Water Benchmarks
of CWANA project

8

Improving water and land productivities in rainfed systems

Editors

Mohammed Karrou, Theib Oweis and Abdeljabar Bahri

ICARDA International Center for Agricultural Research in the Dry Areas

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Community-Based Optimization of the Management of Scarce Water Resources in Agriculture in CWANA

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EXECUTIVE SUMMARY

Climate change has led to more severe conditions throughout the world as well as in Morocco. In general, rainfall has declined and average temperatures have increased. These new rainfall patterns are threatening water supplies. Fluctuations and reductions in annual rainfall have led to severe and frequent droughts throughout the Central and West Asia and North Africa region. Consequently, water resources have become scarce. Increasing municipal and industrial demand for water has resulted in steadily decreasing allocations for agriculture. The major agricultural use of water is for irrigation, which is therefore most affected by decreasing supplies. Therefore, innovations are needed to increase efficiency in the use of the water that is available.

The main objective of the project is the adoption by farming communities of strategies and tested technologies that optimize the conjunctive use of rainwater and scarce water resources in supplemental irrigation systems for improved and sustainable water productivity in rainfed areas. This requires the development of technological, institutional and policy innovations, using an integrated and participative approach, which is the specific objective of the research activities conducted at the benchmark site in Morocco.

The project started in 2004 with an overview of previous research and on-farm trials on irrigation water management and water-use efficiency in Morocco. This helped identify the potential technologies to be tested. Then, based on agreed criteria, the benchmark site at Tadla was chosen and characterized by analyzing existing bio-physical data together with socioeconomic information collected during meetings and two participatory workshops, at which farmers and farmers' associations were the main participants.

The participatory workshops also helped identify the two representative communities of the Tadla irrigated area and the group of farmers with whom the on-farm trials were conducted. Research, dissemination and capacity-building activities were conducted from 2004/05 to 2007/08.

To test and evaluate new techniques and technologies that can improve water productivity under supplemental irrigation systems, various on-farm trials were conducted. The aspects studied were:

1. Evaluation of improved surface irrigation and crop management packages in wheat and sugar beet:

In this case, three treatments were compared: 1) farmers' usual irrigation and farmers' usual crop management; 2) improved surface irrigation with farmers' crop management; and 3) improved surface irrigation and improved crop management package.

2. Effect of planting date on wheat land and water productivity under supplemental irrigation conditions:

In these trials, two sowing periods were generally compared – the first week of November and the first week of December.

3. Identification of wheat varieties adapted to supplemental irrigation:

The cultivars chosen were Achtar and Mehdia (bread wheats) and Tomouh and Marjana (durum wheats). During the fourth season, four other varieties were added, because they were introduced into the region by the seed company; these were Salama and Radia (bread wheats) and Carioca and Vitron (durum wheats). The experiments were conducted on six farms in the region.

4. Nitrogen (N) fertilizing of wheat under supplemental irrigation:

The N rates chosen to compare with the average amount usually used by farmers (around 140 kg N/ha), were 60, 120 and 180 kg N/ha.

5. Deficit irrigation in wheat:

The options that were tested were: 1) irrigation at 70% of field capacity (FC); and 2) irrigation at 100% of field capacity. These two options were compared with the farmers' usual practice.

6. Effect of planting date on sugar beet production:

Seven and twelve farmers who planted at different periods were selected in the first and second seasons, respectively, and data from their plots were collected. These farmers were divided into three groups according to planting period – early, intermediate and late. So, there were no on-farm trials, per se.

7. Improvement of the technical package of drip irrigation and fertigation in citrus:

This experiment was conducted during the 2005/06 and 2007/08 seasons in a farmer's citrus orchard in the Bradia area of the project. The test consisted of applying a pre-established irrigation and fertigation program on one part of the orchard, and the farmer's usual practice on another part as a check.

In all these trials, yields and water application and use were measured and water productivity was calculated. Moreover, the data collected from these experiments on wheat and from the surveys and interviews with the farmers participating in the trials, and their neighbors, were used to evaluate the economic impact and adoption of the technologies, using marginal analysis.

In addition to the technical and economic evaluation of the technologies, the current water policy and institutional set-up in Morocco was described and future perspectives were identified.

Other project activities were the dissemination of information and improved technologies, capacity building and publications.

The results of the on-farm trials showed that, in general, there were differences in the performance of farmers in managing water and crops. It seemed that those who were previously involved in the Regional Agricultural Development Authority (Office régional de mise en valeur agricole, ORMVA) extension programs did better than the others.

The experiments with the water and crop management packages showed that both yield and water productivity (WP) of wheat and sugar beet obtained using improved irrigation and crop management were in general higher than those using the farmers' usual practice. Wheat and sugar beet performed better when they were planted early. In wheat, biomass, grain yield and water productivity were improved by 20%, 26% and 29% during the first cropping season; by 35%, 45% and 15% during the second year; and by 26%, 20% and 50% when the crop was sown in early November. This technique also saves irrigation water because the plants escape the late rainfall deficit that enhances irrigation water demand and increases with late planting.

The study to validate the CropSyst model showed that there was a high and positive relationship between observed and simulated wheat yield and evapotranspiration (R2=65–70). The model predicted an increase in grain yield of 1000 kg/ha with a planting date as early as 15–20 October. The effect of deficit irrigation (70%) on yield was not significant in 2006/07. In variety tests, the difference between the genotypes used was in most cases not significant, although Tomouh (durum wheat) and Achtar tended to be more productive. This shows low genotypic variability. No significant differences were observed between the different nitrogen rates on wheat. This is probably due to the effect of the preceding crop. In fact, sugar beet that in most cases precedes wheat, receives high amounts of N and a significant part of it remains in the soil and is used by the wheat. At all farms and for the three cropping seasons, deficit irrigation (70% of field capacity) gave as much yield as full irrigation (100% of field capacity). This result was also confirmed using the CropSyst model. Yield was only reduced in one case (one farm and one year). However, this technique saves up to 1200 m^3 of irrigation water.

From the experiment on drip irrigation scheduling of citrus, we can conclude that 1) applying the new irrigation program saved 2788 m^3/ha and 2060 m^3/ha of water in the first and second season of the experiment, respectively; and 2) applying more water does not necessarily mean producing significantly more crop. In the first season, we obtained 31.8 t/ha under the irrigation program versus 35.6 t/ha using the farmer's practice. In the second year, yields increased from 38 t/ha for the farmer's practice to 45 t/ha with our program. So, water productivity was significantly higher for the irrigation program compared to the farmer's practice. Finally, the farmer has to choose between producing more, but lower quality, fruit with more irrigation water or producing less but good quality fruit, with less water.

Economic evaluation of the technologies showed that 1) the economic performance of some technologies, such as nitrogen rate, changes from year to year due to rainfall fluctuation and the amount of residual N in the soil (after sugar beet) making the technology recommendation process very difficult; 2) the new durum wheat varieties are more water-use efficient than bread wheat varieties; 3) early sowing period can be one of the best water-use efficient technologies to recommend to farmers in the two communities; 4) in all cases the change in technologies offers a rate of return above 100% (considered as a minimum rate of return acceptable to farmers); and finally 5) the adoption of the new technologies tested implies substantial increase in farmers' net benefits (between 110 and 222%) because of the very high agronomic performance of these technologies.

As far as policy issues are concerned, it was shown that in spite of the relatively good performance of irrigation systems in term of improved water-use efficiency in Morocco, the water scarcity and increasing demands from other water users have compelled the Moroccan decision-makers to set up new policies and strategies to save water and make better use of the resource. However, there are still deficiencies in the implementation of the new laws and procedures. Consequently, water is still overused and the gap between the potential land and water productivity and that obtained at the farmers' level remains high. To overcome these problems, there is a need to implement the new laws on water pricing to save water and its quality, for the wide dissemination of water-saving and better crop management techniques, for crop diversification and the introduction of new crops with high added value such as fruit orchards, vegetables and industrial crops.

In terms of water management at Tadla, data from on-farm trials, surveys at the farm level and interviews with stakeholders and decision-makers have shown that supplemental irrigation is one technique that can save water and improve its productivity without reducing yields. However, this technique requires flexibility in water allocation and since irrigation water is managed by the Administration at the perimeter level, it is difficult to match irrigation scheduling with the critical stages of the crops. The ideal solution is for each farmer to control their own water and so be able to irrigate at the right time. This solution can only be afforded by producers who have their own wells and they are very few. The alternative that can benefit most farmers who get their water through ORMVAT (Tadla Regional Agricultural Development Agency, Office régional de mise en valeur agricole de Tadla), is to group planting time and hence, the periods of the crops' critical growth stages and supplemtal irrigation application. For this reason, ORMVAT should develop (it has already started) a policy of encouraging and promoting early sowing by the majority of farmers at the same time. Another option is that the State should use funding to encourage the construction of small reservoirs by individuals or groups of farmers, so that they will be able to store water when it is available and use it for supplemental irrigation at critical stages.

Studies on the adoption of technologies by farmers showed that the rate and degree of adoption of some technologies, such as suitable varieties and early planting adapted to supplemental irrigation, were high by the end of the project. However, this trend was observed more in farmers involved in the on-farm trials than in those who participated in field days. So, more intensive diffusion of the information is needed.

Parallel to the research work conducted at the Tadla Rainfed Benchmark site in Morocco, complementary studies were conducted in Syria, Algeria and Tunisia. In Algeria, activities concerned the use of treated wastewater for supplemental irrigation in wheat production. Results are promising since they showed the positive effect of supplemental irrigation on grain yield. However, the use of this technique requires more investigation into the quality of the treated water before its dissemination. In Syria, the evaluation of supplemental irrigation (SI) and the adaptation of new technologies in wheat production showed that SI improves water productivity and adopters of this approach to irrigation achieved higher net returns compared to non-adopters. However, the use of surface irrigation techniques still dominates and the adoption of new and water-saving techniques (sprinkler, drip irrigation) is still low.

In Tunisia, it was shown that methodologies based on functional relationships between crop yield and transpiration rates are most suitable for qualitative analysis on the role of water as a main limiting factor for cereal production. A model using precipitation and potential evapotranspiration data is proposed as a tool for exploring options for improving rainfall use efficiency at a regional level.

Background

Water scarcity in West Asia and North Africa (WANA) is a well-known and alarming problem. Today the issue is of increasing concern to national governments and research institutions. Increasing water scarcity is threatening the economic development and the stability of many parts of the region. At present, agriculture accounts for over 75% of the total consumption of water. However, with rapidly growing demand it seems certain that water will increasingly be reallocated away from agriculture to other sectors. Moreover, opportunities for the significant capture of new water are now limited. Most river systems suitable for large-scale irrigation have already been developed. Few major resources of renewable groundwater remain untapped and current resources are subject to overexploitation, with extraction exceeding recharge rate in many cases.

While gains in efficiency are potentially available from improved distribution and use of water in fully irrigated agriculture, a great proportion of the region's agricultural livelihoods are based on dryland farming systems where production is dependent on low and extremely variable rainfall. The challenge in rainfed areas is to enhance productivity through improving on-farm water use efficiency and supplementing rainfall either through water harvesting or the strategic use of sources of renewable water to augment essentially rainfed production. However, conventional practices, which have been developed for managing water under normal water supply conditions, are not suitable under conditions of water scarcity. The need for special management of water under conditions of scarcity, based on maximizing the return from each unit of water available for agriculture, now applies to almost all the countries of WANA.

Technologies for improved management of scarce water resources are available. However, many of these technologies are not widely implemented or are not seen as feasible by farmers. This can be attributed to a number of constraints, including technical, socioeconomic and policy factors, but most importantly the lack of community participation in the development and implementation of improved technologies. This project is based on community participation in research and the development, testing and adaptation of improved water management options at the farm level.

The project consisted of three main components: the *Badia* Benchmark site in Jordan, with two satellite sites in Saudi Arabia and Libya; the *Rainfed* Benchmark site in Morocco, with three satellite sites in Tunisia, Algeria and Syria, and the *Irrigated* Benchmark site in Egypt, with two satellite sites in Sudan and Iraq.

Objectives and outputs

The main long-term development goal of the project is to achieve sustainable and profitable agricultural production in the dry areas of WANA based upon the efficient and sustainable management of the scarce water resources.
To reach this goal the project developed and tested, *with community participation*; water management options that increase water productivity, optimize water use and which are economically viable, socially acceptable and environmentally sound.

The research concentrated its activities in the three benchmark sites. Each benchmark site was linked to satellite sites as indicated earlier. These satellite sites were designated to complement the research of the benchmark.

The five main expected outputs of the project are:

1. Strategies and tested technologies for the optimal conjunctive use of rainwater and scarce water resources in supplemental irrigation systems adopted by farming communities for improved

and sustainable water productivity in the rainfed areas on WANA
2. Suitable water harvesting techniques to capture and efficiently utilize rainwater runoff in more productive and sustainable agricultural systems integrated and adopted, by people in the WANA drier environments.
3. Techniques and systems that optimize water productivity in irrigated systems, including water management, alternative crops and use of different water sources developed.
4. Alternative improved policy and insituitutional options recommended.
5. Capabilities of national programs and the integration of researchers, extension personnel, farmers and decision-makers in a regional program for sustainable management of water resources enhanced.

The project approach

The project approach is based on five principles: the participation, the integration, the complementarities, the multi-disciplinary and multi-institutions and socio-economic analysis.

a) Community participatory based approach
The project uses an integrated approach, based on community participation. At each site, the local community is a full partner in planning, implementation, monitoring, and evaluation. Farmers work with scientists and extension staff to test a range of "best-bet' technologies and select those that best meet their needs-often adopting the technologies to suit local conditions. This created a sense of 'ownership', leading to rapid adoption of technologies that were found to be effective and relevant.

b) Integrating technologies with policy and institutions
The project addressed problems from a technical, socioeconomic, cultural, institutional, and policy perspectives, with the full participation of the intended beneficiaries and other stakeholders.

c) Benchmark and satellites sites (complementarities)
Benchmark sites were established in the three agro-ecologies (rainfed areas, the *steppe* and irrigated areas) to study these issues. At these benchmark sites, water use was addressed at different levels: household, community, watershed and policy level. Each of these benchmark sites are linked to several ***satellite*** sites as indicated in the previous section.

The benchmark sites represent the majority of the conditions in the above three agro-ecologies. However, some conditions and issues in the region related to the natural resources, the environment and/or the socioeconomics may not be apparent in the benchmark site and thus are addressed in the ***satellite*** sites. Examples include water quality, special soil conditions and local water related policies and institutions.

d) Multidisciplinary, multi-institutions
The project approach requires a multidisciplinary and inter-institutions teams, involving many different research disciplines, to understanding the current situation and to developing and testing water-use efficient technologies under farm conditions.

e) Socioeconomic analysis and community participation
Socioeconomic surveys that characterize the communities involved in the project sites have been conducted in order to identify the main technical, social, economic and environmental problems that constraint the community livelihood improvement. The surveys also focused on the water resources available at the community level and how they deal with this resource. The surveys' results established the base line information for the project target areas and communities. Following that, the community participated in the development of the work plan and the intended interventions that the project would introduce. A community action plan was developed and implemented by the project with full participation of the community.
A community-based participatory monitoring

and evaluation (PME) system was developed in the first phase. The PME involves local people in deciding how progress should be measured, in defining criteria for success and in determining how results should be acted upon. It will strive to be an internal learning process that enables local people to reflect on past experience, examine present realities, revisit objectives and define future strategies by recognizing differential stakeholders' priorities and negotiating their diverse claims and interests.

Technical and socioeconomic indicators of progress and impact were developed during the commencement workshop and were implemented by the project teams. Major indicators include the level of adoption by communities of the introduced technologies.

Rainfed benchmark and satellite sites

Morocco has experienced several years of drought and is suffering from severe water scarcity. The national agricultural research program is aggressively searching for ways to overcome the problem of water shortages, and many options for using existing resources more efficiently have been explored. The option of implementing supplemental irrigation on a large scale as a more efficient practice than conventional irrigation has been explored by researchers at the national level. The focus is on integrating supplemental irrigation into rainfed farming systems, and transferring the approach to other areas of the region. Although supplemental irrigation is the focus of research, all water-related issues and cropping systems using advanced technologies are being investigated in an integrated manner in the Tadla irrigated perimeter of Morocco, chosen as the typical rainfed benchmark site.

The project is conducted by the National Institute of Agronomic Research (INRA) of Morocco and the International Center for Agricultural Research in the Dry Areas (ICARDA). The other partners in the project are the Regional Agricultural Development Authority (Office régional de mise en valeur agricole) of Tadla (ORMVAT) and the Directorate for the Development and Management of Irrigation (DDGI). Financial support was provided by the Arab Fund for the Economic and Social Development, the International Fund for Agricultural Development and the OPEC Fund for International Development.

In 2004, an integrated research program was designed with the participation of the local population, institutions and decision-makers, to insure the integration of new technologies into the local farming systems.

During 2005, the selected sites and communities were characterized. The main constraints to the adoption by farmers of efficient water-use options were identified and analyzed. Field trials were conducted in 2005, 2006 and 2007 and focused mainly on improving water productivity by introducing new technologies such as high-water-use-efficient varieties, supplemental irrigation for some annual crops, deficit irrigation, and drip irrigation in citrus.

Satellite sites were selected and used for complementary research in Algeria, Syria and Tunisia.

Chapter 1: Irrigation water management in Morocco: a review

Chapter 1: Irrigation water management in Morocco: a review

H. Berdai, M. Karrou, M.T. Chati, M. Boutfirass and A. Bekaoui

1.1 Introduction

The Moroccan climate is classified as semi-arid to arid. It is characterized by low and highly variable precipitation. More frequent droughts occurring during recent decades have led to increased water insufficiency.

Under conditions of water scarcity, the development of irrigation management techniques that increase and stabilize crop production and save water is a potential adaptive strategy to combat climate change. Since the 1960s, the Government of Morocco has placed the highest priority on the development of irrigation capacity. Many dams have been built and the irrigation network has been extended and modernized. However, there is still a gap between the size of the total potentially irrigable areas and the equipped (with infrastructure for irrigation) areas (CSEC, 2001). In 2004, this gap was estimated at 123,000 ha and the fully irrigated area at 1,016,000 ha, representing only 13% of the total cropped land (AGR, 2004). Irrigated agriculture contributes 45% of the added agricultural value during normal seasons and 70% during dry seasons. It provides more than 33% of employment in rural areas and 75% of agricultural exports. Irrigation contributes significantly to rural development, food security and combating the effects of the recurrent droughts the country is experiencing (AGR/DDGI, 2002a).

Irrigation then, is an essential and strategic choice for economic and social development. The potential perennially irrigated area is estimated at 1,266,670 ha, taking into account water resources mobilization (AGR, 2004). However, this potential remains limited in comparison to the potential needs of the country. In addition to the hydraulic infrastructure needed to extend irrigation, the best use of water resources requires the implementation of technical and regional policies to intensify production and improve water-use efficiency in irrigated areas (AGR/DDGI/DE, 1995).

The best use of irrigation water is reflected in the strategic approach of the Ministry of Agriculture and the major research objectives of institutions working on sustainable irrigation management. Related research programs can be summarized as follows:

- crop water requirements;
- irrigation techniques, especially surface irrigation;
- irrigation scheduling; and
- soil and water quality as affected by irrigation and drainage.

The droughts that Morocco has experienced since 1980 have reduced the average annual rainfall by 21% (Barakat and Handoufe, 1998). The frequency of dry years (below annual average rainfall) increased from 10% in 1940–1980 to 30% and 50%, respectively, for the1980s and the 1990s (Barakat, 2000). Given the national potential water resources, which are limited and erratic, and the high frequency of dry years, Morocco is undergoing a severe water deficit from year to year (Table 1.1 CSEC, 2001). Indeed, according to the World Bank (1995), an estimate of supply and demand in a water balance analysis shows that Morocco will experience a severe water shortage in less than 20 years' time (water resources < 350 m^3/inhabitants/year). Water shortages will be more severe in the Souss-Massa perimeter where the water table decreases by 0.5 to 2 m each year (CSEC, 2001) than in the other irrigated areas of the country.

Water quality is also becoming a serious problem due to human activities. Water pollution generated by the urban, industrial

Table 1.1: Water balance (mm^3) between resources and demand in 1994 and by the year 2020.

Hydraulic basin	1994			2020		
	Resources	Demand	Balance	Resources	Demand	Balance
Loukkos, Tangérois and Mediterranean coast	795	390	405	1285	1030	255
Moulouya	1355	1310	45	1430	1610	-180
Sebou	2280	1805	475	4940	3860	1080
Bou Regreg and Atlantic coast of Casa	520	425	95	785	765	20
Oum Er Rbia and Atlantic coast of Safi	3535	2780	755	3940	3815	125
Tensift and Bengrir	1230	1245	-15	1860	1610	250
Souss-Massa	1005	1055	-50	1175	1340	-165
Guir, Ziz and Rheris	545	665	-120	695	720	-25
Drâa	510	625	-115	580	640	-60
Sahara	10	5	5	20	15	5

Source: CSEC (2001).

and agricultural sectors reduces water availability, poses a health risk for the population and threatens the socioeconomic development of the country (DGH, 2002).

Under conditions of increasing water scarcity and deteriorating water quality, saving and protecting water resources has become the highest priority for development institutions and the main objective for research organizations and programs in Morocco (AGR/DDGI/DE, 1995; AGR/DDGI, 2002a; DGH, 2002). In fact, the High Council for Water and Climate (CSEC) during its ninth session 'Water Management and Saving', recommended an increase in water productivity, and a change in the popular perception of water use through the management of demand and the rationalization of consumption (CSEC, 2001).

Following these recommendations, the Ministry of Agriculture launched a multi-dimensional strategy and a workplan aiming at the rational use of irrigation water and its valorization in irrigated areas using a participatory approach. Actions implemented under this strategy are institutional, technical, economic, and educational. They target water-saving and environmental protection through the rational use of agrochemical inputs (fertilizers, pesticides) and improved irrigation management (AGR/DDGI, 2002a). Therefore, the research program focuses on themes related to water management and natural resources management, including:

- improvement of water application in the field;
- conversion of surface irrigation to localized irrigation techniques that save water;
- supplemental irrigation;
- sewage water treatment and reuse; and
- impact of irrigation on natural resources quality.

These activities have been supported directly by national funds and by many bilateral or multilateral cooperation projects.

The purpose of this report is to synthesize the principal results of the demonstration trials conducted in Morocco in general and in the Tadla region in particular, on irrigation water management of the main crops. The idea is to identify the best agricultural management practices, including irrigation, which make it possible to reconcile the increase in land and water productivity with the sustainability of farming systems on the one hand, and water saving on the other.

1.2 Crop water requirements and supplemental irrigation management

1.2.1 Research activities

Experiments on crop water requirements started in 1951 in many irrigated areas of Morocco. Initially, soil water content was measured using the auger (gravimetric) method. This period produced interesting results on the main growth stages of crops, the changes in their water consumption (ETR) and the sensitivity of their different growth stages to water availability.

In the second phase, starting in 1975, drainage lysimeters were introduced in some experiments to measure maximum evapotranspiration (ETM). ETM was used to differentiate water treatments and estimate crop water consumption. This method permitted the fine tuning of the results obtained by the gravimetric method and the development of crop coefficients (Kc) and crop production functions for some crops.

Analysis of results obtained by AGR/DDGI/DE (1995) showed that:

- Of a total of 240 trials conducted at different experimental stations, 133 (55.4%) were on the determination of crop water requirements, including 45 trials (18.7%) on actual evapotranspiration (Eta) and 88 (36.6%) on ETM.
- Experiments conducted on deficit irrigation, irrigation at sensitive stages and supplemental irrigation totaled 107 (44.6% of the total number of trials).
- Among the 240 trials, 134 (55.8%) were conducted in the Tadla perimeter and 37 (15.4%) in the Souss-Massa region; 77 of these trials were on cereals, 105 on industrial crops (sugar beet, sugar cane and cotton), 33 on vegetables (especially in Souss-Massa), 21 on forages and 4 on citrus (exclusively in Souss-Massa).

The most important results confirmed in several trials on wheat, sugar beet, alfalfa, cotton, vegetables and citrus are presented.

