water.
Development of guidelines on the use of epurated water for different cropping systems.
Dissemination of results

Deliverables:
Guidelines for optimal use of non-conventional water resources in irrigation
Setting strategies for the recycling and re-use without any environmental and health hazards
Water saving potentiality through reuse of non-conventional water resources
End-Users participation and creation of water user association for non-conventional water resources
Cost benefit analysis for the use of Non-conventional water resources

Results and Conclusions:
Yields were doubled for almost all plants when irrigated with treated wastewater (tomato, maize, green beans). The WUE was the highest for the plants receiving 120%ETM.
The alternation of saline water with treated wastewater has increased the WUE and has reduced by 50% the total nitrogen lost under treatment irrigated with treated wastewater.
The economic analysis of the reuse of treated wastewater allows farmers to reduce the cost of the fertilizers inputs saving up to 350 Euro/ha depending on the crop. This could be a great incentive for the promotion on recycling treated wastewater in agriculture.
The amount of water saved is estimated to 185,500 m^3/year for the community of Drarga. This water saving could reach up to 20 millions m^3/year at the regional level of Agadir which is about 10% of the conventional water resources.
The studies on cereals demonstrate that supplemental irrigation stabilizes bread wheat yield under arid condition of Morocco - there is a three times increase of grain yield of wheat when the amount of water increase from 100 mm to 300 mm. Plants growing under rainfed condition yielded almost zero production. If water is the limiting factor, and land is available, it appears more effective to use treated waste water as supplemental water source at a rate of 200 mm.

The nitrate concentration in the groundwater is reduced by 70% when sewage water is treated before used for agricultural purposes. The percentage of diarrhea in the rural community of Drarga is reduced by 80%.
Tertiary wastewater treatment could meet the environmental goals, but didn't match the crop nutrition requirement.

Research theme 6: "Recycling of drainage water for sustainable irrigated agriculture"
Pilot area: Harris- Behira Govenorat, Western Nile Delta, Egypt
Partner: NWRC - Cairo, Drainage Research Institute, Delta Barrages, Egypt

Objectives:

To test different management practices by using recycled drainage water for irrigation;
To monitor the impact of drainage water reuse options on crop yields and characteristics, soil salinity and salt distribution, groundwater quality and water use efficiency; and
To develop a drainage water reuse guidelines.

Programmed Activities:

Collection of meteorological data (rainfall, temperature, ETo)
Plant productivity and product quality
Physiological data related to photosynthesis, evapotranspiration, water potential and osmotic potential under different treatments.
Evaluation of the performance of the different irrigation treatments with non-conventional water.
Impact on soil characteristics, soil physical properties.
Quantification of water and nutrient saved for each cropping system.
Development of guidelines on the use of drainage water for irrigation.
Dissemination of results

Deliverables:

Guidelines for optimal use of drainage water resources in irrigation
Setting strategies for the recycling and re-use without any environmental and health hazards
Water saving potentiality through reuse of drainage water resources
End-Users participation and creation of water user association for drainage water resources.

Results and Conclusions:

Using of drainage water (EC=4.3 dS/m) and available saline water in the experimental area (mixed water with EC=3.5 dS/m), did not result in any significant difference in the yield of both crops under investigation. However, the yield was about 40% lower than under conditions of irrigation with the fresh Nile water of 1.2 dS/m.
The leaching fraction used in the pilot area is very large (about 0.4) to overcome salinity problems. The proper leaching fraction has to be determined for each area according to its irrigation water quality and soil characteristics (salinity-drainage condition).
Salinity distribution along the soil profile showed no trends and no significant changes. Sometimes there is salinity build up on the top soil layer rather than the lower layers, which may be explained by the fact that salts are moving up from lower layers to the top soil layer during the dry period between irrigation intervals and during the non-irrigation period at the end of the season.
The drawbacks of use of non-conventional water in irrigation could be accepted if we consider the social impact, since without irrigation with drainage water and/or available saline water source, at least 50% of this area would be without any agricultural activity.
New strategies to overcome negative effects of the use of non-conventional water resources should include an appropriate crop rotation with the crops of different salt tolerance degree.
There is a high potentiality of using drainage water successfully in irrigation assuring the presence of a good quality water source to meet the leaching requirements and to be alternated with the low quality one according to the salt sensitivity of the crop growth stage. This could lead up to 60 to 70% saving in the fresh water and in elimination of negative impacts on soil productivity. Those are crucial conditions to get benefits of each drop of drainage water in irrigation particularly under Egyptian conditions, where drainage water is present in enormous quantities (around 15 billion m^3) - nearly one-third of the fresh water allocated for agriculture.
The process of development of the water user association at the experimental area is going on, but, this requires time and support of different agencies.
The guidelines for drainage water reuse consists of agricultural, environmental and socio-economic parts which recognizes different aspects of use of non-conventional water in irrigated agriculture.