1.2.2 Wheat

Cereal crops cover an area of 5 million hectares (averaged from 1992–1996), representing 70% of the total cropped area in Morocco. About 92% of the cereal area is in rainfed zones under arid or semi-arid conditions with highly erratic annual rainfall varying from 200 to 400 mm (Chati et al., 1999). Dry episodes are very common and frequent with differing intensities from one period to another and from region to region. They generally lead to a significant reduction in crop production. A positive correlation was observed between cereal grain yield and rainfall (Barakat et Handoufe, 1998). To overcome this problem and improve and stabilize yields in these areas, irrigation is one of the most recommended solutions.

Crop growth and irrigation management

In Morocco, irrigation of wheat is supplemental to precipitation. Such irrigation is applied to overcome the delay or lack of precipitation during the growing season in order to sustain crop water needs. It is a crucial factor, regulating and controlling production both in terms of quantity and quality.

Therefore, wheat yield improvement depends on targeting irrigation to the most important stages insofar as the crop expresses specific water needs for given growth stages. Any lack of water during these sensitive stages compromises production. Under such conditions, high-yielding varieties adapted to irrigation will not express their production potential.

In addition to a knowledge of crop water requirements, irrigation management in wheat requires the identification of growth stages that are sensitive to water shortage. Irrigation of this cereal has been mainly studied in the Tadla area.

Crop production in Tadla

Cereals are the dominant crops in the Tadla perimeter (43.5% of the area). The annual production is 360,000 tonnes, representing 5% of the national production average from 1998 to 2002. Changes in the cropped area show a net increase in bread wheat and a decrease in durum wheat. This is due to changes in the culinary habits of the population and the high productivity of bread wheat varieties, but more importantly, to the strategy of subsidies for this crop launched by the Government in the early1980s.

Wheat/sugar beet is the dominant rotation in the Tadla region. Vegetable crops and alfalfa are also planted after cereals.

Wheat is generally planted after the first rains in autumn. However, if a summer crop is to be sown after wheat, a technique of pre-planting irrigation, locally called *demkel*, is practiced to enable wheat to be planted early. In the Tadla region, 60% of wheat plantings take place in December and 33% in January. Early (November) and very late plantings (end of January to beginning of February) are rare.

Harvesting starts in May and finishes in mid-June, when grain moisture is around 10%. The crop cycle takes approximately 160 days.

Stages of growth

The growing cycle of wheat can be divided into four main stages limited by clearly distinguishable stages that reflect the physiological age of the plant. These stages are: 1) Germination–beginning of stem elongation; 2) Beginning of stem elongation–heading; 3) Heading–milky grain; and 4) Grain maturation. The four stages have different sensitivities to water stress. Conclusions drawn from experiments conducted at Ouled Gnaou Station in Tadla perimeter on a clay–silty soil (Handoufe et al., 1987) indicated that:

- During germination–stem elongation stage of wheat, changes in soil moisture show that water absorption is slow and is limited to the top 40 cm because the root system is still at the juvenile stage. During this vegetative stage, wheat can tolerate moderate water stress, because of the stimulation of root development and the resultant increased water availability to the plant from lower soil layers. This explains the ability of wheat to resist drought during the tillering stage (Handoufe et al., 1987). In many cases, the plants can rely on rainfall alone to satisfy their water requirements during this stage provided germination and emergence are ensured.
- The critical period for wheat is the reproductive stage (beginning of stem elongation–flowering). During this stage, plant water requirements increase. Water absorption usually starts from the top layers that dry out first. Any water stress that occurs during this stage, especially around anthesis, causes sterility of the spikelets and a reduction in kernel number. When water stress is severe, it can destroy the whole crop. A 50% moisture reduction from ETM during this stage can decrease yield by 45%. This sensitive period usually coincides with moisture deficit and hence irrigation is one of the options to supply the needed water.
- Wheat is also sensitive to water deficit during the grain maturation stage. Any water stress that happens before the dough stage induces grain shriveling because of the high climatic evaporation that usually occurs during this period of the year. It is recommended that measures be taken to avoid water stress during the 10 days of the dough grain stage.

Phenological data have been accurately observed during 24 crop cycles at Ouled Gnaou Station in Tadla. Most of the data concern semi-late bread wheat varieties with planting dates from mid-November to mid-January. In terms of crop development, no significant difference was noticed between bread and durum wheats. However, planting dates and climatic conditions have an effect on the duration of growth stages (Table 1.2).

From ten years' data on wheat varieties with planting dates ranging from 17 November to 4 January, a net variation in the duration of different growth stages was observed depending on climatic conditions. These stages can last from 54 to 72 days for stage I, 22 to 44 days for stage II, 24 to 39 days for stage III and 24 to 44 days for stage IV (SID, 1987).

Table 1.2: Duration of growth stages in wheat at Ouled Gnaou, Tadla.

Planting dates	Time length in days				Cycle in days
	Stage I	Stage II	Stage III	Stage IV	
15 November	60	45	35	35	175
1 December	60	30	40	35	165
15 December	60	30	40	35	165
1 January	60	30	35	35	160
15 January	60	25	30	35	150

Stages: I) Germination–beginning of stem elongation; II) Beginning of stem elongation–heading; III) Heading–milky grain; and IV) Grain maturation. Source: SID (1987).

At the same time, the effects of temperature, water and nitrogen on wheat growth stages were investigated (Handoufe et al., 1987). The authors found that water and nitrogen supplies at booting delay the heading time.

Crop coefficient and net water requirement

Experiments carried out at Tadla on irrigation management in wheat, measuring ETM and class A pan evaporation to determine the crop coefficient (Kc), gave the following Kc values (Chati et al., 1995):

- Stage I: average duration of 60 days, Kc = 0.70;
- Stage II: average duration of 30 days, Kc = 0.75;
- Stage III: average duration of 40 days, Kc = 0.80; and
- Stage IV: average duration of 35 days, Kc = 0.45.

Irrigation trials conducted at Ouled Gnaou experimental station in Tadla have shown that water consumption wheat varied from 340 to 420 mm depending on planting dates (SID, 1987). While ET cannot be covered by rainfall in all cases, late planting carries higher risks of exposing wheat to rainfall deficits and increases the share of irrigation to cover the crop's total water requirements. On average this share was about 50% of ET (170 mm) for early plantings and 70% (290 mm) for late plantings.

Irrigation scheduling

The results of supplemental irrigation management trials at Ouled Gnaou can be summarized as follows (SID, 1987):

- Based on the local average annual rainfall and wheat water requirements, a standard supplemental irrigation amount of 80 mm is recommended
- Generally, three irrigations are recommended for early planting and four irrigations for late planting. In both cases, the first irrigation should be given after planting. A second irrigation is needed in March at the heading stage and the third irrigation to be applied in April when the grain reaches its mid-milky to mid-dough stage. Two irrigations are recommended during April for late planted.
- Only wheat planted in January requires irrigation in early May.
- Irrigation may be stopped at least one month before harvest, i.e., at early-dough stage to avoid weed germination and grain quality damage.

Total irrigation needs amount to 2550 to 3400 m^3/ha, i.e. 3 to 4 irrigations of 850 m^3/ha each are required to cover the net irrigation water needs of wheat (165 to 300 mm), depending on the planting date.

Supplemental irrigation

Supplemental irrigation is a technique that consists of applying small quantities of water during critical periods to improve and stabilize yield, save water and balance low water availability with a sustainable production level.

In Morocco, supplemental irrigation has been studied in a number of experiments in many regions such as Chaouia, Abda, Doukkala, Saiss, Gharb and Tadla, mostly in cereals (Karrou and Boutfirass, 2001). The results show that supplemental irrigation alleviates water deficit, increases wheat yields and improves water-use efficiency (Boutfirass 1990, 1997) (Table 1.3).

However, yield increase is closely correlated with the growth stage of the crop at which water is applied. Results show that water supplied at the pre-anthesis stages had more effect on yield than that at post-anthesis. Moreover, irrigation at tillering leads to yield improvement and post-anthesis irrigation valorization (Table 1.4).
If it is possible to apply more water to the crop, the best way to manage this is to target the three critical stages of wheat (tillering, heading, grain filling) by applying 60 to 70 mm at each stage (Table 1.5).

Similar results were reported by Chati et al. (1999) in a supplemental irrigation project (1990–1995). Therefore, we would suggest one, two or three irrigations at the most for wheat in areas under similar conditions, depending on water availability (AGR/DDGI, 2002b).

Based on above studies, the following may be concluded:

- When there is a rainfall deficit early in

Table 1.3: Effect of supplemental irrigation on water-use efficiency (kg grain/mm/ha) in wheat (60 mm water supplied at various growth stages).

Year Rainfall	1988/1989 341 mm	1989/1990 332 mm	1990/1991 342 mm	1991/1992 247 mm
Treatment				
Rainfed (no irrigation)	14.90	13.10	11.82	4.99
Irrigation at Tillering stage	19.10	13.90	15.25	9.78
Irrigation at Heading stage	18.00	16.10	12.85	6.28
Irrigation at Grain filling stage	16.10	13.40	12.26	3.93

Source: Boutfirass (1990, 1997).

Table 1.4: Effect of different supplemental irrigation regimes on grain yield and total biomass (kg/ha) of wheat.

Cropping season Annual rainfall	1993/1994 307 mm		1994/1995 129 mm	
	Grain yield	Total biomass	Grain yield	Total biomass
Water regime				
Rainfed	1815	7667	616	3000
T30*	1923	9583	1041	4088
H30	2321	8611	1072	4000
T60	2532	11917	1432	4688
H60	2795	9750	713	2938
T30+H30	2394	10583	795	3500
T90	3559	12000	1667	5938
H90	2936	9139	1309	3188
T45+H45	3025	11333	1418	5125
T120	5177	15445	2153	6750
H120	3125	10138	1444	4438
T60+H60	3129	11611	1821	4938

*T: Tillering, H: Heading stages; 30, 45, 60, 120 irrigation water (mm) supplied at the corresponding stage.
Source: Karrou (1999).

Table 1.5: Effect of supplemental irrigation at tillering, heading and grain filling (60 to 70 mm each stage) on wheat grain yield (kg/ha).

Region and rainfall	Water supply (mm)	Grain yield (kg/ha)	Reference
Chaouia, 332 mm	180 mm	6712	Boutfirass 1990
Saïss, 460 mm	180 mm	7908	Belbsir 1990
Tadla, 302 mm	220 mm	8722	Karrou et al. 1993

the season, a first irrigation at planting or during tillering should be applied. The general rule adopted in these trials is to apply water whenever there is less than 35 mm of rain during the first 10 days after planting. Such irrigation allows the wheat's requirements to be met, ensuring growth and development up to the booting stage. This irrigation is more efficient when it is combined with early planting. Any water deficit during this stage leads to a yield reduction. Drought characterization studies conducted by Barakat and Handoufe (1998) in the main cereal cropping areas of Morocco emphasized the importance of irrigation at planting in cases of water deficit. In fact, rain deficit from December to February is a good indicator of agricultural drought;

- When there is a soil moisture deficit during booting–flowering, supplemental irrigation needs to be applied, since the crop is mostly sensitive to water stress during this period. Indeed, any lack of moisture during this stage causes a 40% reduction in yield; it is the stage where the main yield component, kernel number, occurs;
- When it is possible to apply more water, then a third irrigation can be applied before the grain dough stage. But such irrigation does not increase yield all the time. Its efficiency is influenced by rainfall conditions and planting dates. Such an irrigation can be recommended after flowering in deep soils and after milky grain in shallow soils.

Cultural practices adapted to supplemental irrigation

Crop variety

Research work that was conducted in the arid and semi-arid zones of Morocco (Boutfirass 1990, 1997; Chati et al., 1995; Laaroussi, 1991; Lahlou, 1989) concluded that the criteria that should be taken into account when choosing varieties that use water more efficiently are:

- rapid vegetative development
- high harvest index
- fitting the crop cycle with the rainy season

Water-use efficiency and grain yield and its stability can also be improved if drought resistant varieties are used. These varieties are characterized by their earliness, rapid soil covering, high rate of grain filling, remobilization of assimilates from the shoot to the grain under drought conditions, stability of grain number per spike, and capacity to maintain transpiration under water stress (Karrou and El Mourid, 1994). Among varieties resistant to terminal drought, are Merchouch 8, Kanz, Arrihane, Achtar and Amira in bread wheat and Marzak, Oum Rabia, Acsad 65 and Yasmine in durum wheat.

Planting date

Early planting (November) is recommended in arid and semi-arid areas. It allows the crop to benefit from autumn rainfall, cover the soil early, meet maximum water needs during the rainy season and escape terminal drought. It has been shown that early planting allows better control of water deficit (Table 1.6, Baidada, 1989).

Table 1.6: Evapotranspiration and water deficit under different planting dates of wheat in two regions of Morocco.

Planting dates	Saïss region			Chaouia region		
	10 Oct	20 Nov	1 Jan	10 Oct	20 Nov	1 Jan
ETM(1) (mm)	382	498	540	379	473	523
ETa(2) (mm)	294	318	294	272	274	242
Water deficit (1) (mm)	88	180	247	108	199	281
WDI(3) (%)	23	36	46	28	42	54
CR (4). (%)	77	64	54	72	58	46

(1) ETM = Maximum evapotranspiration, (2) ETa = Actual evapotranspiration, (3) WDI = Water deficit index, (4)CR = Covered requirement. Source: Baïdada (1989).

Significant increases in water-use efficiency, water use and grain yield were obtained (Tables 1.7 and 1.8). A percentage yield increase from 25 to 50% was seen with early as compared to late planting (Karrou and El Mourid, 1994).

Seeding rate

Studies on seeding rates (from 200 to 500 seeds/m²) showed that the optimum rate under supplemental irrigation is 300 seeds/m² (Table 1.9).

Table 1.7: Effect of planting date and water regime on wheat grain yield (kg/ha).

Water regime	Planting date			
	1–5 Nov	20–25 Nov	10–15 Dec	1–5 Jan
125 mm	5754	5287	4745	2478
70 mm	4856	4090	3454	1817
45 mm	4256	3537	2944	1479
Rainfed	3492	2447	1966	1063

Source: Bahaja (1994).

Table 1.8: Effect of planting date on water-use efficiency (WUE), water use (WU) and grain yield of wheat (GY)

	1984/85 (384 mm rainfall)			1985/86 (286 mm rainfall)		
	WUE kg/mm	WU mm	GY kg/ha	WUE kg/mm	WU mm	GY kg/ha
November, 1st week	9.8	286	2801	12.2	295	3570
December, 1st week	7.2	251	1818	12.8	285	3630
January, 1st week	6.1	226	1375	6.0	244	1470

Source: Bouchoutrouch *(*1993).

Table 1.9: Effect of seeding rate on yield (kg/ha) of wheat under supplemental irrigation.

Seeding rate seeds/m²	Grain yield* (kg/ha)	Biomass* (kg/ha)	Grain yield** (kg/ha)	Biomass** (kg/ha)
200	–	–	6067	14381
300	4409	9868	6948	15087
400	4530	11140	6023	15648
500	4330	12793	6175	16078

Sources: *Bahaja (1994) with 60 mm irrigation; **Aït Yassine (1995) with 170 mm irrigation.

Nitrogen application
Nitrogen (N) application under supplemental irrigation improves wheat yield and water-use efficiency (Karrou, 1992). However, the management of applications is a problem. For instance, the application of N late in the season (after booting) may increase the protein content of the grain more than grain yield.

In the case of supplemental irrigation early in the cycle, an early application of nitrogen is recommended to benefit from the available soil moisture after planting. Fertilizer rate and time of application depend on the soil and climatic conditions of the region, supplemental irrigation regimes and the targeted yield.

Under the conditions at Tadla and a 3-irrigation regime (at tillering, booting and flowering), an application of 80 kg N/ha gave an optimum yield of 6800 kg/ha for early planting (first week of November) and 5800 kg/ha for late planting (late December to early January). The check (with no nitrogen) gave only 4500 kg/ha. An application of 120 kg N/ha did not increase yields significantly more than 80 kg N/ha (Chati et al., 1995).

Nitrogen application is appropriate early in the season (winter time) when temperatures are still low. Indeed, soil N measurements in the Tadla region have shown that during spring and summer, plant nitrogen requirements could be obtained from the soil, because thermal and moisture conditions favor mineralization of soil organic matter (Handoufe et al., 1992).

1.2.3 Sugar beet

Sugar beet covers about 13% of the agricultural area in Tadla and the preceding crop is usually wheat. It produces 670,000 tonnes, representing 23% of the national production (average of 1998–2002).

Trials with irrigation on sugar beet have been conducted since 1961. The results obtained at the Ouled Gnaou experimental station (Tadla) are summarized in the following sections (SID, 1987; Chati et al., 1999).

Crop production and irrigation management

Crop production

- Sugar beet is planted in October (30% of the area), November (43%), December (21%), and January (6%)
- Sugar beet is harvested between May and August
- The crop duration depends on the planting date (Table 1.10). Early planting leads to a longer cycle.

The growth cycle of sugar beet is characterized by four stages, the length of each stage depending on the planting date (Table 1.11).

Table 1.10: Vegetative life cycle duration as affected by the planting date

Planting date	Vegetative life cycle
Early planting (Sep–Oct)	276 to 240 days
Normal planting (Nov–mid-Dec.)	230 to 210 days
Late planting (end Dec–Feb)	190 to 170 days

Source: Chati et al. (1999).

Table 1.11: Duration of growth phases in sugar beet

Planting date	Duration of growth phases (days)			
	Establishment I	Pre-tuberization II	Tuberization III	Maturation IV
Early planting	48	86	70	30
Normal planting	89	28	78	–*
Late planting	81	38	70	–*

*Missing data. Source: Chati et al. (1999).

The duration of the tuberization stage in early planted sugar beet is longer than when the crop is planted normally or late. However, late planted crops have a longer establishment stage. This behavior of the crop depends on the prevailing climatic conditions. Cold winters and cool autumns, respectively, induce the reduction or activation of physiological activities and so extend or shorten the duration of the crop's growth cycle.

Water stress can be measured using the leaf weight/root weight ratio which is a good indicator of growth and development conditions (Table 1.12). Under favorable conditions variations in this ratio are not significant; showing a high correlation between the activities of the top part of the plant and the roots. On the other hand, when water is limiting, the ratio increases because sugar beet shoots rather than roots are then favored.

Table 1.12: Impact of irrigation on sugar beet growth

Treatments	Irrigation water (mm)	Leaf area index	Leaf weight /root weight
A	215	2.8	0.34
B	305	2.9	0.23
C	350	3.9	0.17
D	435	4.9	0.16

Source: Chati et al. (1999).

Evapotranspiration

Maximum evapotranspiration (ETM) in different crop cycles (early, normal and late) depends on the prevailing climatic conditions and the physiological activities of the crop. The water consumption regime varies with the development stages.

Maximum water consumption for sugar beet varies from 690 mm to 1220 mm. On average, it is 770, 870 and 940 mm for early, normal and late plantings, respectively (Table1.13).

In early plantings, ETM is high during the establishment phase (3.6 mm/day). It decreases during winter to a minimum of 1.6 mm/day before increasing in spring to reach a maximum value of 6.3 mm/day in early summer.

Table 1.13: ETM (mm) of sugar beet during different crop cycles

Cycle	Planting date	Total ETM (mm)
Early	21/10/86	884
	21/10/86	747
	01/10/86	735
Normal	21/11/82	870
	15/11/83	794
	17/11/94	690
	17/11/94	760
Late	11/12/83	708
	21/12/84	793
	11/12/86	1219

Source: Chati et al. (1999).

Crop coefficient

During the establishment and maturation phases when the plant's physiological activity is low, Kc is less than 1. However, during spring when physiological activity increases and temperatures are higher, Kc increases up to 1 (Table 1.14)

In early plantings Kc is relatively high compared to other planting dates, showing that conditions are optimal and the crop does not need any regulation. However, late planted crops are affected, because their cycle starts during winter and continues during periods of high climatic demand.

Table 1.14: Crop coefficients of sugar beet for different planting time

Crop phases	Planting dates		
	Early	Normal	Late
Establishment	0.94	0.83	0.68
Tuberization	1.00	0.94	0.87
Maturation	0.77	0.88	0.75

Source: Chati et al. (1999).

Supplemental irrigation

In 7 out of 10 cropping seasons, 7, 8 or 9 irrigations were needed to satisfy sugar beet water requirements, depending on the planting date; with the lowest irrigation numbers under early planting.

Irrigation water volumes varied from 4200 to 5400 m^3/ha, depending on the planting time, for the vegetative period of sugar beet that lasts between 245 and 215 days. The total quantity of water at the plot level varied from 5950 to 7650 m^3/ha.

Trials conducted on sugar beet since 1984 have shown that yield is greatly affected by climatic conditions (Chati et al., 1999) and by the number and frequency of irrigations (Table 1.15).

Table 1.15: Yield of sugar beet under different rainfall and irrigation conditions

Planting date	Number of irrigations	Rainfall (mm)	Yield (t/ha)
15/12/84	12	142	104
03/12/85	3	247	36
20/10/86	3	193	56
08/10/88	3	346	91

Source: Chati et al. (1999).

An analysis of Kc and the irrigation calendar shows two phases that are sensitive to water conditions. These are phase 1, which is the planting–tuberization phase (a wet period) and phase 2, that is the tuberization–maturation phase (a dry period).

Irrigation during the establishment–tuberization phase

From 1986 to 1995 rainfall recorded during the establishment phase varied from 67 mm (1995) to 290 mm (1988) and the number of irrigations applied varied from 3 to 1. Reduction in irrigation during phase 1 affected the yield just slightly (Table 1.16, treatments B, C and D).

Using the same water limitations during phase 1 but with adequate water supply during phase 2, a recovery in growth occurs and yields improve (Table 1.17, treatments B, C, D). This result shows that it is possible to reduce irrigation water during phase 1 without affecting the yield too much, under limited water resources.

Table 1.17: Yield of sugar beet under different irrigation scenarios

Water treatments	Number of irrigations (Phase I)	Number of irrigations (Phase II)	Yield (t/ha)
A	3	3	66
B	2	5	75
C	1	6	73
D	1	5	64

Source: Chati et al. (1999).

Irrigation during the tuberization phase

During the tuberization phase the number of irrigations needed is higher during low rainfall and with a late planting date because then the growth cycle continues during the summer. This situation affects yield (Table 1.18).

Therefore, irrigation water limitation during tuberization significantly affects yields (Table 1.19).

So, water requirements of sugar beet are higher during the tuberization phase. The time of resuming irrigation during phase 2 affects the yield slightly (Table 1.20).

Sugar beet is a crop that can recover from early water stress during tuberization and restore its physiological activities. However, yield is much related to the time of beginning irrigation. Any delay in the second irrigation from its optimal time will certainly reduce yields. The optimal date for beginning irrigation depends on the planting date and rainfall.

Table 1.16: Effect of water stress on yield of sugar beet during phase 1

Water treatments	Number of irrigations (Phase I)	Number of irrigations (Phase II)	Yield (t/ha)	% Decrease in yield over A
A	3	3	66.3	–
B	2	3	63.3	5
C	1	3	54.6	18
D	1	3	51.7	22

Source: Chati et al. (1999).

Table 1.18: Effect of irrigation and planting date on yield of sugar beet

Planting date	Treatments	Phase I		Phase II		Yield (t/ha)
		Number of irrigations	Rainfall (mm)	Number of irrigations	Rainfall (mm)	
28/10/87	A	1	256	3	109	73
	B	1	256	4	109	77
17/11/94	A	1	67	4	76	67
	B	1	67	5	76	68
22/12/88	A	3	141	6	19	64
	B	2	141	5	19	59

Source: Chati et al. (1999).

Table 1.19: Effect of reduced water on yield of sugar beet during tuberization (one irrigation)

Planting date	Treatments	Phase I		Phase II		Yield (t/ha)
		Number of irrigations	Rainfall (mm)	Number of irrigations	Rainfall (mm)	
03/12/85	A_1	1	200	6	47	73.2
	B_1	1		4		59.6
	C_1	1		3		54.4
	D_1	1		5		64.2
	E_1	1		3		51.7
	F_1	1		2		36.4
22/12/88	A_2	1	141	6	19	64.3
	B_2	1		5		58.8
	C_2	1		4		64.1
	D_2	1		5		57.4
	E_2	1		4		49.0
	F_2	1		3		46.3

Source: Chati et al. (1999).

Table 1.20: Effect of the timing of the first and second irrigation on yield of sugar beet

Planting date and treatments	Total number of irrigations	Rainfall (mm)	Days between 1st and 2nd irrigation	Yield (t/ha)
24/10/89				
A	7	352	152	83.1
B	6		170	71.0
C	5		170	66.6
D	5		190	58.7
17/11/94				
A	3	144	174	37.4
B	4		159	53.8
C	5		144	66.7
D	6		128	67.8
E	7		113	67.5

Source: Chati et al. (1999).

Irrigation water use efficiency
Early and normal plantings are more efficient than late plantings in terms of irrigation water use (Table 1.21). However, an improvement in irrigation water-use efficiency was seen in crops that received a small amount of water compared to those that were fully irrigated, because of less water loss in the stressed treatments.

Table 1.21: Effect of irrigation amounts and planting date on water use efficiency (wue)

Planting date	Total amount m^3/ha	Yield (t/ha)	wue kg/m^3
	3870	104.0	26.9
08/10/1988	3320	94.9	28.6
	3100	86.6	27.9
	5430	64.3	11.8
17/11/1994	4670	58.8	12.6
	3870	64.1	16.6
	3910	67.8	17.3
22/12/1988	3570	66.7	18.7
	2900	53.8	18.6

Source: Chati et al. (1999).

The irrigation of sugar beet should be based on the two main phases, phase 1 or establishment–pre-tuberization and phase 2 or tuberization–maturation.

The number of irrigations depends on climatic conditions, especially rainfall. During the rainy season, sugar beet can tolerate irrigation deficits. In this case, resuming irrigation to secure optimal soil moisture during phase 2, allows the crop to compensate for the delay in growth without compromising yields.

1.2.4 Alfalfa

In Morocco, alfalfa is grown in all irrigated areas. It is adapted to different ecological and soil conditions. In the Tadla region, this forage legume covers around 18,000 hectares. It is the main forage crop grown in the area (72%).

Alfalfa is a high-yielding crop giving good quality hay. It has high nutritive value (high protein, mineral and vitamin contents) when it is harvested at the flowering stage. It is also considered as a good preceding crop for the other cultivated species.

Crop production

After dormancy or cutting, alfalfa undergoes three stages:
- vegetative recovery and bud growth
- rapid growth through elongation of inter-nodes
- growth reduction during the floral stage
- growth and flowering ending with fecundation and fructification

Alfalfa should be harvested/grazed during the early stages, when it produces high quality forage with high levels of protein and carotene. The best stage for harvesting the crop is during flowering. Production from spring harvests is higher than from other seasons. The same result can be achieved with autumn harvests, but longer intervals between cuttings are needed (Chati, 1991). The relationship between alfalfa production and evapotranspiration is summarized in Table 1.22, Corlier, 1977).

This table shows that, on average, alfalfa production decreases with age (especially in Sonora) and increases with the amount of irrigation.

Evapotranspiration

Alfalfa’s water requirements are very high due to:
- the very long active growth period of the crop, lasting 9–10 months per year under the Tadla conditions
- the large number of cycles per year, varying from 7 to 12 cuttings
- more than half of the crop’s growth taking place during the hottest and driest months of the year.

The average annual maximum evapotranspiration is around 1520 mm. It varies from 1400 to 1600 mm/year depending on the climate, cutting management and the age of the crop. Water requirements are at a minimum during January averaging 1.3

Table 1.22: Annual yield of alfalfa in relation to water consumption

Variety	Africaine				Sonora			
	Yield (t/ha)				Yield (t/ha)			
Years	100% ETM		80% ETM		100% ETM		80% ETM	
	Fresh	Hay 14%	Fresh	Hay 14%	Fresh	Hay 14%	Fresh	Hay 14%
1	101	25	70	18	50	7	25	6
2	152	38	112	28	160	40	117	29
3	115	29	118	30	108	27	102	26
4	–	–	–	–	102	26	82	21

ETM: maximum evapotranspiration. Source: Corlier (1977).

mm/day and at a maximum in June and July averaging 8.5 mm/day (Table 1.23) (Chati et al., 1999).

Crop coefficient

Trials conducted at Ouled Gnaou experimental station (Chati et al.,1999) led to the following conclusions:

- alfalfa is sensitive to water stress just after cutting
- the active phase, under Tadla conditions, is between the end of February and early December
- during the active phase, lasting 10 months, the number of cuttings (harvests) averages 7 to 8

For the better valorization of irrigation water, the use of crop coefficients should consider:

- soil coverage by the crop;
- the age of the crop;
- time and frequency of cuttings; and
- management (intensive or extensive).

The crop coefficient Kc varies from 0.70 to 0.85 depending on the period of the year:

- December, January and February : Kc = 0.70;
- March, April and May : Kc = 0.80;
- June, July and August : Kc = 0.85;
- September, October and November : Kc = 0.75.

Irrigation scheduling

Irrigation should be sufficient to wet the root zone, that is the top 40 cm layer during the first year and 80 cm layer during subsequent years. For the soils in Tadla, the average rate is 65 mm corresponding to a water level of 850 m^3/ha per irrigation.

Crop establishment

The following irrigations are recommended for good seedling establishment:

- one pre-irrigation for seedbed preparation before planting (*demkel*),
- one first irrigation after planting to ensure seed germination, and
- a second irrigation 8 to 10 days after the the one to ensure stand establishment.

After second irrigation, water application intervals should extend beyond 15 days, because the crop cannot extract water from deep horizons.

Transition period

In February, alfalfa moves into the active phase and a cleaning cut is necessary at this time. This cutting should be followed by irrigation in early March. After this irrigation, crop growth increases. Irrigations to supplement rainfall will then be necessary. Two irrigations in April and May and three in June are recommended. Experiments have shown the importance of spring irrigations in promoting alfalfa growth throughout the whole year.

Table 1.23: Average maximum daily evapotranspiration (mm/day) of alfalfa at Ouled Gnaou, Tadla

Months	Decade	Year 1	Year 2	Year 3	Year 4
January	1		0.5	1.3	1.5
	2		1.4	0.7	1.8
	3		1.7	1.7	1.5
	Total		37.7	38.7	49.5
February	1		2.1	1.7	2.7
	2		2.4	2.8	3.7
	3		2.0	1.6	3.6
	Total		61.0	57.8	92.8
Marsh	1		0.9	1.7	4.2
	2		2.4	2.1	4.0
	3		2.6	2.8	2.9
	Total		61.6	68.8	113.9
April	1	1.8	2.7	5.8	6.2
	2	1.9	3.2	5.5	7.3
	3	2.4	4.1	4.1	5.6
	Total	61.0	100.0	154.0	191.0
May	1	3.2	5.2	5.4	4.7
	2	3.5	7.0	5.7	5.6
	3	3.6	6.5	5.7	7.1
	Total	106.6	193.5	173.7	181.1
June	1	3.8	7.6	6.6	
	2	5.6	7.1	6.0	
	3	7.5	8.0	6.5	
	Total	169.0	227.0	191.0	
July	1	9.5	6.2	7.2	
	2	10.0	6.8	7.4	
	3	9.5	9.0	7.2	
	Total	299.5	229	225.2	
August	1	9.8	7.5	7.3	
	2	10.0	6.3	7.0	
	3	10.4	7.4	6.7	
	Total	312.4	219.4	216.7	
September	1	8.0	7.6	7.8	
	2	11.7	4.5	7.5	
	3	9.2	6.4	6.7	
	Total	289.0	185.0	220.0	
October	1	577	5.6	4.5	
	2	4.6	2.5	3.9	
	3	4,3	2.1	4.2	
	Total	150.3	104.1	130.2	
November	1	3.8	2.6	4.4	
	2	3.0	1.9	2.9	
	3	0.8	1.3	3.2	
	Total	76.0	58.0	105.0	
December	1	0.8	1.3	1.7	
	2	1.4	1.4	1.2	
	3	1.5	1.5	1.4	
	Total	38.5	43.5	44.4	
Total (mm)		**1502**	**1519**	**1625**	**628**

Source: Chati et al. (1999).

Summer period
During summer, water consumption in alfalfa is at a maximum and irrigation water-use efficiency is at its lowest. To cover the crop's water requirements during this period, it is better to irrigate very often with reasonable amounts of water.

In fact, widely spaced irrigations have two consequences: first, they induce rapid drying of the top soil layers forcing the crop to explore deeper horizons for water. This water depletion slows down growth and decreases production. Secondly, they favor soil cracking leading to higher irrigation rates that may reach 120 mm. A portion of this water is lost through macro-porosity.

Winter period
During the winter, alfalfa undergoes vegetative dormancy induced by the low temperatures. Its water consumption becomes low. In a normal year, rainfall is sufficient to cover the crop's water requirements during winter. A portion of the rain may be stored in the profile and be used later when the temperature is favorable for growth. In dry years, one irrigation a month is recommended during this season.

Time of stopping irrigation

Forage production
Flowering is the optimum stage for cutting. Irrigation is recommended after the emergence of the first flowers, i.e., one week before cutting. Irrigation should be stopped after this stage, because it does not produce any improvement in forage production.

Grain production
Many studies have shown that if the objective is grain production, irrigation should not be applied at flowering. This results in reduced leaf growth and hence favors grain production. To ensure good quality grains, the best time to supply water is at fecundation. The crop should then remain dry during grain maturation.

Irrigation optimization

Irrigation experiments (Chati et al., 1999) have shown that:
- alfalfa production increases with the number of irrigations – but not proportionately;
- the average maximum evapotranspiration (ETM) of the crop at maximum production is 1750 mm; and
- optimal production is obtained with the application of 70 to 85% ETM. This involves a 10% yield reduction for a 15% irrigation water saving (Table 1.24).

Table 1.24: Irrigation water saving and related yield reduction.

Level of coverage (%)	Reduction in dry matter production (%)	Reduction in economic income (%)
90	5	6
80	6	10
7	16	25
60	20	30
50	28	35
40	35	60

Source: Chati et al. (1999).

1.2.5 Citrus trees

Morocco is among the top 12 producers of citrus worldwide. In the Mediterranean region, it is among the three highest exporting countries. The main varieties cultivated are: Navel, Late Valencia, Sanguine and Semi-Sanguine, Mandarin and Clementine.

Citrus trees cover more than 75,000 hectares over the country. The production is mainly export-oriented.

Extension activities and programs in the citrus sector concentrate mainly on the improvement of cultural practices and the rehabilitation of orchards and introduction of new and competitive varieties.

Irrigation of citrus trees in the Tadla region is necessary because rainfall is low and erratic, temperatures are very high during summer and relative humidity is low.

Irrigation management

Surface irrigation

Traditional irrigation of citrus trees (*robta*) consists of irrigation in pits or dikes. An on-farm survey on farms where this technique is used, leads to the following conclusions:

- It is very difficult to achieve homogeneous distribution of water over the plot.
- Net water requirements are estimated at 12,000 to 17,000 m^3/ha/year.
- The irrigation rate is 750 to 850 m^3/ha per irrigation.
- Water loss at the plot level is estimated at 30 to 45% (PGRE, 2002).
- The frequency of irrigations depends on climatic conditions.
- For a normal year, irrigation is applied: 1) once every three weeks from the end of autumn to the beginning of spring; and 2) once every two weeks during the hottest months (June, July, August, and September). Consequently, the total number of irrigations a year is 15.
- This technique requires a lot of labor for irrigation and maintenance of canals, pits and dikes.
- It increases loss of fertilizer.

Given these problems, most citrus producers in the region would prefer to switch from surface irrigation to drip irrigation.

Drip irrigations

Trials conducted on drip irrigation in citrus trees in Morocco started with the regional project on supplemental irrigation (1990–1995) at two sites – one in the Souss-Massa region at the Taroudant experimental station and the other in the Tadla perimeter where two trials were installed, one on a farmer's field as a demonstration and one at the Ouled Gnaou experimental station.

The main objectives of these trials were to find the easiest ways of scheduling irrigation and to establish the crop yield response curves to irrigation water supply.

The main constraints to the application of this technique are:

- **Water sharing**: famers depend on irrigation water that is under the control of the local irrigation management authority (ORMVAT). Consequently, farmers do not have the freedom to decide when to irrigate and how much water to apply. The suggested solution to this problem is storage basins
- **Choice of the best equipment**: the efficient operation of the system requires a preliminary technical study to better assess the system's characteristics (type of nozzles, energy losses, flow, etc.).

Irrigation scheduling

Many studies have been carried out to compare the reference evapotranspiration calculated by methods other than the lysimetric method. Class A pan evaporation is suggested for irrigation scheduling (Bekraoui and Arfani, 2003).

Deficit irrigation of citrus

The treatments used in the trials conducted in the Souss-Massa region are presented in Table 1.25.

The results of irrigation water reduction are summarized in Table 1.26 (Abouali, 2003). These results show that:

- The average yield is low because the citrus orchards are still young.

Table 1.25: Water treatments in citrus.

Treatments	Annual crop cycle		
	January–March	May–August	September–December
T1	100%	100%	100%
T2	80%	100%	80%
T3	80%	80%	80%
T4	60%	80%	60%
T5	60%	60%	60%

Source: Abouali (2003).

Table 1.26: Water use, yield and agronomic efficiency of citrus trees

Season	Parameters		T1	T2	T3	T4	T5
1998/99	Water use	mm/ha	1607	1398	1286	1077	964
	Yield	t/ha	11.42	8.27	8.64	7.28	4.91
	Water productivity	kg/m³	0.71	0.59	0.67	0.68	0.51
1999/00	Water use	mm/ha	1795	1562	1436	1203	1077
	Yield	t/ha	14.6	10.86	10.22	6.78	6.25
	Water productivity	kg/m³	0.81	0.70	0.71	0.56	0.58
2000/01	Water use	mm/ha	1833	1595	1466	1228	1100
	Yield	t/ha	12.34	9.37	7.29	7.4	5.41
	Water productivity	kg/m³	0.67	0.59	0.50	0.60	0.49
2001/02	Water use	mm/ha	2130	1853	1704	1427	1278
	Yield	t/ha	16.13	16.45	14.85	14.04	13.02
	Water productivity	kg/m³	0.76	0.89	0.87	0.98	1.02
Average	Water use	mm/ha	1841	1602	1473	1234	1105
	Yield	t/ha	13.62	11.24	10.25	8.87	7.40
	Water productivity	kg/m³	0.74	0.69	0.69	0.71	0.65

Source: Abouali (2003).

- The average yield of two varieties (Late and Navel) over four seasons varies with the treatment. It is 7.4 t/ha for the least irrigated treatment and 13.6 t/ha for the most irrigated one. The corresponding water productivities are 0.65 and 0.74 kg/m³.
- Average water applications varied from 1100 to 1850 mm/ha.
- Water reduction in treatments T2 and T3 led to a slight decrease in yield and efficiency, as compared to the check (T1).
- Within the tested rates of water application varying from 964 to 2130 mm/ha, any water application results in increased production. The relation between yield and irrigation rates is a linear equation ($y = 0.0072 X$; $r = 0.81$).
- The whole growing cycle is sensitive to changes in the water regime, but the most sensitive period is between May and late August (T2 and T4).
- Irrigation water applications below 1500 mm/ha give yields lower than 10 t/ha; whereas, with 1500 mm/ha, yields are more than 12 t/ha.

1.3 Impact of irrigation on natural resources

1.3.1 Introduction

In the irrigated areas, intensification of crop production can lead to soil degradation – most commonly soil salinization, reduced organic matter content, soil compaction, and deteriorating structural stability. Soil resources are limited and non-renewable, so any degradation significantly affects their productivity.

In addition, aridity and drought make limited water resources even more. In irrigated areas, where the main aquifers are located, underground water resources can be affected by agricultural pollution, mainly due to inadequate irrigation management and the application of high rates of chemical fertilizers and pesticides. Groundwater contaminated by nitrates and pesticides also causes health problems in the rural populations using it for drinking. This water can also be subject to salinization due to salt leaching.

Reducing water and soil degradation is one of the most urgent priorities for the Ministry of Agriculture, besides saving water. Therefore, along with efforts and incentives made to save water and improve efficiency in irrigation, the Ministry of Agriculture has implemented many activities to protect water and soil resources.

1.3.2 Status of natural resources (water and soil)

Status of water resources

A study conducted under the National Plan for the Protection of Water Quality (PNPQRE, 2002) showed that intensive agriculture is a very important source of groundwater pollution. However, its impact on surface water is less marked.

Of the 29 main aquifers surveyed in Morocco, 12 were classified as being in a 'critical state' because of their high salinity and level of nitrates. Sites where nitrate contamination is increasing and where the concentration is higher than the permitted rate of 50 mg NO_3^-/l include: Moulouya, Tadla, Gharb, Doukkala, and Loukkos. Most of these aquifers are also saline.

Controlling the diseases and weeds promoted by the micro-climate created by irrigation requires intensive pesticide use. These chemicals can contaminate the aquifers making the water undrinkable.

An analysis of groundwater resources in Tadla (PGRE, 2002) covered the Beni-Amir and Beni-Moussa areas. It showed that using this water for irrigation in the Beni-Amir area involves a high risk of soil salinization and a low risk of soil alkalization.

A survey of 100 wells in Tadla from August 1996 to April 1998 showed that 14 to 50 wells had an NO_3^- concentration exceeding 50 mg NO_3^-/l (Table 1.27, Aghzar et al., 2002).

Survey data showed that sites that were extremely polluted were those located close to urban areas and upstream of sugar factories.

State of soil resources

Salinization and sodification

According to FAO, soil salinization is the most serious problem leading to the decreased productivity of arable land in irrigated areas in the arid and semi-arid zones. Salinity occurs because of the presence of concentrations of highly-soluble salts in the root zones of the soil. By osmosis, these salts prevent the roots from absorbing water (physiological stress). Excessive levels of sodium and chloride induce ion-specific toxicity in plants. However, salt tolerance varies with species and variety.

Soil sodicity is associated with the excessive availability of sodium ions (Na^+) in the clay complex. It leads to the degradation of soil structure and a decrease in soil water infiltration.

Soil salinization occurs in most irrigated areas and more particularly in those of Tafilalet, Ouarzazate and Haouz. Unfortunately, the amount of land lost to soil salinization because of irrigation without sufficient drainage, is not known. The available data are fragmentary and incomplete. A study

Table 1.27: Concentration of nitrates in wells in Tadla (August 1996–April 1998)

Nitrate concentration (mg NO_3^-/l)	Number of wells						
	August 96	February 97	August 97	October 97	December 97	February 98	April 98
0–25	29	26	22	15	32	5	32
25–50	55	44	48	35	44	43	47
>50	16	30	30	50	14	20	16
50–100	13	25	27	44	11	19	12
>100	3	5	3	6	3	1	4

conducted in 1992 estimated the area threatened by excess water and salinity to be 500,000 ha. These are located mostly in large-scale irrigated areas (PAN, 2001).

In the Tadla Irrigated Perimeter, a survey of land quality carried out in February–April 2000 (PGRE, 2002) showed that:

- Soil salinity covers an area of 19,330 ha, representing 25% of the total region studied. This area is far larger than the 3000 ha previously estimated. Soil salinity is mostly found downstream of Beni-Amir in the area irrigated by groundwater and recycled drainage water. Soil salinity in Beni-Moussa East has decreased significantly compared to the situation in the 1980s and the beginning of the 1990s. The main reason for this is the lowering of the water table. However, some local areas of salinization remain downstream of Beni-Moussa.
- Soil sodicity affects 12,344 ha (15% of the area studied). Sodic soils (exchangeable sodium percentage (ESP) >10%) are found mainly in areas where irrigation is based on underground water downstream of Beni-Amir.

In the Doukkala Irrigated Perimeter, the areas affected by salinization and sodification are limited and localized. They occur, particularly, in the rocky zones of Sidi Bennour, Tnine Gharbia and the Faregh extension and are caused by defective drainage (PGRE, 2003).

Waterlogging and water stagnation

Waterlogging occurs when surplus water cannot drain away and the water table rises. It has negative effects on crops and soils since it creates asphyxiating conditions for plants and aerobic biological activity in the soil and enhances the accumulation of salts on the surface after the water has evaporated.

Waterlogging also has negative effects on people, since stagnant water constitutes a favorable medium for the transmission of water-related diseases (Khallaayoune, 1993). This occurs, for example, with bilharzia or human schistosomiasis caused by *Schistosoma haematobium*, which spread through the irrigated area upstream of Tessaout due to the increased numbers of the snail *Bulinus truncatus*, which is the intermediate host of the parasite. A campaign against this disease was launched in 1982. Unfortunately, the parasite re-appeared in 1994 at new sites indicating the persistence of the transmission of the disease (Attaf, 1997).

Reduction in soil organic matter

In irrigated areas, the return of crop residues to the soil is very low or even negligible (Berdai et al., 2002). Indeed, these residues (cereal straw, sugar beet sheets and tops, etc.) are generally exported as animal feed. This results in a considerable decrease in soil organic matter. These losses are amplified by 1) intense mineralization of the native organic matter in the soil, due to the hydrous and thermal conditions favorable to the growth of mineralizing micro-flora, and 2) erosion.

In the Doukkala Irrigated Perimeter, a 48% loss of organic matter was recorded over a period of 30 irrigated years (Namam et al., 2001). This loss has resulted in the deterioration of the physical and chemical fertility of the soils irrespective of their texture.

Compaction and deterioration of structural stability

This degradation is related to 1) sodification of the ground (peptization), 2) inefficient management of organic storage, and 3) plowing techniques in irrigated areas. A survey carried out in the Doukkala Irrigated Perimeter (PGRE, 2003) showed that the soils present problems related to their permeability and their low internal drainage. The stability of the aggregates is medium to poor. A decrease in soil organic matter is responsible for the reduction in the resistance of the soil to the destroying forces of irrigation and plowing. In the same way, plowing under wet conditions using heavy machines contributes to soil compaction and the formation of a hard pan in the deep horizons; thus making the process of water infiltration even more difficult.

Conclusion

From the examples presented, we can conclude that the rate of degradation of natural resources – water and soil – in some irrigated areas has started to increase so compromising sustainable agricultural development. Urgent measures must be taken to control the degradation of these resources, to stabilize and improve the productivity of irrigated areas and to ensure that these areas continue to play the important role they have had in the national economy.

1.3.3 Review of measures to protect water and soil resources

National level

Law on Water 10/95

The objective of this law is to ensure better coordination among the different stakeholders and sectors in water management and to form the basis for the development of the national plan for water management and allocation.

National Plan for the Protection of Water Quality (PNPQRE)

The draft version of PNPQRE (2002) presents a comprehensive and precise framework for the protection and improvement of the quality of water resources in Morocco. It includes pollution control activities, funds, and the application of the ‘polluter pays’ principle, as well as a range of measures allowing for the coherence and sustainability of the actions undertaken (coordination, partnerships, sensitization and evaluation of the actions). Moreover, an optimal system of follow-up and monitoring of water quality and data management, covering all these components, is proposed.

Standardization of water quality

Standards for the quality for water intended for irrigation and drinking, as well as a decree defining the quality level of surface waters, have been established and published (BO, 2002). These standards will be used to guide efforts to control pollution in irrigated areas and to set priorities.

Ministry of Agriculture level

The deterioration of soil and water quality in irrigated areas was and continues to be one of the priorities of the Moroccan Ministry of Agriculture. Two Regional Offices of Agricultural Development (Tadla and Doukkala) have currently launched networks to monitor the quality of soil and water. These systems have been set up to ensure the long-term monitoring of the quality of natural resources (soil and water) in relation to the way the land is used. They are used as decision-making tools for the rationalization of cultural practices and the safeguarding of natural resources.

In addition, all the actions undertaken by the Ministry with regards to the rationalization of the use of irrigation water and its valorization in irrigated areas (AGR, 2002) enable the quality of water resources to be preserved. These actions contribute to environmental protection through the combined effects of the rationalization of agrochemical inputs and the control of irrigation. In the same way, considering the level of agricultural intensification that the Tadla area has experienced and in order to prevent nitrate pollution of groundwater resources in the area, a program of rational use of nitrate fertilizers was developed through on-farm demonstration trials (Moughli, 1998). It aims to reduce the excessive application of nitrogen in wheat and sugar beet.

This demonstration program currently continues to rationalize nitrogen fertilization in terms of the amount, frequency and times of application. It covers vegetable crops, which are very widespread in the zone. The program will be later extended to all crops in the area. In parallel, a program of technology transfer of the best fertilizer practices is being carried out for the benefit of farmers.