Research theme 7: "Sustainable use of highly saline water for irrigation of crops under arid and semi-arid conditions"
Pilot area: Experimental Station of Agricultural Structures and Irrigation Department of Çukurova University, Adana,
Partner: Çukurova University, Faculty of Agriculture, Adana, Turkey
Objectives:

- to investigate new strategies of using saline water for crop production under arid and semi-arid conditions;
- to obtain the characterization of the plant growing parameters of investigated varieties as a function of irrigation with saline water of different salt concentration levels;
- to evaluate the yield production and yield loss in relation to the salt concentration level of irrigation water;
- to assess the salt balance under different irrigation programs;
- to classify the investigated crops with respect to their salt tolerance degree;
- to obtain the suitable leaching fractions for getting high yield from investigated crops and non-salinisation of soils irrigated with saline water.

Programmed Activities:

- Collection of meteorological data (rainfall, temperature, ETo)
- Plant productivity and product quality
- Physiological data related to photosynthesis, evapotranspiration, water potential and osmotic potential under the different treatments
- Evaluation on the performance of the different irrigation systems (water distribution efficiency, clogging, etc.)
- Impact on soil characteristics, soil aggregate stability using "Henin" method.
- Quantification of water and nutrient saved for each cropping system
- Evaluation of alternating freshwater with Non-conventional water during the sensitive stage
- Development of guidelines on the use of epurated water for different cropping systems
- Dissemination of results

Deliverables:

- Guidelines for optimal use of saline water in irrigation
- Setting strategies for the recycling and re-use without any environmental and health hazards
- Water saving potentiality through reuse of saline water resources
- End-Users participation and creation of water user association for Non-conventional water resources
- Cost benefit analyses for the use of saline water resources

Results and Conclusions:

- There is no statistically significant difference between the irrigation of wheat with waters with EC of 0.5 (fresh water), 3.0, 6.0, 9.0, and 12.0 dS/m: grain yields ranged from 5940 to 6484 kg /ha, dry-matter yields varied from 1154 to 1349 g/m^2 and harvest index varied from 0.36 to 0.42.
- Highest soil salinity was observed in the 0-10 cm soil layer in treatments with ECw of 12 dS/m and 12 dS/m+10% leaching as ECe=4.3 dS/m.
- Highest average SAR was determined in the top layer of soil as 9.74 in the treatment irrigated with water of 9.0 dS/m, followed by 12.0 dS/m treatment as 7.53 and 7.11 dS/m in the treatment irrigated with 12 dS/m +10% leaching. SAR values increased with increasing salinity of irrigation water.
- WUE ranged from 1.286 to 1.444 kg/m^3. As the salinity level of irrigation water increased WUE values also increased slightly.
- Saline irrigation water can safely be used for irrigation of wheat crop in the Mediterranean region because of effective winter rainfalls leach the salts out of the root zone as long as an efficient drainage system is provided.

Research theme 8: "Development of screening legumes and forage nursery for salinity tolerance"
Pilot area: ICARDA, Aleppo, Syria
Partner: International Center for Agricultural Research in the Dry Areas (ICARDA)
Objectives:

- to screen lentil and chickpeas varieties available at ICARDA and National Programs for salinity tolerance;
- to test 10 to 20 varieties of each under greenhouse condition for plant characterization and yield quantity and quality;

Programmed Activities:

Phase 1: Bench screening, available varieties of lentil, chickpeas, and at least one selected forage legumes will be test for three salinity levels 3, 4-5, 8 dS/m. This test will be conducted with three treatments:

Dry seed with three salinity levels and control

Pr-soaked seed with fresh water and then with three salinity levels

X-rated seed to study the impact of x-ray on plant salinity tolerance as dry seed and pre-soaked seed with three salinity levels and control.