To assess the pollution problem at the regional and plot level, a model of the risk of nitrate leaching was proposed for the first time and applied to the Tadla area (Berdai et al., 2004). This model is based on three sets of factors related to the vulnerability of the aquifers, the farmers' interventions and the hydrodynamics and biogeochemistry of the soil. It allows the exploitation of databases related to the soil and agricultural practices adopted by farmers in the area to explain the levels of nitrate pollution of underground water. It also defines a certain number of measured or calculated parameters (indicators of pollution), which can be used for the evaluation of the impact of agricultural practices on the nitrate quality of groundwater.

At the scientific level, this study contributes a real sharing of knowledge on the dynamics of mineral nitrogen in the unsaturated layer of the soil during various farming cycles in a Mediterranean irrigated area. Compared to previous work on this subject in several regions of the world, the results of this study show important differences in the carbon–nitrogen cycle due to the specific pedo-climatic context studied. The risk of nitrate pollution of the water table is not comparable with any other agronomic phenomenon, in particular any of those in the sub-humid zones, and is the result of 1) intense mineralization of the native organic matter of the soil for and after the cropping season, 2) appreciable release of fixed ammonium, and 3) chronic over-fertilization. Prospects for more detailed studies of this nitrogen pool, which is currently neglected in the strategies for nitrogen management in the agricultural systems of Tadla but which could contribute actively to the nitrate pollution of groundwater in the area, are promising. These studies will also allow for a better understanding of the status of soil nitrogen fertility in Tadla.

At the practical level, the knowledge gained from these studies make it possible to support recommendations for the efficient management of irrigation, nitrogen and farming systems, which will support the action plan for water resources protection in the area. Therefore, the choice of crops and suitable rotations, the incorporation of crop residues with high C/N ratio, such as cereal straw, early and high density sowing without nitrogen application, and summer crops, constitute an effective means of reducing the risk of nitrate leaching.

Finally, at the methodological level, the 'research and development' approach adopted in Tadla deserves to be applied to other irrigated perimeters and other types of pollutants, particularly pesticides, which pose a serious threat to the quality of groundwater and public health.

1.3.4 Future prospects

The Work Plan for the Protection of Soil and Water Resources (PAPRES, 2003), which describes the strategy of the Ministry of Agriculture for the preservation of natural resources aims to ensure the sustainability of intensive agriculture in irrigated areas and to preserve livestock and public health.

- The PAPRES consists of many activities which can be summarized as follows:
- launching a follow-up and monitoring system for soil and water quality in the areas of Regional Agricultural Development Authorities (ORMVAs);
- delimiting vulnerable zones in terms of natural resources degradation which require special attention in terms of farming systems;
- summarizing existing research results, experimental and demonstration trials to identify the best agricultural management practices, which make it possible to balance productivity and the sustainability of farming systems;
- evaluating, with farmers and water users' associations, the potential production techniques at the agronomic, economic and ecological levels (demonstration trials);
- developing indicators for efficient practices and their application on the ground;
- sensitizing, teaching and advising farmers about the adoption of optimal practices;
- reinforcing basic knowledge by research and experimentation related to the preservation of soil quality and the pollution from chemical leaching program, and;

- evaluating the impact of the PAPRES on the quality of soil and water resources.

The activities of the PAPRES, which aim at minimizing the negative impact of irrigation projects on the environment by a permanent monitoring of the quality of natural resources, are launched through cooperation projects (funded by international organizations). In addition, the majority of the activities requested within the framework of the PAPRES are also included in a 'research and development' project in CWANA (ICARDA/ Morocco) relating to 'the optimization of the management of scarce water resources in agriculture in Central and West Asia and North Africa'.

1.3.5 Conclusions

During recent decades, water saving and natural resources conservation, particularly water quality, have become a major concern and a principal objective in development programs in Morocco. Indeed, the increasing scarcity of national water resources and the degradation of their quality have encouraged the country to take a particular interest in the economy of water, primarily in irrigation and the control of all types of pollution, in parallel to the development and management of water resources.

The major portion of the hydraulic potential is used in intensive cropping systems in irrigated areas. A considerable effort is needed to achieve optimal water management in these areas, taking into account not only water potential, but also water requirements and the technical and socioeconomic constraints.

Water inefficiencies in an irrigated area can have several causes, such as:

- losses at the level of the irrigation network (infrastructure, water management, water rotation, etc.);
- losses at the level of the field (related to irrigation techniques, irrigation equipment, inefficient control of the technique and irrigation scheduling by farmers, etc.); and
- losses due to the non-optimal management of farming systems, (comprising all the cultural practices adopted in the irrigated area from the choice of crops and rotations, to the technical package, etc.)

Water economy requires that the sources of water loss within irrigated areas must be controlled and the best techniques of agricultural production allowing optimal agricultural production, water saving and conservation of natural resources must be identified. It is with the aim of contributing to this knowledge that this report was brought out with the following objectives:

- At the regional level, to identify different sources of water losses at the level of the irrigation network and to present the program carried out by the Ministry of Agriculture to mitigate these losses; and
- At the plot level, to present a synthesis of the main experimental results obtained at the national scale on crop water requirements, irrigation scheduling, irrigation techniques and water saving, re-use of water in agriculture, and the impact of irrigation on soil and water resources.

Potential production techniques, such as irrigation, deserve to be evaluated in partnership with farmers on their farms through demonstration trials and decision-making models (expert systems). Such evaluations will make it possible to establish an adapted guide to good agricultural practice and to upport work plans for saving water in irrigated areas.

Finally, the optimization of water management within the irrigated perimeters cannot be conceived without a program of sensitization, training and advice for farmers on the adoption of the best agricultural management practices. A training scheme must provide farmers with the capacity to modify behavior in a field where the routines are strong.

1.4 References

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Chapter 2: Rainfed benchmark Site selection and characterization

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2.1 Characteristics of the TadlaIrrigated Perimeter

The Tadla area was selected as the Moroccan benchmark site for this study, (Figure 2.1). This area is located in a semi-arid region (300 mm average rainfall) and was chosen because it represents the rainfed areas of Morocco and of many other countries, where farmers have access to limited water. In addition, both groundwater levels and average rainfall are decreasing. Two communities representative of the Tadla area were selected to implement the project.

The Tadla Irrigated Perimeter is located in the Middle Atlas of Morocco, about 200 km south-east of Casablanca at an altitude of 400 m. It is bordered to the north by the Khouribga plateau, to the east by the Oued Zem plateau, to the west by the Oued El Abid River and to the south by the Atlas Mountains (Figure 2.2).

The perimeter is a large monotonous plain of 325,095 ha with 259,600 ha of arable land. The source of water is the Oum Rabia River and its tributaries Oued Srou and Oued El Abid. The perimeter is divided into two zones:

- The rainfed zone, known as '*bour*', with an area of 133,600 ha which not only contains cropped land; but also forest, pasture and non-productive areas. Although, it is mainly rainfed, some farmers have access to irrigation (small- and medium-scale irrigation);
- The large-scale irrigated zone with an area of 98,300 ha is divided into two sub-zones separated by the Oum Rabia River:

Figure 2.1: Location of the Tadla Benchmark site in Morocco.

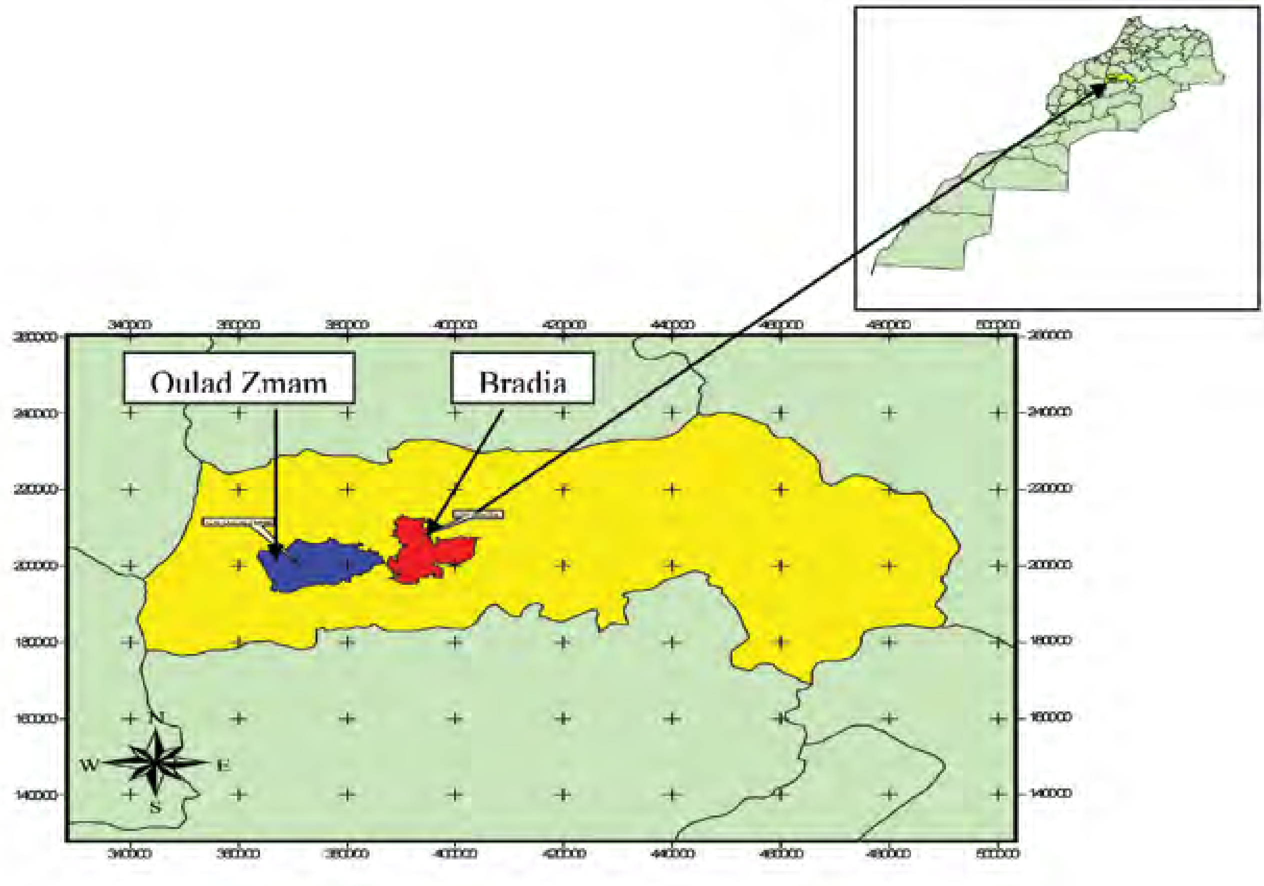

Figure 2.2: Geographic location of the Tadla region and of the two communities covered by the project

- Beni Moussa sub-zone in the west with an area of 69,500 ha, which is fully irrigated from the Bin El Ouidane dam that was built on the Oued El Abid River. This large sub-zone is called Beni Moussa-East and West.
- Beni Amir sub-zone on the right-hand side with an area of 27,500 ha, where the water source was the Oum Rabia River; but since 2001/02, it became the Ahmed El Hansali dam built on this river.

The dominant crops in the perimeter are cereals. In the *bour* (rainfed area), cereals cover 51% of the cultivated area and in the irrigated areas the main crops are cereals (19%), sugar beet (5.7%), vegetables (3.5%), citrus (3.4%), olive trees (7%) and forages (10.4%).

Physical environment

Agroecological characterization of the Tadla region

The climatic data used in the following analysis came from Ouled Gnaou weather station, which is the main weather station in the Tadla area. It has a complete record of climatic data for the period 1970–2007 (37 years of data) that allows for a deep analysis of the general weather conditions and variability in the region. This report describes these conditions and will be complemented by another that will deal with the spatialization of the agro-climatic parameters for the whole of Tadla perimeter and the two communities studied (Bradia and Ouled Zmam).

A graphical presentation of the rainfall data (Figure 2.3) shows that the annual amount varies from one year to another. No cyclic phenomenon of wet and dry years is observed. However, the data show that less rainy years have become more frequent during the last two decades and in general, the amount of annual rainfall has tended to decrease. From 1970 to 2006, the average rainfall reduction was about 4.3 mm per year. The annual rainfall variability was very high (CV=34%). For the period studied, the highest rainfall amount (640 mm) was received in 1971 and the lowest (107 mm) in 1981. The moving average, in Figure 2.4, shows the change in the rainfall regime at Ouled Gnaou Station since 1971.

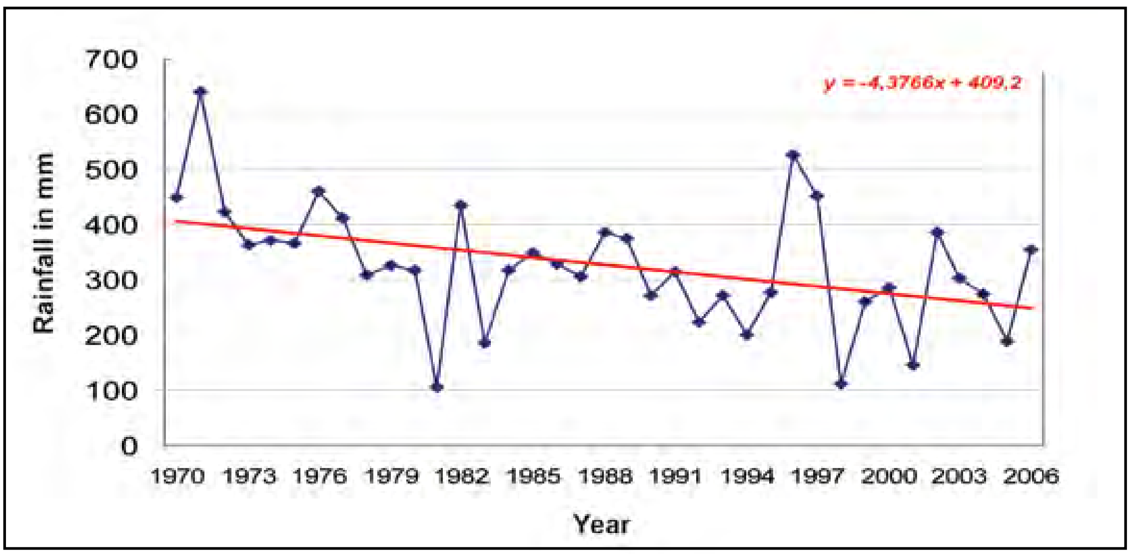

Figure 2.3: Annual rainfall variation in the Tadla area.

The Standardized Precipitation Index (SPI) is used to quantify the precipitation deficit for selected time scales. A drought event is defined for each time scale as a period in which the SPI is continuously negative, reaching values of -1.0 or less. A drought begins when the SPI first falls below zero and ends when the SPI becomes positive. The SPI analysis for January–March shows that the values of the index have decreased and have always been negative over the last five years (Figure 2.5). This means that droughts have become more frequent during this period of the year that usually coincides with the critical phases of crops growth (tillering and stem elongation of wheat). For the set of 33 years' data analysed, this index reached its lowest value (-2.92) for the period January–March during the year 2000, indicating an extreme drought during that year. The highest value (+2.06) was recorded in 1996.

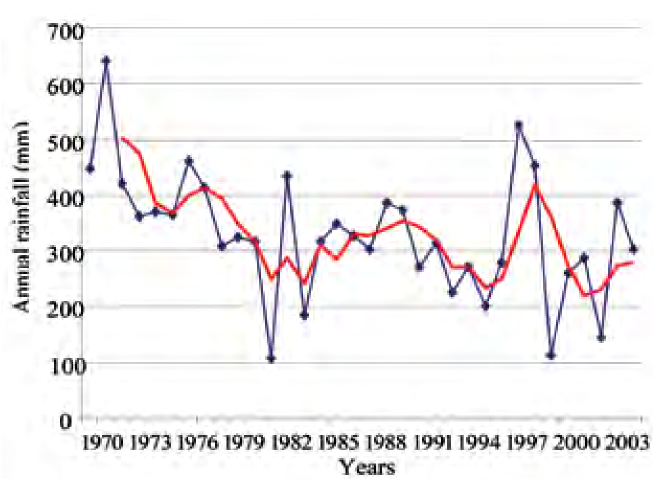

Figure 2.4: Moving average of annual rainfall at Ouled Gnaou Station.

For the October–December period, there has been a tendency for a small increase in SPI over the last 5 years. Consequently,

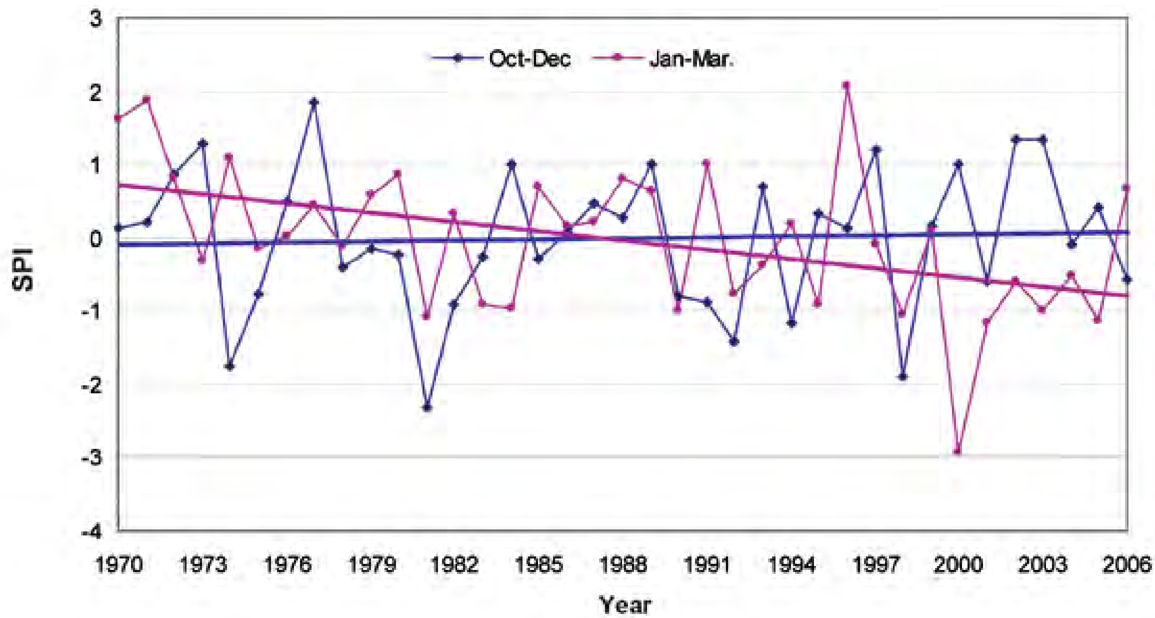

Figure 2.5: Standardized Precipitation Index in the Tadla area.

the analysis suggests that if the trend for the occurrence of droughts is maintained, farmers need to change their water management approach. Early planting (in October) and supplemental irrigation in January–March may improve yields and water productivity.

In semi-arid zones, sowing is a critical operation in crop production. An optimal planting date that allows for the early establishment of a good stand can reduce the effect of water stress due to the reduction of soil evaporation and allow the crop to escape drought. However, the choice of sowing date is a difficult decision for the farmer to make under conditions where the risk of drought is high. Consequently, the development of a decision-making tool to forecast sowing will be helpful to farmers. For this purpose, the concept of 'first significant rain' (FSR) was seen as an important tool in decision making to plan sowings in these areas. The FSR is defined as being the time after October when the first rainfall sufficient for both germination and emergence is received.

An analysis of the first significant rains at Ouled Gnaou Station (Figure 2.6) shows that, for the period 1970–2003, the condition of having received a total of 25 mm during 10 successive days was met on about 7 November. This threshold was reached in 23% of the studied time series before 16 October, in 46% between 16 October and 30 November and in 31% after 30 November. During 1981, 1985, 1992, and 1998, the defined condition (25 mm of rain during 10 successive days) was not met.

The probability of receiving the first significant rains in the Ouled Gnaou region on or about 16 November is 70%. Since this station is located in an irrigated area, the farmers can start sowing on 1 November, which corresponds to the median (50% chance).

Knowing the risks of dry periods is an important element for crop and water management in irrigated zones. The analysis of the risk of dry periods at Ouled Gnaou Station, calculated from daily rainfall records from 1970 to 2003, shows that October is the most risky month. However, in spite of a few fluctuations over time, November and December are the least risky and the most stable. In this area, crop establishment in early November is more desirable; it should be avoided in October.

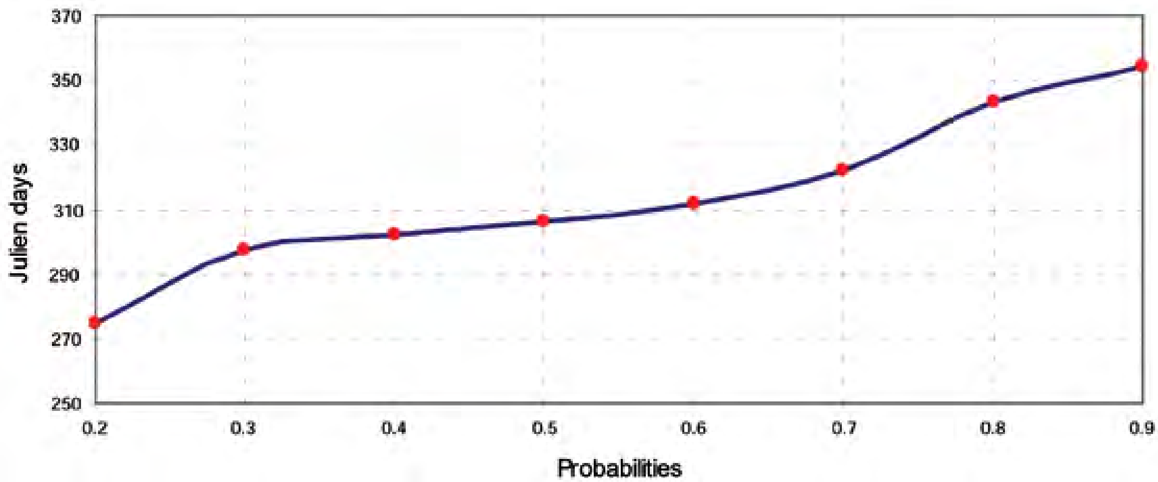

Figure 2.6: First significant rainfall at Ouled Gnaou Station (Tadla).

Between the middle and the end of the growth-cycle, the risk of having long dry periods at Ouled Gnaou Station is high during February and March (Figure 2.7). This risk decreases during April and January. Consequently, irrigation is recommended between February and March.

Soil and water resources

The dominants soils in the region are mollisols (soil taxonomy), which are deep and suitable for irrigated farming. Other soil types are shallow and have low water-holding capacity. The most important constraint related to soil is salinity. It comes from two sources: the aquifer (groundwater) and the origin of the Oum Rabia River. Salinity levels are higher in Beni Amir than in Beni Moussa, both East and West. This is the main difference among these three zones, because it prevents the cropping of certain species.

Another problem is pollution of the soil by nitrates due to inadequate management of nitrogen fertilizer application. During the

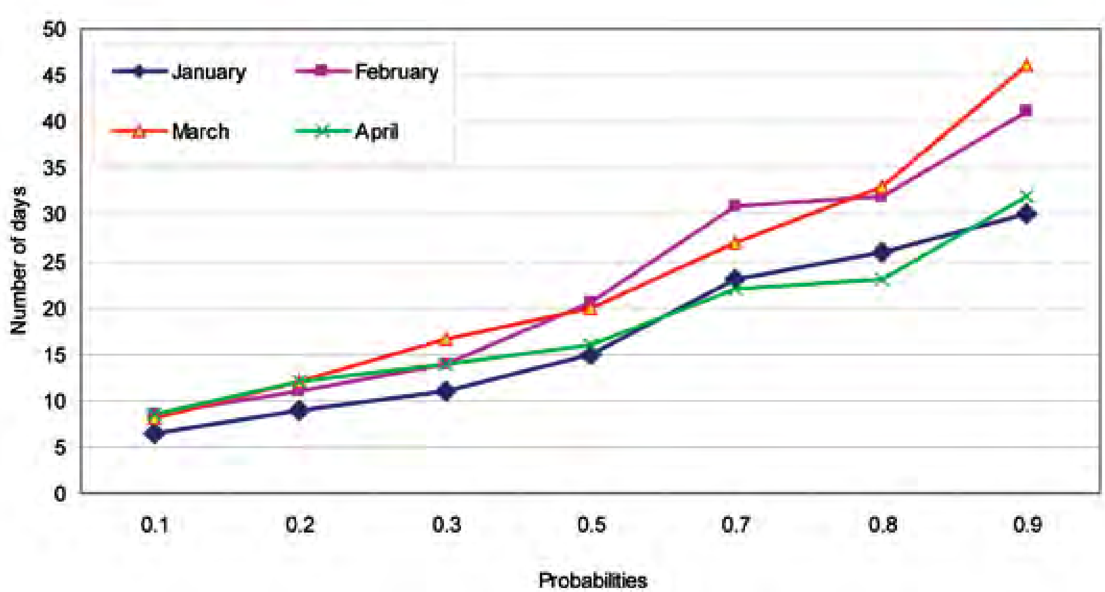

Figure 2.7: Length of drought periods at the end of the season in Tadla.

cropping season the level of this pollutant remains relatively low because a high proportion of the nitrates are leached by rainwater.

The main river in Tadla, Oum Rabia, originates in the calcareous high plateaus of the Middle Atlas. The annual average flow of this river is 35 m^3/sec with a maximum of 1,700 m^3/sec and a minimum of 8 m^3/sec. The most important tributary of Oum Rabia is Oued El Abid, which has an average flow of 32 m^3/sec.

There are two dams in the Tadla Irrigated Perimeter, Ahmed El Hansali dam built in 2001 across the Oum Rabia, which has a total capacity of 740 million m^3 of water, and Bin El Ouidane dam built in 1954 on the western Oued El Abid, which has a total capacity of 1500 million m^3. A constant decline in precipitation has significantly affected the water levels in the dams. In fact, the available water in these dams does not reach even half of their storage capacity.

- The irrigation and drainage network consists of:
- Main canals: 200 km;
- Primary and secondary canals: 630 km;
- Tertiary canals: 1800 km;
- Collectors: 427 km;
- Drains: 416 km.

Groundwater resources comprise two aquifers: the unconfined upper aquifer and the deeper confined aquifer. Changes in the level of the water-table are monitored by the piezometric stations of ORMVAT (Tadla Regional Agricultural Development Agency, Office régional de mise en valeur agricole de Tadla) and the Oum Rabia Basin Agency. The water level is continually declining because of the pumping of water from wells and the low rainfall. From 1987–1993, and to a lesser extent from 1997–1999, there was a significant rise in the level of the water-table, especially in the Beni Moussa region. This re-charge was due to high rainfall and infiltration. This latter was due to inadequate irrigation management.

The procedure for programming irrigation is based mainly on the amount of water stored in the dams at the beginning of the growing season and on the estimates derived from monitoring rainfall. The total amount of water allocated to ORMVAT is fixed by the Oum Rabia Basin Agency at the beginning of the season.

ORMVAT, through its Department of Irrigation and Drainage Management, is responsible for the organization of water distribution in the two zones (Beni Amir and Beni Moussa) of the perimeter. The way the water is distributed differs from one region to another. In Beni Amir, distribution is based on the area (hectares) and in Beni Moussa it is based on the importance of the crop (sugar beet, alfalfa). This poses two problems:

- The problem of adjustment between the crops' requirements and the basis of the system of water supply. This highlights the apparent contradiction between the rigidity of the distribution system and the new approach of giving farmers the freedom of choice in the crops they want to plant; and
- The problem of water availability at the beginning of the cropping season. This procedure affects 27,000 farmers and an irrigation network of 3000 km. The program for water distribution consists of a certain number of water turns (water rotation) among farmers for each growing season. This program is then sent to the Network Management District (NMD) for approval.

The irrigation calendar is based on:

- Crops that need to be irrigated;
- The irrigation schedule for each crop, taking into account the irrigation flow;
    - For sugar beet: 8 hr/ha if the flow is 30 l/s, or 12 hr/ha if the flow is 20 l/s (= 1 allowance).
    - For fruit trees: 4 hr/ha if the flow is 30 l/s, or 6 hr/ha if the flow is 20 l/s (1/2 allowance).

Water rotation is in general at weekly intervals (168 hr per week). It covers an irrigation block of 25 to 40 ha and it is distributed among farmers, after taking into account:

- The planned crops and their water requirements in the irrigated zone of Beni Moussa; and

- The total area of the farm independent of the crops grown in the irrigated zone of Beni Amir.

Each week, farmers have to present their water demands to the '*aiguadier*', the person responsible for collecting the demands. Each '*aiguadier*' is responsible for 400 to 1000 farmers and, based on cropped areas, he determines the duration of irrigation. He also measures the flow at the level of the tertiary and secondary canals taking into account the water requirements per block.

Each official at the Center of Network Management compiles all the demands supplied by the '*aiguadiers*' under his authority; and then sends them to the NMD requesting a water release which is under the control of the National Electricity Office (NEO).

Copies of the irrigation programs are sent to the water distribution agent and to the water-gate guard, who are responsible for the execution of the pre-established program.

The distribution agent regulates the flow at the secondary network and the water-gate guard at the tertiary one. Because of the deterioration of the irrigation network, some disturbance in the water distribution operation (water turn approach) can occur and make the farmers unhappy, especially the ones who are on the downstream side of the network.

Socioeconomic environment

It was difficult to obtain comprehensive demographic data for the Tadla Irrigated Perimeter. Consequently, only some information about the population, the transformation of agricultural products and the transport infrastructure is presented in this document.

Population

According to the last agricultural census of 2004 (Recensement général de la population et l'habitat, RGPH 2004), the total population of the region (Beni Mellal and Azilal provinces) is 1,324,662, with women making up 50.2% and population growth remaining high. Between 1971 and 1994, the number of inhabitants has doubled.

Demographic structure by age of the population is changing rapidly. The economically active group represents around half of the population (57% for Beni Mellal). However, it faces the problem of unemployment, which forces young people to migrate from rural areas to the cities or even abroad (mainly to Italy and Spain). The structure by age also shows that the economically inactive group (less than 15 and more than 60 years old) remains dominant.

Agro-industrial infrastructure

The agro-industrial sector is well developed in the irrigated area. The number of agricultural product processing plants has increased significantly since independence. In fact, then the total industrial infrastructure consisted of only 3 cotton seed processing units. Now, it is more diversified and is composed, according to ORMVAT (2004), of:

- 3 sugar refineries with a total capacity of 14,400 t/day;
- 9 modern olive oil factories with a total capacity of 40,000 t/year;
- 496 traditional olive oil processing units with a total capacity of 20,000 t/year;
- 1 milk factory with a total capacity of 70,000 l/day;
- 1 animal feed factory with a total capacity of 20,000 t/year;
- 1 freezer unit with a total capacity of 3,000 t/year; and
- Orange packing stations with a total capacity of 25,000 t/year.

2.1.1 Characteristics of the Tadla communities

Population

The two communities belong to the district of Fkih Ben Salah. The number of villages ('*douar*') is 17 in Ouled Zmam with a population of 31,595. There are only 13 in Bradia but with 36,530 inhabitants (Table 2.1).

Table 2.1: Demographic data.

Data	Bradia	Ouled Zmam
Population	36,530	31,595
Number of villages	13	17
Number of farmers	6415	2998
Number of households	5478	6204

Source: ORMVAT (2003).

The data of the 1996 general census of agriculture, show that there are 8 villages in Ouled Zmam and 21 in Bradia (RGA, 1996). This information can be considered definitive as the census is an official document, even although the data supplied by ORMVAT (2003) suggests that these numbers are 17 and 13 for the two communities, respectively. These differences can be explained by the definition of the term 'village' used in the two publications. The total rural population of the two communities is estimated at 9,967 in Ouled Zmam (Table 2.2) and 33,732 in Bradia (Table 2.3).

Table 2.2: Rural population in Ouled Zmam.

Family groups and villages	Population	Number of households
Oulad Amar	1044	155
Oulad Ahmed	1467	212
Oulad Ghalam	1853	261
Oulad Massoud	1519	228
Ahle Souss	3284	398
Hadrane	253	36
El Hajjaje	321	41
Ouled Mimoune El Hejjaj	226	24
Total	**9967**	**1355**

Source: RGA (1996).

Land

Collective land represents 34% of the total area in Bradia and only 23% in Ouled Zmam. In this latter community, the private ('*melk*') status of land dominates and is 74% of the total area. Small farms represent only 36% in Ouled Zmam but 73% in Bradia. This structural difference between the two communities explains the difference in the way the farmers chose their farming techniques and crops.

Table 2.3: Rural population in Bradia.

Family groups and villages	Population	Number of households
N'Ghamcha	738	78
Lahmara	257	30
Ouled Kacem	68	9
Msala	366	41
Bni Aouane	1771	211
Ouled Smida	2003	209
Ouled Zahra	2489	309
Oulad Jbir Labane	692	89
Skhifate	3997	628
Ouled Abdelkarim	501	69
Laassara	4971	607
Lafjagna	1617	213
Daadaa	384	47
Aamar	1511	181
Ouled Khancha	193	26
Ouled Rahou	2858	354
Lamrabta	3473	425
Labbakar	1164	149
Dhara	2194	282
Labhalil	1198	140
Aribtate	1287	149
Total	**33732**	**4246**

Source: RGA (1996).

Crops

Cereals, sugar beet and alfalfa are grown by both communities. However, Bradia is characterized by the presence of citrus and vegetables and Ouled Zmam by olive trees. Because of salinity problems, milk production has developed in Beni Amir, where the number of milk cows and livestock organizations is very high for this region.

Extension services

The two communities rely on the Tadla regional extension services (ORMVAT) for technical advice on agricultural production. There are many cooperatives and farmers' associations each having different objectives such as sugar beet processing, milk collection, irrigation management, trade in cereals and livestock. For milk collection alone, there are 11 cooperatives in Bradia and 9 in Ouled Zmam.

2.2 Site selection

Bradia and Ouled Zmam sites were selected because they are representative of the Tadla region in terms of water resources and agricultural production systems. In fact, the source of irrigation water was the major criterion used in the selection process. At Bradia, water comes mainly from the irrigation network (surface water). While at Ouled Zmam, the majority of farmers use groundwater in addition to surface water. As far as agricultural production systems are concerned, the main crops grown in the region are cereals, sugar beet, alfalfa and citrus trees, and these are present at the selected sites.

Two participatory workshops were held to select relevant communities, one in Ouled Zmam and the other in Bradia. Their main objectives were 1) to ensure a minimum level of participation by the community by raising awareness of the project and its major objective, which is the efficient use of water in supplemental irrigation, and 2) to improve the interaction of researchers with community members and partners such as the Chamber of Agriculture, local authorities, farmers' associations, cooperatives, etc.

The specific objectives of the workshops can be summarized as:

- to explain to the local community the major objective of the project, which is the improvement of water-use efficiency in irrigated agriculture;
- to establish a network among the participants so that they address issues of communal interest and communicate better;
- to identify the community, its resources, linkages, potentials, and constraints according to the perception of its members; and
- to identify community members that are willing to host project field trials.

Participatory methods were used in the workshops. Interactive and flexible approaches were followed, and top priority was given to visualization as a stimulus to the communication and capitalization of the information. Different tools were used to reach these objectives – Venn and flux diagrams in the plenary sessions and agricultural activities, constraints and potentials during group work.

Before organizing the workshops, the project team made many visits to ORMVAT and contacts with local and provincial institutions were established to prepare for the meetings. With the aid of local authorities and ORMVAT staff, potential farmers (35 in Ouled Zmam and 50 in Bradia) to attend the event were identified. For efficiency and to ensure that the objectives of the workshop were achieved, a discussion guideline was prepared by a group of researchers and engineers. It was, then validated by all scientists involved in the project. Two similar and consecutive participatory community workshops were organized on 12 and 13 April 2004.

Each workshop had two sessions; one plenary meeting with all participants and the second small thematic group meetings. The first session focused on the presentation, by farmers, of a general description of the community and its linkages and fluxes with its environment. This first meeting also facilitated the establishment of communication among participants. The second session that was meant for exchange of information and the discussion of problems by small groups, focused on the following topics:

- Agricultural activities (crop and livestock production);
- Water resources and irrigation; and
- Institutional and socioeconomic aspects related to agricultural production and irrigation water.

2.3 Outputs of the participatory workshops

2.3.1 Community of Ouled Zmam

Analysis of actors and fluxes

The importance of fluxes and relationships between the community and its environment is illustrated in Figure 2.8. Four institutions have the highest degree of relationship with the community. These are ORMVAT, sugar refineries, milk cooperatives, and the agricultural bank. Among them, ORMVAT is of the greatest importance because it allocates water, ensures maintenance of the irrigation network and provides technical assistance to the farmers. Other ORMVAT services are provided in collaboration with cooperatives and associations.

During the meetings, community members raised problems that they had with ORMVAT. These problems can be summarized as:

- Water price has increased.
- Little technical advice to farmers and less maintenance of the irrigation network.
- ORMVAT is no longer involved in commercial negotiations with the sugar refineries, which have become more powerful than the producers and impose their own rules.

Farmers' relations with the main partner institutions in the region were also discussed during the workshop and the results ranked ORMVAT as the main partner. The nature of these relations is summarized in Table 2.4.

The sugar refineries are ranked number two, in terms of services offered to the community. These institutions have a monopoly of the marketing of raw sugar beet. They give cash advances on production to ensure that the crop is planted. These advances and loans are paid back by farmers at the end of the growing season at high rates of interest.

All farmers agreed that they have big problems with the refineries. These problems are related to the determination of sugar content and to the quality of the products. A third important community partner is the milk cooperative. This cooperative collects and purchases milk from its members at a variable price. It also offers payment facilities, provides feed and health (medical) coverage up to 25%. This last service is particularly appreciated by the cooperative members. However, all farmers think that the price of milk remains very low because of the lack of other milk companies in the region. Central Dairy dominates the milk market. This situation does not encourage the development of milk production and valorization.

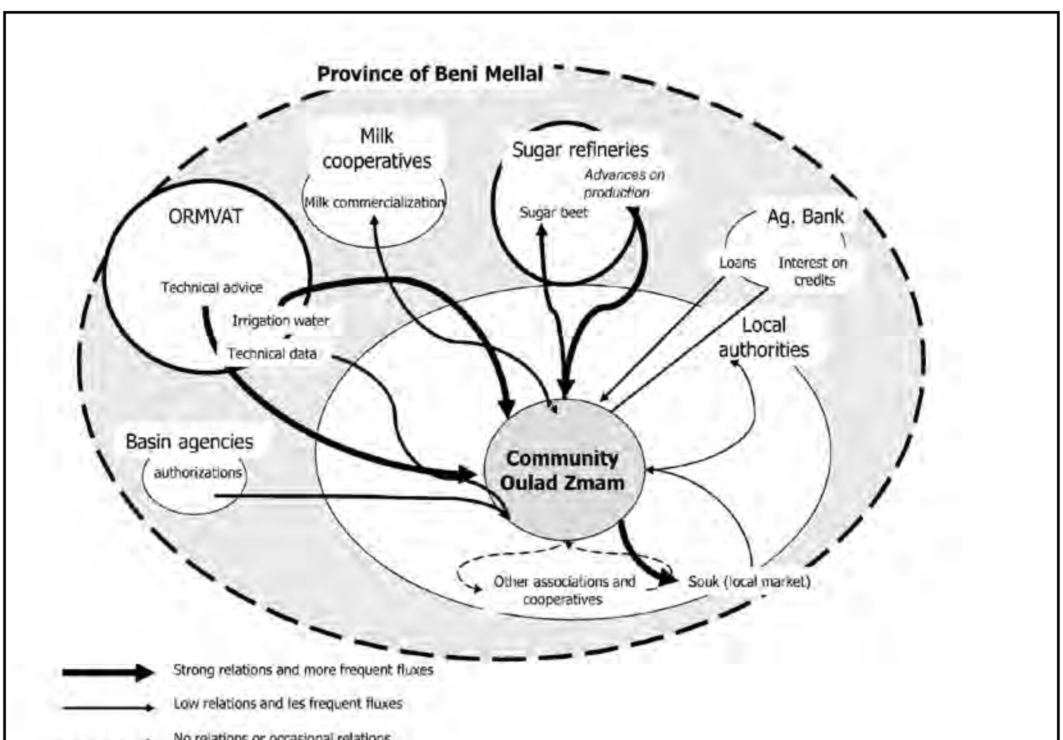

Figure 2.8: Fluxes and relations between the community of Ouled Zmam and its environment.

Table 2.4: The functions of local institution and community responsibilities (Ouled Zmam).

Type of institution	Services offered by institution	Community obligations	Major problems
ORMVAT	Irrigation water supply Extension Administrative certificates Maintenance of the network Rural development (access to village, roads) Analysis of water and soil Artificial insemination through cooperatives	Payment for irrigation water Payment for soil analysis Provision of information through surveys Organization into cooperatives to facilitate ORMVAT interventions Contribution to the success of ORMVAT programs	ORMVAT is no longer involved in commercial negotiations ORMVAT is no longer involved in the program of yellow nightshade weed control ORMVAT is unable to maintain the irrigation network because of the lack of financial and human resources Irrigation water allocated is not sufficient Lack of extension staff
Sugar factories	Give cash advances to acquire inputs (seeds, pesticides, fertilizers) Loans Provides sugar beet pulp	Provision of the raw product (sugar beet) Payment of advances on inputs Reimbursement of loans Payment of the price of sugar beet pulp	Problems with the determination of sugar content by the refinery (underestimated) Interest on loans is high Absence of a role for the Association of Sugar Beet Producers of Tadla, even if producers pay the membership fee Role of the producers in the evaluation of product quality Elimination of the financial contribution of the refinery in the early harvesting of sugar beet No technical advice is provided by the refinery Not all farmers are using certified and good quality sugar beet seeds
Milk cooperative	Marketing of milk Health coverage for members up to 25% Facility of payment and provision of feed	Provision of milk Payment of membership fee	Price for 1 liter of milk paid by 'Central Dairy' is very low Monopoly of 'Central Dairy' and absence of competition
Agricultural bank	Loans	Reimbursement and payment of interest	Requirement for guarantee of loans (property title, etc.) Complexity of the procedures for taking out loans Requirement for the mortgage operation (complex operation) Non-generalization of exemption from reimbursement of loans under drought conditions as it is in rainfed agriculture High rate of interest High cost of suing of debtors

The agricultural bank is an institution that is also important in the region. Provision of short, medium, and long-term loans is the main service provided by the bank. However, the complexity of the procedures and the absence of a mortgage do not encourage the farmers to deal with the bank.

Finally, we noted other important institutions in terms of water management; but with which the community has very limited interaction. They are:

- The Water Basin Agency that authorizes the digging of wells. It also decides how much surface water is allocated to the irrigation network. According to farmers, the agency does not, unfortunately, take into account the specificity of the regions when it determines the amount of water allocated;
- The local authority that is involved in the coordination and follow-up of agricultural activities. This institution also plays an important role in ensuring security and in delivering administrative certificates; and
- Private companies that supply agricultural inputs such as pesticides and fertilizers, on a local or regional level.

Other institutions were mentioned by farmers; but they are not important to them. They include research institutions, the Livestock Producers' Association of Tadla, certified seed company, and others. It was noted that the Association of Sugar Beet Producers was criticized by the participants. The membership fees for the association are high and taken directly by the sugar refinery when the producers deliver their products. According to farmers, the association is supposed to protect their interests by ensuring that the quantity of sugar beet delivered is correctly determined by the refinery.

Results from the irrigation focus group

Water resources and management

There are two sources of water in the Ouled Zmam community – surface (dam) and underground (aquifer) water – and three combinations of irrigation water:

- the first is where underground (aquifer) water is the only source (as in the case of sector 509) and the sector is located in a large rainfed area where only 30% of farmers own wells (varying in depth from 90 to 129 m). The problems associated with this type of water are the increasing depth of wells and salinity;
- the second is where a mixture of surface and groundwater is used, with 1/3 of the water coming from pumping and 2/3 from surface water (as in the case of sector 506); and
- the third is also mixed, but 1/3 of the water comes from the dam and 2/3 from pumping (as in the case of sector 507).

The irrigation network is judged to be very old and requires rehabilitation. There is a shortage of water downstream of the network because of the deterioration of the system. This problem is also related to the surface irrigation system used in this region. Some tertiary canals do not encourage the introduction of new and high-water demanding cash crops (freedom of choice of crops). Also the 'water turn' procedure (water distribution in rotation among farmers) makes it difficult for irrigation scheduling of different crops.

The most dominant irrigation technique (Photo 1) is '*robta*' (flooding surface irrigation of small basins).

This technique (photo 1) is very old; but has been modified by reducing the dimensions and increasing the number of basins. This

Photo 1: Traditional technique of surface irrigation.

increase is due to the degradation of soil leveling. It is a technique that is well adapted to local systems of crop production. The disadvantages of '*robta*' are the high cost of labor, water losses, reduction in the cropped area because of irrigation furrows (water channels), and high duration of irrigation. Farmers continue to use '*robta*' because they have not tried any other more efficient techniques in this region. Moreover, farmers lack the confidence to invest in new systems like drip irrigation in which salinity problems can cause deterioration of the irrigation materials.

Crops that are the first to benefit from irrigation water are sugar beet, alfalfa, wheat (bread wheat), olive trees, vegetables, maize, and sesame. However, irrigation of the three last crops depends on the availability of water.

Professional organizations

Even if farmers' associations exist, they are not functional because of ineffective management and lack of members. According to the farmers, the status of these associations is not clear. Moreover, there is no aid from the State as was previously agreed with the associations of water users in agriculture. These associations, which are supposed to be involved in water management, only play a role in the negotiation of irrigation programs and planning. The number of members does not exceed 10% of farmers in the community.

With regard to agricultural product marketing, individual farmers sell their products immediately after harvest. This behavior highlights the farmers' risk of falling into debt. In this situation, it is difficult for farmers to develop an appropriate marketing strategy. For example, milk prices remain very low and vary tremendously from year to year and within a year.

Crop management

In general, agricultural practices do not differ much from one community to the other. However, the agricultural areas are distinct.

In Ouled Zmam, the dominant soils are iso-humus (2/3), 1 to 2 m deep and calcixerolls (1/3). The problem of salinity in both water and soils is becoming worse. Dominant crops are wheat (durum and bread), alfalfa and sugar beet.

Generally, agricultural mechanization is well developed. Technical packages are specific to the crop and to the system of irrigation used.

Deep summer plowing in some situations and offset disking and drilling are the usual techniques used in the cereal/cereal rotation. However, the choice of techniques and tools for soil preparation is influenced by the preceding crop. When sugar beet is the preceding crop, one offset disking is sufficient. Superphosphate is incorporated in the soil during preparation in the autumn at the rate of 150–200 kg/ha. Urea is broadcast once at the tillering stage at the rate of 200–300 kg/ha when the soil is wet. The rate of seeding is 180 to 200 kg/ha. Only 70% of farmers practice chemical weed control. Some farmers apply the chemical early and others late. No fungicide is used. The number of irrigations varies from 1 to 5 depending on water availability (rainfall). Achtar and Merchouch are the most used (bread) wheat varieties. The rotations used are wheat/alfalfa and wheat/sugar beet.

Technical management of sugar beet depends a lot on the income (wealth) of the farmer. Nevertheless, adaptive management is well known to most farmers. The most common problems are those related to nematodes and weeds. The number of irrigations in one cropping season varies from 11 to 14.

Production is only moderate compared to the potential of the region. In the case of cereals, actual yields are divided into three groups according to the techniques used: 5,000–6,000, 3,500 and 1,800–2,500 kg/ha. Average yields are between 3,000 and 7,000 kg/ha, depending on farm size and rainfall conditions. For sugar content, polarization varies from 10 to 19. The levels declared by the refinery often show large discrepancies even for harvests from the same plot.

2.3.2 Community of Bradia

Analysis of actors and fluxes

In general, the fluxes seen in Oulad Zmam are the same as those observed in the Bradia community. Only the order of the ranking of the four institutions changed. As with the Ouled Zmam community, ORMVAT is the main institution with the highest level of interaction with the Bradia community. Farmers ranked their relationship with the agricultural bank in second place, followed by the milk cooperatives and finally the sugar beet factory (Figure 2.9).