Phase 2: Greenhouse screening study: top 10 to 20 (upon availability of varieties) varieties will be tested with the same above treatments under greenhouse (controlled condition).

Phase 3: (continuation of research at the field level depends on availability of funds) Top 3-5 varieties to move for field-testing at the farmers field

Dissemination of results

Deliverables:

Salt tolerance of lintel, chickpeas and some forage crops.

Tested varieties of lintel, chickpeas and some forage crops and their appropriate agronomic practices in cotton- and wheat-based rotations.

Degree- and/or non degree-training opportunities in the field of crop and water salinity management in collaboration with the CIHEAM-IAMB.

Results and Conclusions (concerning the phase 1):

The in-vitro screening of 200 lentil and 205 chickpea varieties indicated that the chickpea varieties were more saline tolerant than the lentil varieties. Pre-soaking of the seeds in water with a very low salt content (EC 0.5 dS/m) substantially improved emergence, shoot growth, and survival of the species at the higher salinity levels.

Chickpea showed a reduction of the emergence percentage between the control and the most saline treatment of respectively 13 % and 18 % for chickpea and 10% for vetch.

During early seedling, salinity affected the development of the seedlings that showed symptoms of water stress. These symptoms could be observed in the form of leaf water potential, pod number and weights, and water content.

Chickpea varieties F.89-74, F.87-59 and ICCV2 may be categorized as ion excluders or includers depending on their responses to salinity. However, these properties varied according to the cultivar when subjected to the different levels of salinity. Generally, salt tolerant varieties are capable of growing at relatively higher salinity levels as compared with the salt-sensitive cultivar F.97-265 (Flowers et al., 1977). Cultivars F.97-74, F.87-59 and ILC 3279 were found to have higher salt tolerance and produced more dry matter than F.97-265.

Vetch has a more severe reaction to salinity than chickpea, which is confirmed by growth and yield. The effect on growth and yield was more pronounced for vetch than for chickpea.

To better understand the difference of responses on osmotic adjustment and water use efficiency, additional greenhouse experiments in sand and soil need to be conducted for chickpea; vetch and lentil genotypes. The top 2 genotypes of each crop should susbequently be tested in the field. Similar observations should be made in the field as in the greenhouse. Soil salinity, the EC and average chloride concentration of soil water, and the chemical composition of soil water should also be analyzed.

IV. COMMENTS

The programmed activities are realized at 7 out of 8 experimental sites. They were not completed only at the site of Souss-Massa (Morocco) due to continuos problems to establish contacts with the local coordinators. The WASIA research project focussed on the integration of know-how, research finding and experiences gained in the three research networks of IAMB (WUE, CIS and NWRM), through which possible water saving in irrigated agriculture could be achieved. At each experimental site, the activities are carried out allowing for the interaction between different aspects of water saving elaborated by each of research networks. E.g. in the case of the research themes 1 and 2, water saving strategies have included deficit irrigation at different growing stages (WUE-Net) together with the use of low quality (saline) water (NWRM-Net) and its impact on the performance of irrigation systems (CIS-Net). In the case of research theme 5, the use of treated wastewater (NWRM-Net) is analysed considering the alternation of different irrigation strategies during the growing season (WUE-Net) and application of furrow, sprinkler and drip irrigation systems (CIS-Net), etc. The overall scheme of integration of activities concerning to three research lines of the collaborative research network is presented in Figure 1 which illustrates different layers of interaction for each research themes. The implementation of the project as such integrated approach has allowed for the creation of a conceptual framework which takes into consideration different aspects of water saving in irrigated agriculture of the Mediterranean region.

The research project WASIA has contributed in the integration of the collaborative research network activities under one umbrella at different sites in the Mediterranean region which has resulted in an increased exchange of research findings and available information, development of new data-bases, different research techniques and application of updated technologies. Such outcomes, along with wide experiences and ample information available at the institutions involved in the research program, will certainly increase the competence of decision makers and research staff in the developing countries of the Mediterranean and help in the setup of comprehensive strategies for water saving in irrigated agriculture.