The services offered by these institutions remain the same. Services and problems related to different institutions are presented in Table 2.5.

Results of group discussion

Water resources and management

The results of the water resources working group can be summarized as follows:

- Around 90% of irrigation water comes from the dam. The rest (10%) is from the aquifer (wells).
- Groundwater quality is low (salinity) and this limits its use in irrigation. However, the level of use varies from one area to another. Some regions have good quality water.
- Around 90% of wells are traditional.
- Optimal water application depends on the condition of the soil surface. Soil leveling allows uniform water distribution across the field. Unfortunately, the use of this technique (leveling) that saves 40% of applied water is only seen with the 5% of farmers who own a tractor.

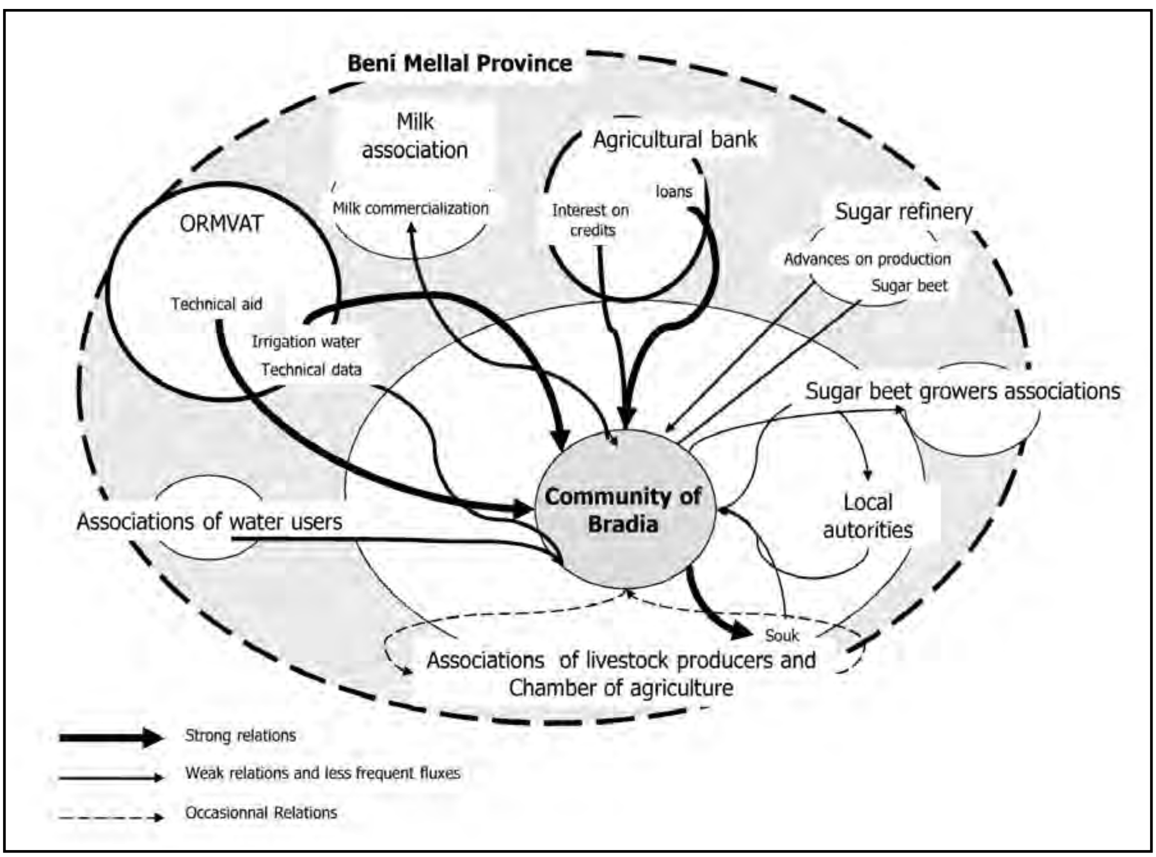

Figure 2.9: Fluxes and relations between the community of Bradia and its environment.

Table 2.5: The functions of local institution and community responsibilities (Bradia).

Type of institution	Services offered by institution	Community obligations	Major problems
ORMVAT	Irrigation water Extension Equipment and maintenance of networks Contribution to construction of roads Animal vaccination Water and soil analysis	Water dues Payment of costs of soil analysis Provision of information through surveys	Reduction in the paid water flow Non-adjustment between water supply and demand Imbalance between the amount of irrigation water released and the annual requirement Periods of payment of dues for irrigation water are not well adapted (February after planting of crops). Farmers suggest that payment take into account the level of crop production. Lack of action on network maintenance Irrigation water dues are high Absence of water 'policemen' There is a link between water allocation and cereal/sugar beet rotation (there is no freedom of choice of crops)
Sugar factories	Marketing of sugar beet Financing of inputs for sugar beet by credit advances Credit	Provision of sugar beet	Ambiguity in the relationship between the community and the sugar refinery. There is a problem with sugar quality and sugar beet quantity determination Absence of the role of the association No change in price since 1984 and non-application of measures
Milk cooperative	Sale of milk	Provision of milk to 'Central Dairy' through the cooperative	Low price of milk
Agricultural bank	Granting of credits	Reimbursement of debts and payment of interest	Credit is not granted to individuals but to cooperatives Complexity of the procedures for granting credits Rates of interest are high. The amount of annual credit is not enough for small farmers

In general, irrigation techniques remain traditional and not efficient. In fact:

- 98% of farmers continue to use '*robta*';
- Only 1% of farmers practice drip irrigation and irrigation by siphons. Improving '*robta*' depends on the farmer's financial means, since it requires laser leveling that costs 3000 dirhams/ha (around US$300) which is considered high by farmers for the maintenance of canals;
- The alternative to '*robta*' is drip irrigation; but not many farmers can afford this technique (the equipment is expensive);
- Irrigation water delivery depends on the system of 'water turn' used in the region and on the duration of irrigation controlled by ORMVAT. When the amount of irrigation water provided by ORMVAT (dams) is not sufficient, some farmers who own wells practice supplemental irrigation.

In general, farmers are aware of the importance of using new irrigation techniques for saving water; but they are worried about the cost of these technologies. Farmers are more interested in the output than in resource saving.

Professional organizations

In the community, there are four associations of water users; but most of the farmers are not aware of their existence. These associations are:

- Bin El Ouidane Association with 800 members, who do not pay their membership;
- Rahma Association with 560–600 members, who do not pay their membership;
- Alfadl Association with 500 members, who do not pay their membership; and
- Aloulja Association.

These associations play a role in negotiations with ORMVAT on irrigation canal maintenance and irrigation water release. Some associations even contribute to canal maintenance and repair.

Crop management

Around 40% of farmers resort to deep plowing followed by 2 to 3 offset diskings. The remaining 60% use offset disking only. The average level of fertilizers applied is estimated at 200 kg/ha. Most farmers broadcast seed at a rate of 200 kg/ha. Weed control is taken up when weeds appear. No fungicides are used on crops. Wheat yields under these conditions vary from 3000 to 4500 kg/ha. The dominant rotation is cereal/cereal (70% of cases).

For some farmers who obtain low cereal yields (1000–3000 kg/ha), livestock, olive and alfalfa production provide other means of livelihood. Among the 16 farmers (participants), only 2 grew sugar beet in 2003/04. Farmers avoided this crop because of nematode attacks, the low price of the product and the non-transparency of the sugar refinery in terms of the determination of sugar quality and quantity of the product.

2.4 Conclusions and recommendations

From these workshops and an analysis of project documentation, we can conclude that possibilities for the improvement of water use do exist. These improvements depend not only on technical aspects, but also on organization and policy considerations. Most of the problems mentioned during the workshops are related to water, as illustrated by the following points:

1. **Water cost**: This problem is linked to improvements that could be made by the introduction of new crops that use water more efficiently, adapted irrigation techniques and incentives in terms of agricultural policies.
2. **Decision-making in water management at the canal level**: At present, ORMVAT is responsible for deciding when and how much irrigation water is to be released. This situation does not facilitate the use of irrigation techniques such as deficit irrigation, supplemental irrigation and drip irrigation. These new alternatives (to surface irrigation) can only be used when it is possible to own small basins and when communities have the right to participate in decisions regarding water release from the dams, taking into account their needs and climatic conditions.
3. **Investment in new technologies**, such as drip irrigation, is considered very expensive by most farmers. In fact, the high cost of drip irrigation equipment and the low level of subsidy to acquire it do not encourage farmers to use this technology. Therefore, incentives to shift from surface irrigation to drip irrigation are necessary.
4. **Lack of knowledge of irrigation techniques**: Most farmers, except the bigger ones, use traditional surface irrigation (‘*robta*’) that wastes huge quantities of water and reduces the land available for use by crops. An improved surface irrigation technique (using land leveling) has been developed, and if used by farmers, can improve water-use

efficiency. In addition to this technique, farmers need to adopt other cultural practices including new crops and varieties.

5. **Organizational aspects**: Many organizations (cooperatives, associations) exist in the chosen communities; however, they remain ineffective. Only dairy cooperatives seem to be successful.

A new approach to the integrated management of natural resources, especially water, needs to be developed to involve the community more closely in irrigation water management in order to improve water productivity.

2.5 References

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Chapter 3: Improving water productivity in the Tadla region of Morocco

Chapter 3: Improving water productivity in the Tadla region of Morocco

M. Boutfirass, M. Karrou, A. Bahri, T. Oweis and B. Benli

3.1 Introduction

Climate change has led to more severe climatic conditions throughout the world as well as in Morocco. In general, rainfall has declined and average temperatures have increased. These new rainfall patterns are threatening water supplies. Fluctuations and reductions in annual rainfall have led to severe and frequent droughts throughout the Central and West Asia and North Africa region. Consequently, water resources have become scarce. Increasing municipal and industrial demand for water has resulted in steadily decreasing allocations for agriculture. The major agricultural use of water is for irrigation, which is affected by decreasing supplies. Therefore, innovations are needed to increase efficiency in the use of the water that is available.

A research network across Morocco has developed techniques that improve water productivity. Among the potential techniques and systems is supplemental irrigation and integrated crop management practices, carried out in a participatory manner in which the farmer plays an important role.

The typical Tadla Irrigated Perimeter was chosen as the Moroccan Benchmark site based on agreed criteria between all the stakeholders involved. An integrated research program has been designed and implemented in two representative communities (Ouled Zmam and Bradia) involving the local population, institutions and decision-makers.

In this area, irrigation water consumption varies markedly with water availability, which is very closely related to the rainfall of the previous season. However, farmers are used to applying excess water to their crops. In fact, there are situations where wheat is receiving more than 9000 m^3/ha and sugar beet is receiving more than 12,000 m^3/ha of irrigation water. Moreover, irrigation scheduling is usually not well targeted to the critical stages of the crop, so that it can be used more efficiently. Water is applied by surface irrigation (‘*rabta*’) to plots with a rough surface without any land leveling.

Under these conditions, the yield achieved by farmers in this region is by far lower than the potential. Average yields of 4 t/ha wheat and 40 t/ha sugar beet have been reported.

The main objective of the project is the adoption by farming communities of strategies and tested technologies that optimize the conjunctive use of rainwater and scarce water resources in supplemental irrigation systems for improved and sustainable water productivity in rainfed areas.

The major expected outputs can be summarized as:

- Recommendations for appropriate irrigation systems and schedules to ensure optimal water productivity and net benefits to the rainfed resource users; and
- Strategies for the conjunctive use of rainwater and other scarce water resources in combination to maximize the benefits of each and to increase agricultural productivity in a sustainable way.

To achieve these outputs, improved production techniques compatible with supplemental irrigation have been introduced at the farm level, tested with the full participation of the farmers and evaluated in terms of improved water productivity. Moreover, alternative innovative approaches and practical tools such as models and decision support systems giving enhanced output per unit of water have also been tested.

- The on-farm evaluation trials were conducted jointly with farmers for four years in two representative communities of the Tadla Irrigated Perimeter (Bradia and Ouled Zmam).
- The different themes addressed were:
  - Evaluation of improved surface irrigation and crop management packages;
  - Effect of planting date on wheat production;
  - Identification of wheat varieties adapted to supplemental irrigation;
  - Effect of nitrogen on wheat;
  - Deficit irrigation; and
  - Effect of planting date on sugar beet production.

3.2 Site characteristics and on-farm trials

3.2.1 Climatic conditions

Daily rainfall and air temperatures were recorded at a weather station in the area where the trials were conducted (Lat. 32°3′ N, Long. 6°31′ W, Alt. 450 m). The variation in both parameters is shown in Figures 3.1–3.4. Rainfall varied during the four growing seasons in total amount as well as in distribution. Annual total rainfall was 158.6 mm in the 2004/05 (Figure 3.1), 357 mm in the 2005/06 (Figure 3.2), 296 mm in the 2006/07 (Figure 3.3) and the 288.5 in 2007/08 (Figure 3.4) growing seasons. The first season was dry with most of the rain concentrated at the beginning and in mid-season. During the second season, precipitation was well distributed over the crop growing cycle and the total rainfall matched the 30-year average for the region. The third and fourth years recorded the same total amount of rain for the whole growing season. However, the third year was wet at the beginning, dry in the middle and very wet at the end of the season; and the fourth year was very wet at the beginning, dry in the middle and with only a little rain at the end of the season. This means that, during the life time of the project, we experienced almost all the climatic conditions that generally happen in the area.

Maximum air temperature was high during all four seasons with considerable amplitude reaching up to 18–20°C. The minimum temperature fell below zero only during December/January of the third season.

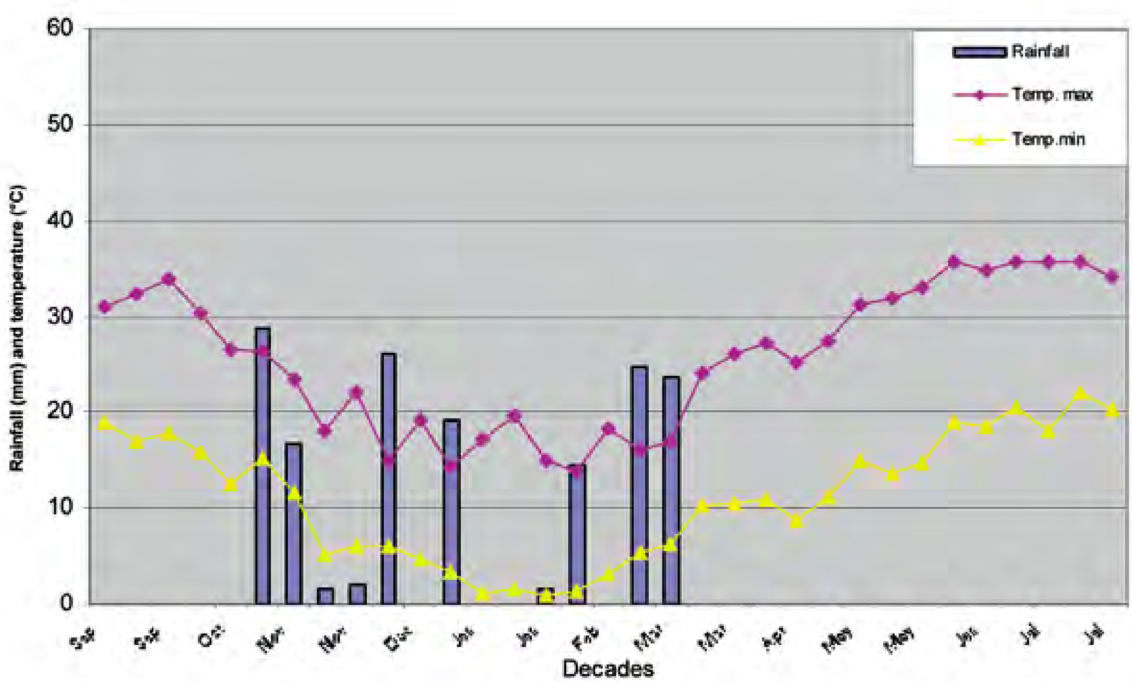

Figure 3.1: Rainfall and temperatures during 2004/05 at Ouled Gnaou Station (Tadla).

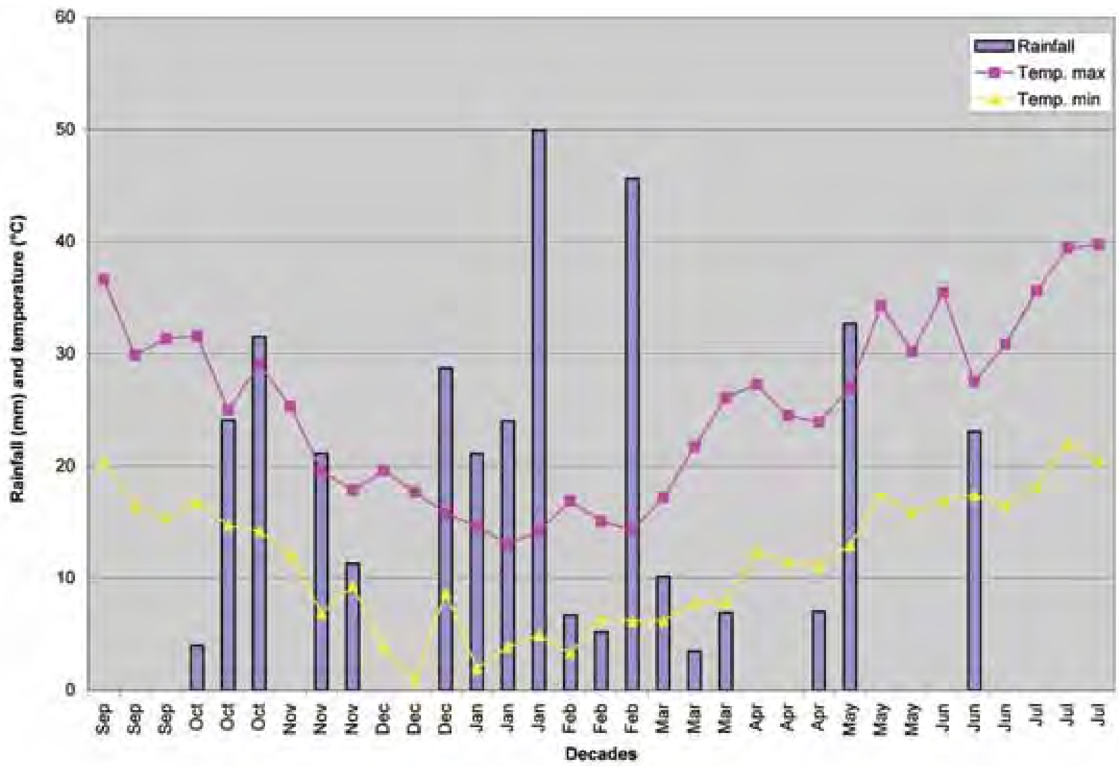

Figure 3.2: Rainfall and temperatures during 2005/06 at Ouled Gnaou Station (Tadla).

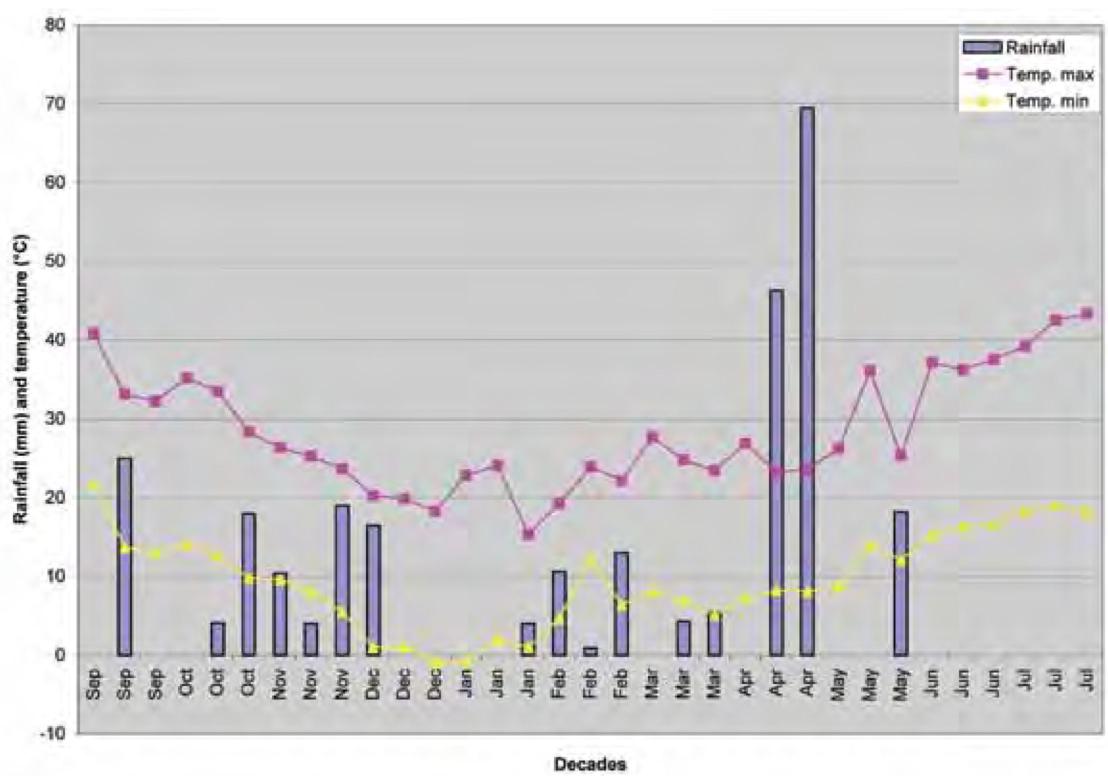

Figure 3.3: Rainfall and temperatures during 2006/07 at Ouled Gnaou Station (Tadla).

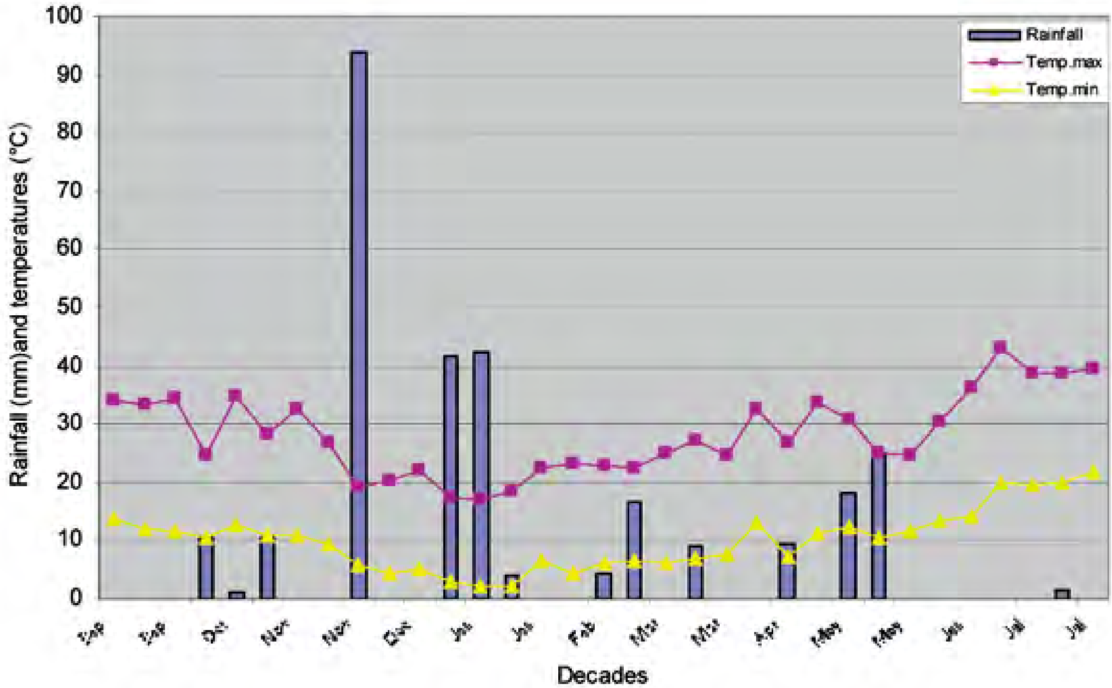

Figure 3.4: Rainfall and temperatures during 2007/08 at Ouled Gnaou Station (Tadla).