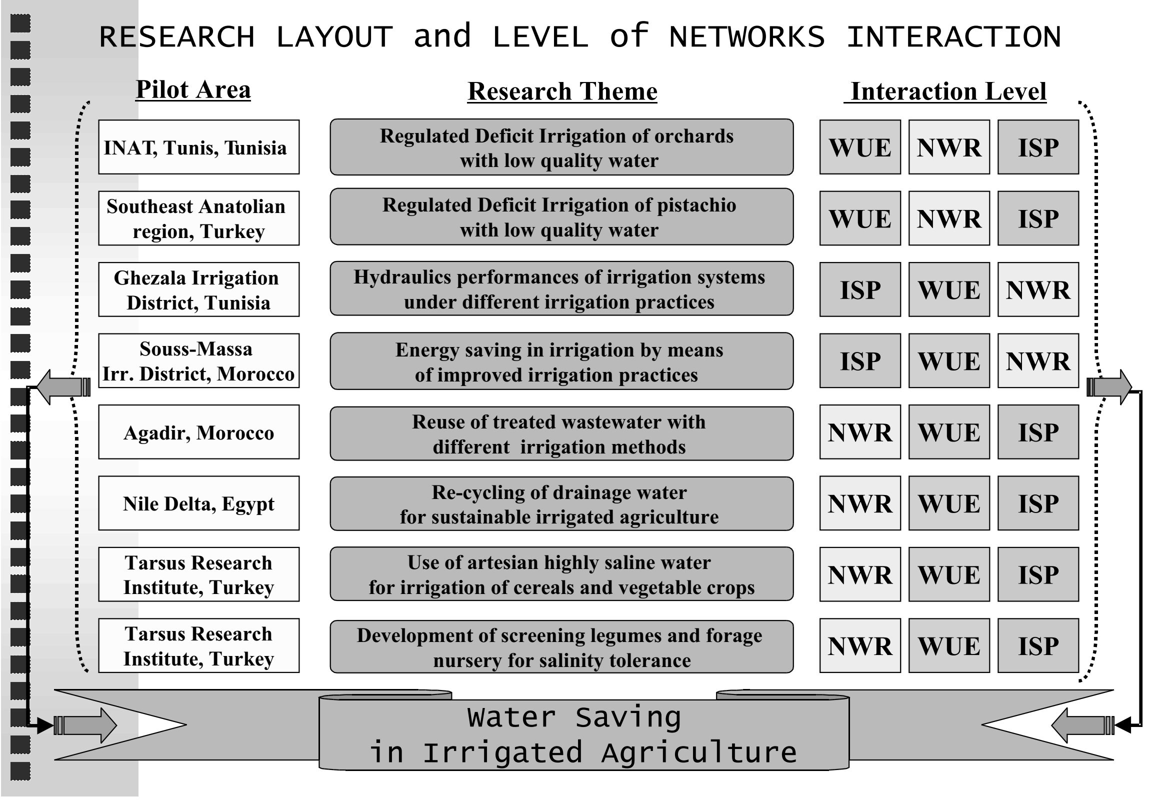

Fig. 1. Conceptual framework for water saving in irrigated agriculture

The deliverables of the project include many important tools which were missing in the most of developing countries in the region (e.g. guidelines for deficit irrigation strategies, guidelines for optimal use of treated wastewater, saline water and drainage water in irrigation, new databases on water demand, software packages, geo-referenced databases, etc.). Moreover, at some sites (Morocco, Egypt and Tunisia), the experiments were carried out in cooperation with the farmer's associations and also at the private farms which is of particular importance because it facilitates the transfer of the research findings to the direct water users and contributes to the implementation of new management strategies on the ground. In Tunisia, at experimental site of Mornaq (INAT), a reference station has been established for the continuation of experimental work on deficit irrigation practices. At the Ghezala - Teskraya Irrigation District (Tunisia), the first test of a new technological tool ("ACQUACARD") for improvement of the performances of pressurised irrigation systems has been done. In Turkey, at the "Pistachio Research Institute", several meetings with pistachio growers were held presenting the deficit irrigation strategies with different fertigation practices. In Egypt, at Harris-Behira Governorat (Western Nile Delta), the process of development of the water user association has initiated. All these achievements and outputs of the project should represent a strong basis for the setup of a new policy and an integrated program on water saving in the region focusing not only on technical but also on socio-economic and environmental aspects of water management. Certainly, it should contribute in better management of land and water resources as well as the development of sustainable agriculture production and food security in the Mediterranean region.

ANNEXE

PUBLICATIONS 1998-2002

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