3.2.2 Soil characteristics

The dominant soils in the region are mollisols (soil taxonomy), which are deep and suitable for irrigation. Soil depth in the experiment plots varies from 60 cm to little more than 100 cm. These soils have a high water-holding capacity. The average soil water content is 26% at field capacity and 15% at wilting point on a weight basis. The bulk density is around 1.4 but increases with depth. The estimated available water at 80 cm depth is 120 mm, and the readily available water is 80 mm.

The most important constraint relating to the soil is salinity that is increasing from year to year. This salinity comes from two sources: the aquifer (groundwater) and the origin of the Oum Rabia River.

3.2.3 Crop management

Seedbed preparation. In all cases, plots were plowed with a disk-plow (one pass) during the summer or in October. Just before planting, two crossed passes with a disk-harrow were done to smooth the seedbed.
Planting. Some farmers still use hand or mechanical broadcasting of seed. However, in the experiment plots, we used a drill for wheat with a seeding rate of 160 kg/ha.
Weed and pest control. Weed control chemicals were systematically applied at the 3-leaf stage in wheat and repeated, if needed, at the tillering stage to keep the plots free of weeds. In sugar beet, chemical weed control was applied at the 4-leaf stage. Mechanical hoeing was done three to four times during the whole growing cycle. However, to control diseases and insects, chemicals were applied only if the degree of infestation justified treatment in both crops.
Fertilizers. In wheat, nitrogen was applied at planting (40 U/ha), tillering (60 U/ha) and heading (40 U/ha). Phosphorus was applied once at planting (90 U/ha). In sugar beet, nitrogen was applied at planting (60 U/ha), at thinning (60 U/ha) and one month later (60 U/ha). Phosphorus (140 U/ha) and potassium (100 U/ha) were applied at planting. In the case of fertilizer experiments, treatments are specified.
Irrigation. Irrigation from the network (canal) is systematically scheduled by ORMVAT depending on two major components: annual amount of water allocated to

irrigation and annual rainfall. However, an average of three irrigations is given to wheat and four to five irrigations to sugar beet. The amount of water applied per irrigation varies from 60 mm to 120 mm. Some farmers are also able to use groundwater.

3.3 On-farm trials

3.3.1 Evaluation of improved surface irrigation and crop management packages in wheat and sugar beet

The efficiency of surface irrigation is greatly affected by the leveling status of the plot. This method of land management controls water distribution and the progress of humectation of the soil profile. When a field is not well leveled, large spatial heterogeneity in irrigation can be seen. In addition, because of the existence of surface depressions due to inadequate land management, water can be lost through percolation. Supplemental irrigation, where the amount of applied water should be limited, is very sensitive to these problems so water productivity can be affected.

To identify and introduce supplemental irrigation and crop management technologies that improve water productivity, conserve water resources and protect the environment (salt, pesticides, nitrates), water and crop management packages were tested and evaluated at two selected pilot sites and compared to the farmers' usual practice for the main crops – wheat, sugar beet and alfalfa. However, for technical reasons, alfalfa was not sampled for yield estimation.

Land leveling and the crop management package were applied in these trials to six farmers' fields during the first season (2004/05) and only on one farm during the second season (2005/06). Three treatments were compared: 1) farmers' irrigation and farmers' crop management (Farmer); 2) improved surface irrigation with farmers' crop management (Improved-I); and 3) improved surface irrigation and improved crop management package (Improved-IC).

The experiment was initially planned for at least two years for crop rotations, but unfortunately, five farmers dropped out for different reasons.

To calculate water consumption using water balance, soil water content at sowing and at harvesting was measured using the gravimetric method at a depth of 60 cm. To estimate biomass, grain yield and yield components, three plant samples (1 m^2 each in wheat and 4 x 2 m linear for sugar beet) were randomly taken from each plot.

Wheat

During the first growing season, the overall average grain yield was more than 6 t/ha. However, in some farms yields as high as 9 t/ha were achieved. The best yield on all farms was obtained with the improved surface irrigation and crop management package (Table 3.1). The other two treatments gave lower yields and were not significantly different from each other. For the total biomass, the same trend was noticed, but the differences were not statistically significant (Table 3.2).

The difference between farmers (farmers' managed treatment) in terms of grain yield and biomass is also significant showing that some are performing better than others. During the second season, the average yield obtained on the farm was more than 7.7 t/ha grain and 16.5 t/ha as total biomass.

Table 3.1: Wheat grain yield under different packages (t/ha).

Farmer	Treatment		
	Farmer	Improved-IC	Improved-I
Salihi	7.27	8.53	7.86
Guermeh	4.52	4.81	4.01
Zaari	3.04	4.65	4.05
Sefrioui	6.37	7.77	5.96
Sawab	8.48	8.48	8.33
Dehbi	5.93	7.47	4.60
Dehbi (05/06)	6.45	9.53	7.18

Table 3.2: Wheat biomass under different packages (t/ha).

Farmers	Treatment		
	Farmer	Improved-IC	Improved-I
Salihi	15.45	16.2	15.71
Guermeh	10.90	10.98	9.74
Zaari	6.67	9.60	9.27
Sefrioui	12.95	15.91	14.15
Sawab	18.10	17.82	17.83
Dehbi	12.38	15.35	11.12
Dehbi (05/06)	14.41	19.42	15.74

The highest grain yields (9.5 t/ha) and total biomass (19.5 t/ha) were obtained with the Improved-IC treatment. The yield in the Improved-I plot was slightly higher than that of the Farmer; but the difference was not significant.

Water productivity (WP) was calculated based on total water consumption (ET) and yield. The results showed that the improved treatment (Improved-IC) exceeded the two others (Table 3.3).

Table 3.3: Wheat water productivity under different packages (kg/m^3).

Farmer	Treatment		
	Farmer	Improved-IC	Improved-I
Salihi	1.18	1.35	1.25
Guermeh	1.02	1.08	0.92
Zaari	1.56	1.90	1.46
Sefrioui	2.88	2.94	2.83
Sawab	1.38	1.74	1.05
Dehbi	1.07	1.12	1.59
Dehbi (05/06)	1.18	1.35	1.25

Sugar beet

Data show that the average root yield was 41 t/ha and the highest yield more than 70 t/ha during the first growing season (Table 3.4). The difference between treatments was highly significant and, as for wheat, the highest yield was achieved with the improved irrigation and crop management package on all farms. Differences between farmers were also noticed.

Table 3.4: Sugar beet root yield under different packages (t/ha).

Farmer	Treatment		
	Farmer	Improved-IC	Improved-I
Salihi	48.33	65/00	53.33
Guermeh	41.67	51.67	40.00
Sefrioui	41.17	57.13	47.67
Sawab	45.00	71.67	36.67
Dehbi	41.67	55.16	47.33
Dehbi (05/06)	28.00	36.00	32.00

The highest water productivity achieved was 13.5 kg/m^3 with the Improved-IC treatment. The lowest value observed was 5.2 kg/m^3 in one of the Farmer treatments (Table 3.5). Differences between farmers were also observed for this crop.

During the second season, root average yield was 32 t/ha. This yield is relatively low compared to the potential of the region and to that obtained by other farmers. In fact, the trial suffered a severe attack of insects that destroyed part of the foliage during the tuberization stage. Nevertheless, the difference between the treatments was significant and, as for wheat, the best yield was achieved with the improved irrigation and crop management package (Table 3.4). This treatment was followed by the Improved-I and then the Farmer treatment.

Water productivity analysis (Table 3.5) gave the same trend as for the 2004/05 season, with the highest value of 4.4 kg/m^3 obtained in the Improved-IC treatment and the lowest (3.2 kg/m^3) in the Farmer plot.

Table 3.5: Sugar beet water productivity under different packages (kg/m^3).

Farmer	Treatment		
	Farmer	Improved-IC	Improved-I
Salihi	7.05	9.98	7.85
Guermeh	9.27	12.91	9.84
Sefrioui	5.23	7.34	6.05
Sawab	8.19	13.49	7.03
Dehbi	7.47	10.02	8.62
Dehbi (05/06)	3.20	4.40	3.60

3.3.2 Effect of planting date on wheat land and water productivity

Terminal drought characterizes the low-rainfall Tadla area in Morocco. Crop growth is mostly restricted to the short winter growing season, which starts with the autumn rains and ends with declining soil moisture and high temperatures in the spring. Supplemental irrigation is a common practice in this dry environment and aims to improve and stabilize yields by adding small amounts of irrigation water to crops during periods when rainfall fails to provide sufficient moisture for normal plant growth.

In the Tadla region, farmers are used to relying on the first rain to sow wheat. This erratic event may delay planting time up to early December. Under these conditions, the crop will emerge late, lack the ability to compete with weeds, have reduced vigor, and will mature later during the terminal drought and high temperatures. This situation leads to a higher evaporative demand requiring more irrigation water, and consequently reduced water productivity. Therefore, the aim of this study was to introduce early planting techniques combined with supplemental irrigation in the Tadla region.

The trials were conducted during the growing seasons 2005/06, 2006/07 and 2007/08 on three different farms. We worked at three farms during the first season, four farms during the second season and seven during the third. Bread wheat, Achtar variety, was planted in large plots varying in size from 0.25 to 0.5 ha depending on land availability at the farm level. Sowing dates were as shwon in (Table 3.6).

The amount of water applied at sowing for early planting was 50 mm. To calculate water consumption using water balance, soil water content at sowing and at harvesting was measured using the gravimetric method at a depth of 60 cm. To estimate biomass, grain yield and yield components, three plant samples (1 m^2 each) were randomly taken from each plot.

In the 2005/06 cropping season, results show that early planting out-yielded late planting in grains (5.8 t/ha vs 4.6 t/ha) and biomass (13.1 t/ha vs 10.9 t/ha) (Table 3.7). However, the best performing farmer, Ferrari, obtained a grain yield of 8 t/ha with early sowing. Water productivity was also positively affected by planting date. The highest water productivity was 1.4 kg/m^3. In this particular situation, not only was yield higher with early planting, but the farmer also managed to save the third irrigation that was applied in two other fields for comparison purposes. Therefore, water consumption was reduced by 1300 m^3.

During the second season (2006/07), there were significant differences in grain yield and total biomass between farmers and between planting dates. Early planting out-yielded late planting in grain (5.5 t/ha vs 3.8 t/ha) and biomass (13 t/ha vs 9.6 t/ha). However, the highest grain yield of 6.8 t/ha was obtained by Erraji with early sowing (Table 3.8).

In terms of water productivity, the only significant difference between the treatments was for grain in Erraji's plot. For biomass, there was no significant difference between planting dates. The main reason for this was that annual rainfall was very low and the farmers used large amounts of irrigation water in both cases to save their production.

In the third season (2007/08) the average yield was higher than in the two previous seasons. There were significant differences in grain yield and total biomass between farmers and between planting dates. Early

Table 3.6: Planting dates on wheat.

	Season 2005/06	Season 2006/07	Season 2007/08
Early sowing	8 Nov 2005	2 Nov 2006	1–2 Nov 2007
Late sowing (farmer's practice)	24–25 Nov 2005	1 Dec 2006	10–11 Dec 2007

Table 3.7: Biomass, grain yield and water productivity in 2005/06.

Farmer	Biomass t/ha		Grain yield t/ha		ET mm*		GWP kg/m³	
	Early	Late	Early	Late	Early	Late	Early	Late
Zoubdi	9.6	7.7	3.9	3.0	585	565	0.7	0.5
Erraji	13.5	11.8	5.5	4.7	696	724	0.8	0.7
Ferrari	16.3	13.3	8.1	6.1	579	709	1.4	0.9
Mean	13.1	10.9	5.8	4.6	620	666	0.9	0.7
CV	12.8		18.5					
LSD	1.6		1.0					

*estimated ET = irrigation + rainfall + change in water storage of the upper 60 cm soil layer.

Table 3.8: Biomass, grain yield and water productivity in 2006/07.

Farmer	Biomass t/ha		Grain yield t/ha		ET mm*		GWP kg/m³	
	Early	Late	Early	Late	Early	Late	Early	Late
Ferrari	14.8	12.3	5.6	4.3	688	583	0.8	0.7
Hattat	10.3	7.6	3.7	2.3	521	462	0.7	0.5
Erraji	13.1	8.9	6.8	3.9	779	622	0.9	0.6
Benaceur	13.7	9.5	6.1	4.5	641	556	1.0	0.8
Mean	13.0	9.6	5.5	3.8	657	556	0.8	0.7
CV	11.7		17.7					
LSD	1.1		0.7					

*estimated ET = irrigation + rainfall + change in water storage of the upper 60 cm soil layer.

planting date out-yielded late in grain (7.7 t/ha vs 6.2 t/ha), biomass (17.8 t/ha vs 14.7 t/ha) and water productivity (1.2 vs 0.8) (Table 3.9). The increase in yield was 26% for grain and 20% for biomass. However, the increase in water productivity was higher, reaching 50%.

Overall, biomass, grain yield and water productivity were improved by 20%, 26% and 29%, respectively, in the first cropping season; 35%, 45% and 15% in the second season, and 26%, 20% and 50% in the third season. However, a maximum improvement of 110% in water productivity was achieved on Sefrioui's farm in 2007/08. The differences between the three seasons are mainly related to total annual rainfall and its distribution.

Table 3.9: Biomass, grain yield and water productivity in 2007/08.

Farmer	Biomass t/ha		Grain yield t/ha		ET mm*		GWP kg/m³	
	Early	Late	Early	Late	Early	Late	Early	Late
Zoubdi	19.1	17.7	8.8	8.1	762	924	1.1	0.9
Erraji	16.3	13.7	7.3	4.9	806	951	0.9	0.5
Nadi	13.0	9.7	5.4	4.0	820	890	0.7	0.4
Ferrari	16.3	13.3	8.1	6.1	579	709	1.4	0.9
Sefrioui	17.3	13.7	8.2	5.5	559	778	1.5	0.7
Hattat	17.6	12.9	7.0	5.6	595	665	1.2	0.8
Mokhtari	18.8	17.4	8.1	7.4	546	584	1.5	1.3
Mean	17.8	14.7	7.8	6.2	667	786	1.2	0.8
CV	11.1		15.2					
LSD	1.1		0.7					

*estimated ET = irrigation + rainfall + change in water storage of the upper 60 cm soil layer.

3.3.3 Identification of wheat varieties adapted to supplemental irrigation

Many wheat varieties have been selected by INRA Morocco. However, the response of these genotypes to supplemental irrigation is not known. The objective of this study was to identify varieties that have high land and water productivity under the conditions of the Tadla region.

To reach this objective, different varieties of wheat (five durum and five bread) were tested during the first year of the project (2004/05) on three different farms under improved crop management and supplemental irrigation.

Taking into account the results obtained, and to meet the farmers' request to reduce the number of varieties, the best ones were selected and grown for the second and the third seasons (2005/07). The cultivars chosen were Achtar and Mehdia as bread wheats and Tomouh and Marjana as durum wheats.

During the fourth season, in addition to these four varieties, we included four other varieties that were introduced into the region by the seed company; these are the bread wheats Salama and Radia and the durum wheats Carioca and Vitron. The eight varieties were grown under the same protocol as in previous years on six farms over the region.

To calculate water consumption using water balance, soil water content at sowing and at harvesting was measured using the gravimetric method at a depth of 60 cm. To estimate biomass, grain yield and yield components, three plant samples (1 m^2 each) were randomly taken from each plot.

Data showed that during the 2004/05 growing season (Table 3.10), there were highly significant differences in grain yield between different farmers' plots. However, the variety effect showed the same trend over the trials. The highest average grain yield was obtained by Tomouh for durum wheat (6.61 t/ha) and Achtar for bread wheat (6.09 t/ha). But, under the best farmer's conditions, the two varieties yielded 10 t/ha and 8 t/ha, respectively.

Other varieties like Marjana durum wheat and Mahdia bread wheat showed significant potential and were reconsidered for the following seasons.

The average total biomass produced over all the trials showed the same trend as for grain yield with Arrihane having a slight advantage over Mehdia in the bread wheats. The average biomass of Tomouh was 15.6 t/ha and that of Arrihane was 14.2 t/ha which was not significantly different from that of Achtar (13.9 t/ha).

Water productivity also varied from farm to farm. The same varieties as in the grain yield analysis came out best considering different environments. The highest water productivity was shown by Tomouh in the durum wheats (1.65 kg/m^3) and Achtar in the bread wheats (1.51 kg/m^3).

During 2005/06, the results obtained showed significant differences between farmers. The lowest average grain yield and total biomass were achieved in the Ouled Zmam area on Basri's farm (3.7 t/ha and 7.8 t/ha, respectively). However, two other farmers obtained similar results and both are located in Bradia (Table 3.10). The highest average grain yield was 5.9 t/ha harvested from Ferrari's plot. This difference between farmers was mainly due to management.

Within each farm, there were no significant differences between varieties in grain yield or in biomass. The slight increase noted with Achtar on Basri's plot might be due to the drought tolerance of the variety under limited water conditions.

Water productivity was also compared between varieties and from farm to farm. The same trend as for grain yield and biomass was shown. The highest average WP was 1.1 kg/m^3 on Rakioui's plot and the lowest was 0.6 kg/m^3 for Basri's plot.
In 2006/07, significant differences between

Table 3.10: Biomass, grain yield and water productivity for different varieties (2004/2007).

Farmer/Variety		Biomass (t/ha)			Grain yield (t/ha)			Water productivity (kg/m3)		
	Season	04/05	05/06	06/07	04/05	05/06	06/07	04/05	05/06	06/07
Rekioui	Ourgh	10.9			5.6			1.46		
	Marjana	13.0	12.8	20.1	6.9	6.3	9.1	1.78	1.2	1.5
	Tomouh	13.2	12.8	21.2	6.1	5.5	9.3	1.57	0.5	1.5
	Amjad	9.5			5.1			1.3		
	Karim	11.5			6.6			1.7		
	Amal	10.6			5.2			1.35		
	Arrihane	14.6			7.0			1.81		
	Mehdia	12.2	12.5	12.1	6.0	5.6	5.6	1.54	1.1	0.9
	Rajae	14.2			6.2			1.61		
	Achtar	15.8	12.1	19.1	7.9	5.1	8.3	2.06	1.0	1.4
Ferrarri	Ourgh	15.4			7.6			1.97		
	Marjana	13.4	10.6	13.6	6.7	5.8	6.0	1.74	0.9	0.9
	Tomouh	22.5	11.5	16.6	10.2	5.7	6.2	2.66	0.9	0.9
	Amjad	15.0			7.8			2.02		
	Karim	15.8			8.1			2.09		
	Amal	18.4			7.9			2.01		
	Arrihane	16.5			6.2			1.57		
	Mehdia	17.4	14.7	20	7.9	6.5	8.0	2.03	1.0	1.2
	Rajae	15.8			7.1			1.81		
	Achtar	17.2	12.4	19.4	7.6	5.8	8.2	1.92	0.9	1.2
Sefrioui	Ourgh	9.5			2.2			0.46		
	Marjana	9.6			4.5			0.91		
	Tomouh	11.0			3.6			0.73		
	Amjad	8.7			2.3			0.47		
	Karim	9.9			2.8			0.57		
	Amal	8.0			2.6			0.52		
	Arrihane	11.5			3.4			0.69		
	Mehdia	9.1			2.9			0.59		
	Rajae	9.0			2.8			0.56		
	Achtar	8.7			2.8			0.56		
Basri	Marjana		8			3.5			0.6	
	Tomouh		7.3			3.3			0.5	
	Mehdia		7.3			3.4			0.5	
	Achtar		8.3			4.8			0.8	
Hattat	Marjana			7.4			3.0			0.5
	Tomouh			12.2			5.2			0.9
	Mehdia			6.7			2.1			0.4
	Achtar			6.4			2.3			0.4
Benaceur	Marjana			9.2			4.6			0.9
	Tomouh			9.2			4.5			0.9
	Mehdia			8.5			3.6			0.7
	Achtar			7.4			2.9			0.6

farmers' plots were recorded for biomass, grain yield and their water productivity. The lowest grain yield and total biomass averages were obtained on Hattat's farm (3.2 t/ha and 8.2 t/ha, respectively) followed by Benaceur. However, two other farmers performed better and Rekioui obtained the highest production in both biomass and grain yield (21 t/ha biomass and 9.3 t/ha grain). Again, these differences between farmers were mainly due to management. The most important components were related to irrigation scheduling and the state of the plot (essentially seed bed preparation and land leveling).

Within each farm, the two main differences noticed in production were the superiority of Tomouh durum wheat on Hattat's farm and the lower yield of Mehdia bread wheat from Rekioui's plot. However, these differences might be explained by the fact that Tomouh was planted near the irrigation flow gate, and received more irrigation water; and Mehdia suffered more weed infestation (*Bromus*).

Water productivity was also compared between varieties and from farm to farm. The same trend as for grain yield and biomass was shown. The highest average WP was 3.4 kg/m³ for biomass and 1.5 kg/m³ for grain on Rekioui's plot. The lowest was 1.1 kg/m³ for biomass and 0.4 kg/m³ for grain on Hattat's plot.

During the last season (2007/08), difference between varieties was not significant and all of them showed a high production potential (Table 3.11). The average yield achieved was 8 t/ha for grain and 17 t/ha for total biomass. However, in some cases bread wheats Achtar, Salama and Radia exceeded 10 t/ha. Differences between farmers were again noted, but the gap was smaller than in previous seasons.

Water productivity also improved compared to previous years. Indeed, the highest WP for grain was 2.4 kg/m³ and the lowest was 0.8 kg/m³.

3.3.4 Effect of nitrogen on wheat

Nitrogen (N) fertilizer is one of the most limiting factors in crop production after water. The application of N should be carefully managed in terms of quantity and time. The crop requirements, the soil type and characteristics and water availability during the growing season are all parameters that affect the efficiency of nitrogen in crop productivity. The objective of this study was to determine the optimum N rate for wheat in the Tadla region.

Table 3.11: Biomass, grain yield and water productivity for different varieties (2007/08).

Farmer	Variety	Grain yield (t/ha)	Biomass (t/ha)	GWP (kg/m³)
Rekioui	Achtar	8.4	18.2	1.9
	Mehdia	6.8	13.4	1.5
	Salama	5.9	13.8	1.3
	Radia	6.3	15.4	1.4
	Tomouh	9.9	19.8	2.2
	Marjana	8.5	16.0	1.9
	Carioca	8.3	16.3	1.9
	Vitron	8.0	16.1	1.8
Ferrari	Achtar	11.5	27.6	2.2
	Mehdia	9.7	21.0	1.8
	Salama	10.5	22.4	2.0
	Radia	10.0	23.7	1.9
	Tomouh	8.0	22.3	1.5
	Marjana	9.5	19.8	1.8
	Carioca	7.5	16.9	1.4
	Vitron	6.9	15.1	1.3
Nadi	Achtar	8.4	19.4	1.3
	Mehdia	5.2	12.4	0.8
	Salama	6.7	15.0	1.1
	Radia	5.5	12.5	0.9
	Tomouh	6.5	15.0	1.0
	Marjana	7.8	17.2	1.2
	Carioca	7.4	16.2	1.2
	Vitron	7.4	15.9	1.2
Sefrioui	Achtar	8.8	23.8	1.6
	Mehdia	8.6	20.1	1.6
	Salama	6.5	17.8	1.2
	Radia	12.6	25.4	2.4
	Tomouh	6.7	15.2	1.3
	Marjana	8.4	17.7	1.6
	Carioca	7.9	16.5	1.5
	Vitron	7.1	16.2	1.3

On-farm trials testing different rates of N application were conducted on three farmers' plots in Bradia in Tadla over two growing seasons. The rates were chosen to include and to compare with the average amount usually used by farmers, that is around 140 kg N/ha. Therefore, the rates tested were 60 kg N/ha, 120 kg N/ha, 180 kg N/ha and farmers' practice.

To calculate water consumption using water balance, soil water content at sowing and at harvesting was measured using the gravimetric method at a depth of 60 cm. To estimate biomass, grain yield and yield components, three plant samples (1 m^2 each) were randomly taken from each plot.

The results of these trials show that there was no significant difference in grain yield and biomass (Table 3.12) between the rates tested on the same farm. However, the farmer Hattat did not do well. His field was so weedy and heterogeneous that his yield was very low. Even though he applied enough water, the irrigation scheduling used was not the correct one.

The lack of response in yield to an increasing rate of nitrogen observed during the two growing seasons obtained by the other two farmers (Ferrari and Sefrioui) could be largely a result of the high residual nitrogen content of the soil on these farms. Samples taken at planting for nitrogen analysis showed an N concentration varying from 25 to 37 ppm. The organic matter content was also more than 3%. In fact, in the crop rotation (wheat–sugar beet) used in the area, farmers are used to apply high rates of nitrogen to sugar beet without considering the soil content at planting.

On average, water productivity followed the same trend as yield with the highest recorded values of 1.6 kg/m^3 for grain and 3.6 kg/m^3 for biomass at the rate of 120 kg N/ha.

3.3.5 Deficit irrigation and wheat

Research conducted in Morocco and other countries with a similar climate has shown good results from some new technologies at experimental stations and under certain on-farm conditions which need to be scaled-out to increase national crop production, contribute to water saving and ensure sustainability of agriculture in rainfed areas.

In the past, crop irrigation requirements did not take into account available water supplies. The design of irrigation schemes did not address situations in which moisture availability is the major constraint on crop yields. However, in arid and semi-arid regions, major changes are needed in irrigation management and scheduling to increase the efficiency in the use of the water allocated to agriculture.

Table 3.12: Effect of nitrogen rate on biomass, yield and water productivity in wheat.

Farmer	Treatment	Biomass (t/ha)		Grain yield (t/ha)		Biomass WP (kg/m³)		Grain WP (kg/m³)	
	Season	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07
Dehbi/Hattat	60 kg N/ha	14.9	5.2	7.0	1.5	1.3	0.9	0.8	0.2
	120 kg N/ha	12.1	5.2	5.1	1.4	1.2	0.8	0.5	0.2
	180 kg N/ha	14.2	4.6	6.2	1.2	1.2	0.8	0.5	0.2
	Farmer	12.6	6.2	5.4	1.8	1.3	1.0	0.6	0.3
Sefrioui	60 kg N/ha	13.9	16.7	5.4	7.0	2.4	2.6	1.0	1.4
	120 kg N/ha	14.0	17.2	6.1	7.5	2.5	2.7	1.1	1.6
	180 kg N/ha	11.1	15.6	4.7	6.6	2.5	2.5	1.1	1.5
	Farmer	11.3	14.6	3.4	6.4	2.5	2.3	1.2	1.4
Ferrari	60 kg N/ha	16.3	17.9	7.7	7.2	2.0	3.4	0.9	1.1
	120 kg N/ha	17.5	18.9	8.1	8.1	2.4	3.6	1.0	1.2
	180 kg N/ha	15.6	17.0	6.4	7.9	1.9	3.3	0.9	1.0
	Farmer	13.1	18.5	6.8	7.2	1.7	3.6	0.9	1.0

Agronomic measures, mainly cropping practices, have been used successfully to improve water-use efficiency. However, deficit irrigation is another option, with plants exposed to certain levels of water stress either during a particular growth period or throughout the whole growth season, without any significant reduction in yields.

On-farm trials were conducted in the Tadla region to evaluate deficit irrigation techniques in areas where rainfall is usually supplemented by irrigation to ensure adequate crop production. The options tested were 1) irrigation at 70% of field capacity (FC) and 2) irrigation at 100% of field capacity. These two options were compared to the farmers' usual practice.

The trials were conducted during the growing seasons 2005/2006, 2006/2007 and 2007/2008 on two different farms during the first season, on three farms during the second and on six farms during the third. Bread wheat Achtar variety was planted in large plots varying in size from 0.25 to 0.5 ha.

Soil water content was measured at sowing, before each irrigation, and at harvesting by the gravimetric method. To estimate biomass, grain yield and yield components, three plant samples (1 m^2 each) were randomly taken from each plot.

During the first season, grain yields and total biomass obtained showed no significant differences between 70% FC, 100% FC and farmers' practice (Table 3.13). However, the amount of water saved by the 70% FC treatment was substantial (around 1000 m^3). Therefore, in terms of water productivity, the difference was significant and the highest WP was obtained with 70% FC (1.2 kg/m^3) followed by 100% FC (1.1 kg/m^3) then farmers' practice (0.8 kg/m^3).

During the second season, the data showed that the 70% FC treatment gave as much grain yield and biomass as 100% FC and the farmers' practice (Table 3.14). The increase in yield was not statistically significant because of a high variability noted among samples. However, the amount of water saved by this option was substantial (around 1200 m^3 on average).

Water productivity for grain production was different in the case of Rekioui, where the 70% FC treatment was followed by the farmers' practice and exceeded the 100% FC. The highest WP obtained was 2 kg/m^3 grain.

In 2007/08, there were no significant differences in average grain yield nor in biomass between the treatments (Table 3.15). 70% FC and 100% FC gave as much as the farmers' usual practice even though the amount of irrigation water applied was higher at the farmers' level. The only situation where yield was significantly reduced in 70% FC treatment was on Rekioui's farm.

Water productivity for grain was variable from farm to farm because of the amount of

Table 3.13: Biomass, yield, actual evapotranspiration (ETa) and water productivity under different irrigation regimes (2005/06).

Farmers	Treatment	Biomass (t/ha)	Grain yield (t/ha)	Eta (mm)	GWP (kg/m^3)
Rekioui	Farmer	10.7	4.4	527	0.8
	70% FC	12.6	5.7	431	1.3
	100% FC	12.2	5.4	472	1.1
Hattat	Farmer	11.2	4.6	555	0.8
	70% FC	12.3	5.0	449	1.1
	100% FC	11.7	5.1	485	1.1
CV		12.2	12.1		
LSD Farm		1.5	0.6		
LSD Trt		1.8	0.8		

water applied. However, WP as high as 2.3 kg/ha was achieved on Hattat's plot.

Throughout the whole set of trials, differences among farmers remained high. This means that the potential for water productivity improvement and water saving exists in the region. However, more effort should be made in terms of extension and diffusion of suitable techniques and management.

Table 3.14: Biomass, yield, actual evapotranspiration (ETa) and water productivity under different irrigation regimes (2006/07).

Farmers	Treatment	Biomass (t/ha)	Grain yield (t/ha)	ETa (mm)	GWP (kg/m³)
Rekioui	Farmer	17.3	7.5	556	1.3
	70% FC	17.4	7.5	372	2.0
	100% FC	17.2	7.3	426	1.7
Dehbi	Farmer	15.0	6.0	533	1.1
	70% FC	9.2	4.9	411	1.0
	100% FC	11.3	5.1	508	1.0
Hattat	Farmer	9.9	3.3	527	0.6
	70% FC	6.4	2.8	338	0.8
	100%	7.0	2.4	512	0.5
CV		9.0	17.6		
LSD Farm		1.2	0.9		
LSD Trt		1.2	0.9		

Table 3.15: Biomass, yield, actual evapotranspiration (ETa) and water productivity under different irrigation regimes (2007/08).

Farmer	Treatment	Biomass (t/ha)	Grain yield (t/ha)	ETa (mm)	GWP (kg/m³)
Rekioui	Farmer	16.3	8.0	526	1.5
	70%	12.9	4.8	388	1.2
	100%	15.6	7.6	662	1.1
Nadi	Farmer	16.5	8.1	618	1.3
	70%	12.2	5.6	554	1.0
	100%	15.6	7.5	769	1.0
Erraji	Farmer	10.3	4.5	439	1.0
	70%	12.7	3.7	371	1.0
	100%	12.9	4.8	590	0.8
Hattat	Farmer	16.9	7.9	427	1.8
	70%	18.3	8.3	361	2.3
	100%	14.8	6.8	711	1.0
Sadraoui	Farmer	14.6	6.6	616	1.1
	70%	14.1	5.8	533	1.1
	100%	15.2	7.4	629	1.2
Dahbi	Farmer	19.3	8.6	494	1.7
	70%	17.3	7.3	452	1.6
	100%	17.7	8.3	791	1.1
CV		14.1	18.1		
LSD Farm		2.1	1.2		
LSD Trt		1.7	1.1		

3.3.6 Effect of planting date on sugar beet production

Sugar beet is a crop contracted by sugar factories. Therefore, the planting schedule is usually pre-established by the factory so that delivery of the product at harvest can be scheduled too, to facilitate its processing.

To evaluate the effect of different planting dates on sugar beet production, 7 and 12 farmers, who planted at different periods, were selected in the first and second seasons, and the data from their plots were collected. These farmers were divided into three groups according to planting date – early, intermediate and late.

During the first season, results showed that early planting improved root yield and water productivity for root and sugar production. The relative sugar content was not affected (Figures 3.5 and 3.6).

During the second season, the results showed a net decrease in yield, water productivity and sugar content with a delay in planting sugar beet (Figure 3.7). The average losses in yield, sugar content and water productivity due to the delay in planting were 43, 15 and 43%, respectively.

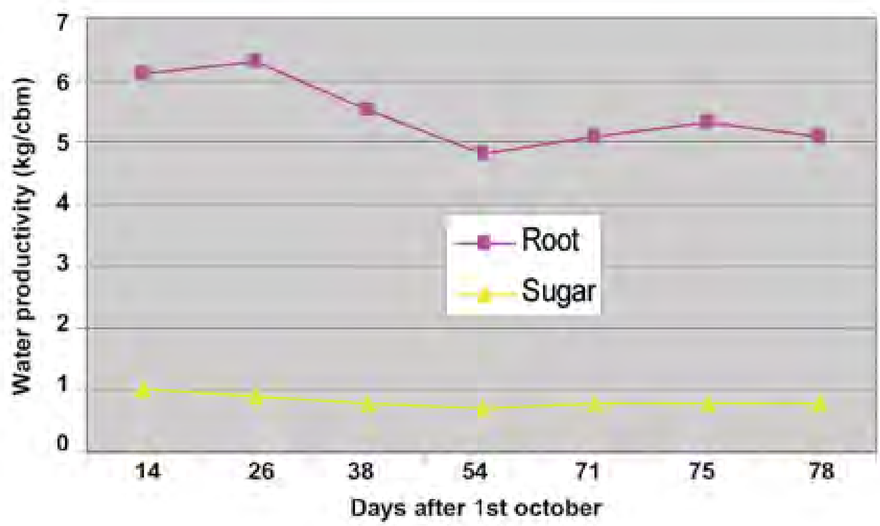

Figure 3.5: Water productivity of sugar beet under different planting dates in Tadla (2005/06).

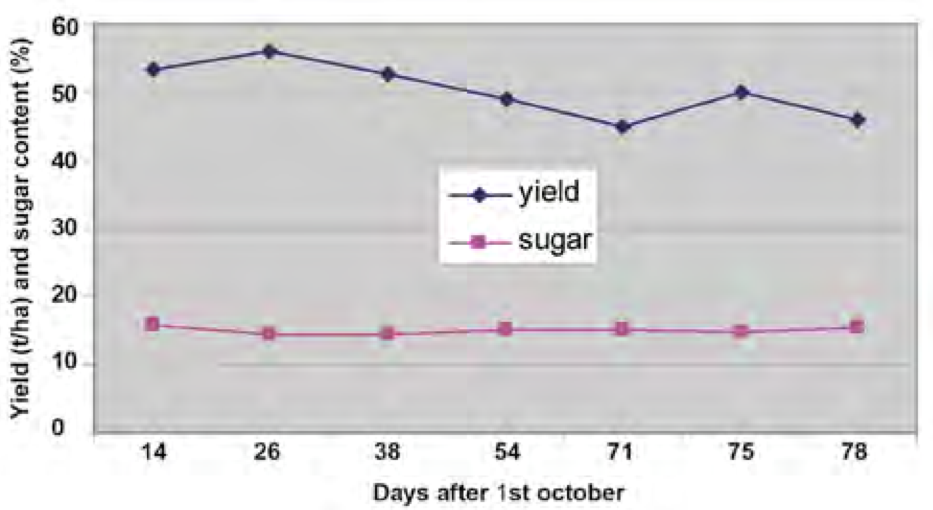

Figure 3.6: Sugar beet yield under different planting dates in Tadla (2005/06).

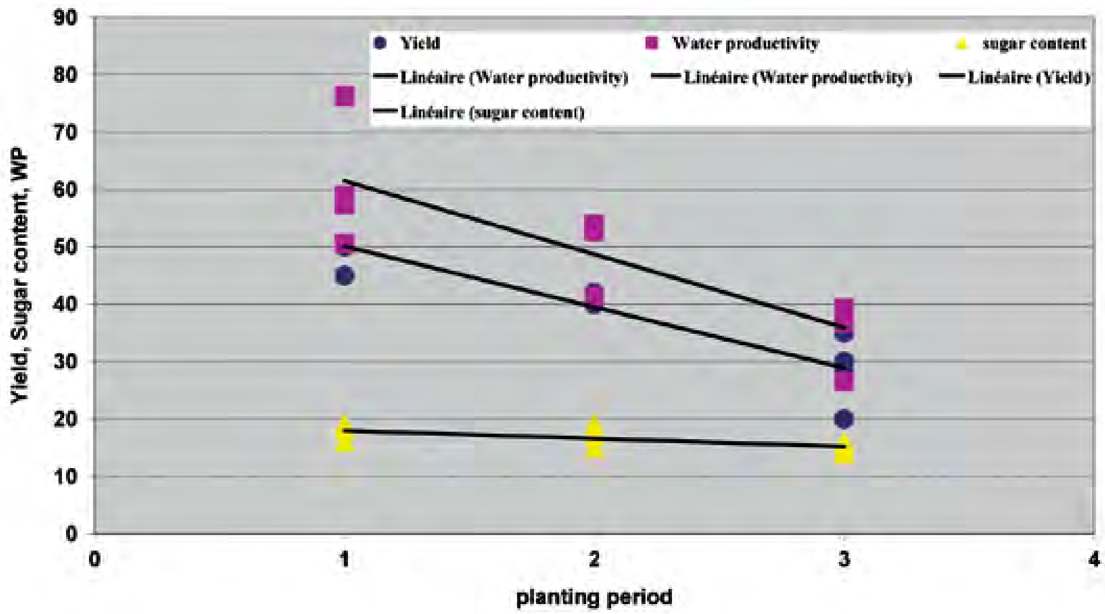

Figure 3.7: Yield (t/ha), sugar content (%) and water productivity under different planting dates of sugar beet (Tadla 2007).

3.3.7 Conclusion and recommendations

On-farm evaluation trials were conducted in the Tadla area with the full involvement of farmers and extension services. These trials lasted for four years and covered different technologies and technical packages that improve water productivity in crop production.

Results show an important positive impact of technologies on yield, water productivity and irrigation water saving in the Tadla Irrigated Perimeter. If we consider the average yield and water productivity of the whole area achieved by farmers (4 t/ha wheat, 0.7 kg/m^3) the improvement due to the new technologies can be estimated at more than 150% as grain yield and 300% as water productivity. With the technologies where irrigation water saving was the main target (planting dates and deficit irrigation), amounts of 1000 to 1300 m^3 were saved. During the initial years of the project, we noted considerable variability in yield between farmers participating in the trials. But, in the final year the gap between the farmers collapsed. In fact, farmers were more convinced and had mastered the introduced technologies. However, Irrigation Water Services have to make more effort to allocate water better in terms of scheduling and quantities.

These technologies and packages should now be taken out to other communities and then to other areas having the same climatic and agronomic conditions. In Morocco, the Haouz, Gharb and Doukkala Irrigated Perimeters are of great importance. However, to ensure more efficient technology transfer and diffusion, technical assistance is highly recommended.

Chapter 4: Evaluation of the CropSyst model in wheat

Chapter 4: Evaluation of the CropSyst model in wheat

H. Benaouda, A. Arfani and M. Karrou

4.1 Introduction

CropSyst is the crop growth model chosen as a decision tool for the Tadla Benchmark project. CropSyst is a daily time step simulation model. The model was developed to serve as an analytic tool to study the effect of cropping systems management on productivity and the environment. The model simulates the soil water budget, soil–plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production, and decomposition. Management options include cultivar selection, crop rotation, irrigation, nitrogen fertilization, tillage operations, and residue management. Simulation parameter organization is based on separate component input files for location, soil, crop, and management data. The simulation control file is built up by combining these component files. The objective of this study was to evaluate the CropSyst model under the conditions of the Tadla region.

4.2 Methodology

An evaluation of the CropSyst model was undertaken using data from the on-farm trials carried out during the 2006/07 cropping season with the Ouled Zmam and Bradia communities. Simulations were made for the effects of planting date, variety and deficit irrigation. Simulated and observed grain yield and evapotranspiration were compared. Other scenarios for planting date and irrigation were also simulated. Details of the conditions and treatments applied in these trials (planting date, variety and deficit irrigation) are described in the previous chapter.

4.3 Results

4.3.1 Planting date

Sowing is a critical operation in crop production in the Tadla region. An optimal planting date that allows for the early establishment of a good stand can reduce the effect of water stress due to the reduction of soil evaporation and allow the crop to drought escape. However, the choice of sowing date is a difficult decision for the farmer to make under conditions where the risk of drought is high. Consequently, using models like CropSyst as a decision-making tool to forecast sowing will help farmers decide on when to plant.

The evaluation of CropSyst for planting dates was made using four on-farm-trials in Ouled Zmam and one in Bradia. Two planting dates were tested early planting in early November, and late planting in early December.

Despite differences between the predicted and observed yield at four sites, the trend is for yield to increase with early planting in both predicted and observed situations (Figure 4.1).

Figures 4.2 and 4.3 show the relationship between observed and predicted grain yield and between evapotranspiration.

4.3.2 Variety

Because of the limitations of genetic coefficients, we used only one variety, Achtar. The results show significant differences between observed and

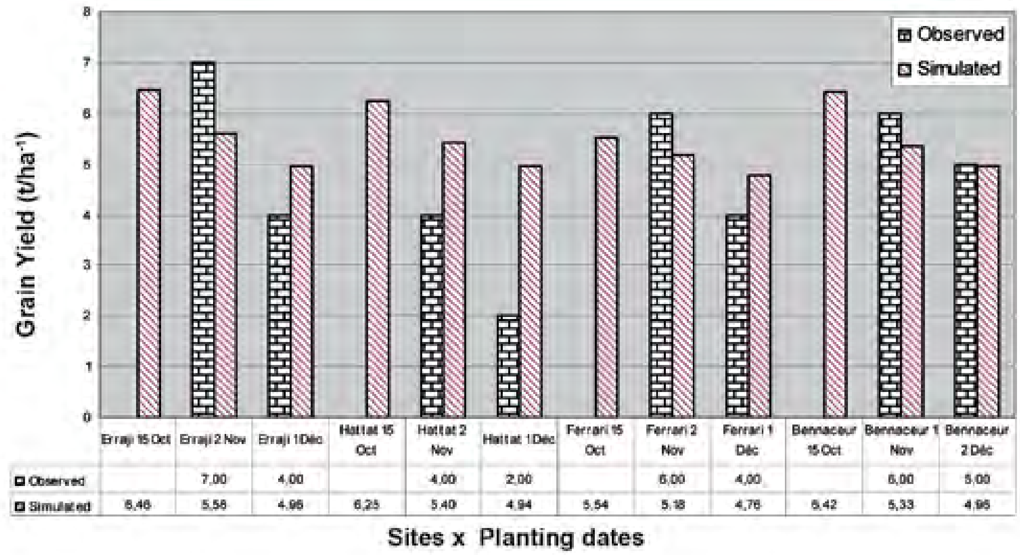

Figure 4.1: Simulated and observed wheat yield with different planting dates 2006/2007.

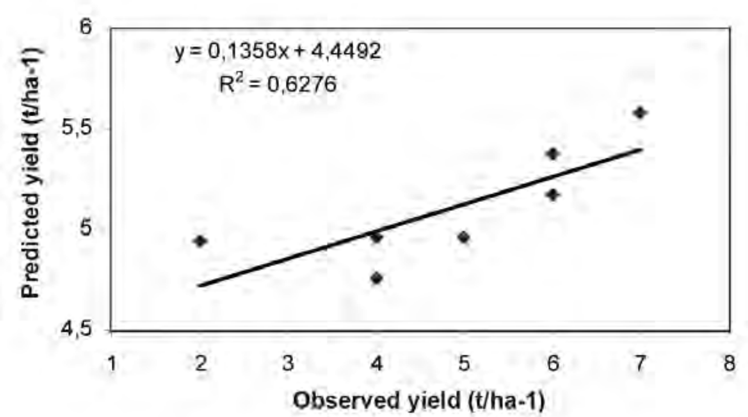

Figure 4.2: Relationship between observed and predicted grain yield.

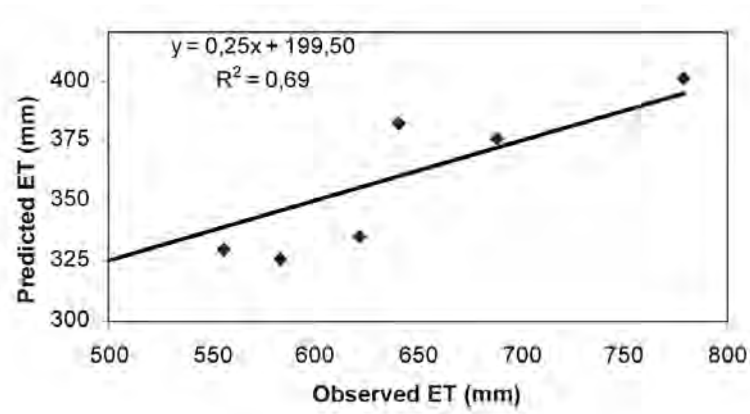

Figure 4.3: Relationship between observed and predicted evapotranspiration.

simulated grain yield for this variety on three farms under different management (Figure 4.4), contrasting with the better simulation performance seen in 2005/06 (data not shown). However the positive effect of early planting on crop performances was confirmed (Figure 4.4).

4.3.3 Deficit irrigation

The evaluation of CropSyst for deficit irrigation techniques was made with data collected from three on-farm trials in Ouled Zmam and Bradia. The options that were tested were irrigation at 70% of field capacity and irrigation at 100% of field capacity. These two options were compared to the farmers' usual practice.

In contrast to the results obtained in the 2005/06 cropping season (data not shown). CropSyst simulation showed no yield differences between irrigation options under 2006/07 conditions (Figure 4.5). The predicted average yield was about 5 t/ha at the three farms, although the observed yield shows major differences between farmers, varying from 2 to 8 t/ha.

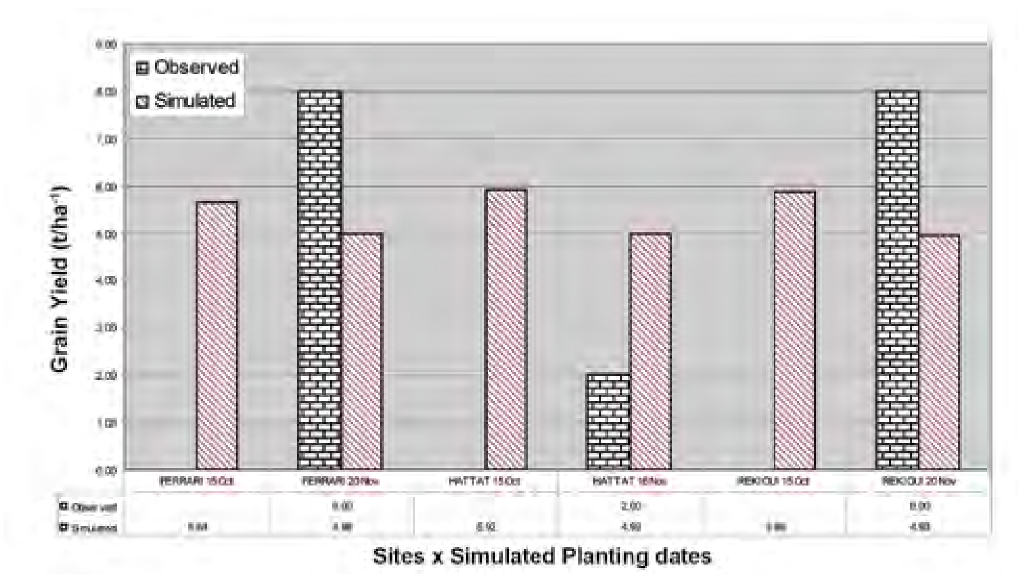

Figure 4.4: Simulated and observed yield of wheat, Achtar variety 2006/2007.

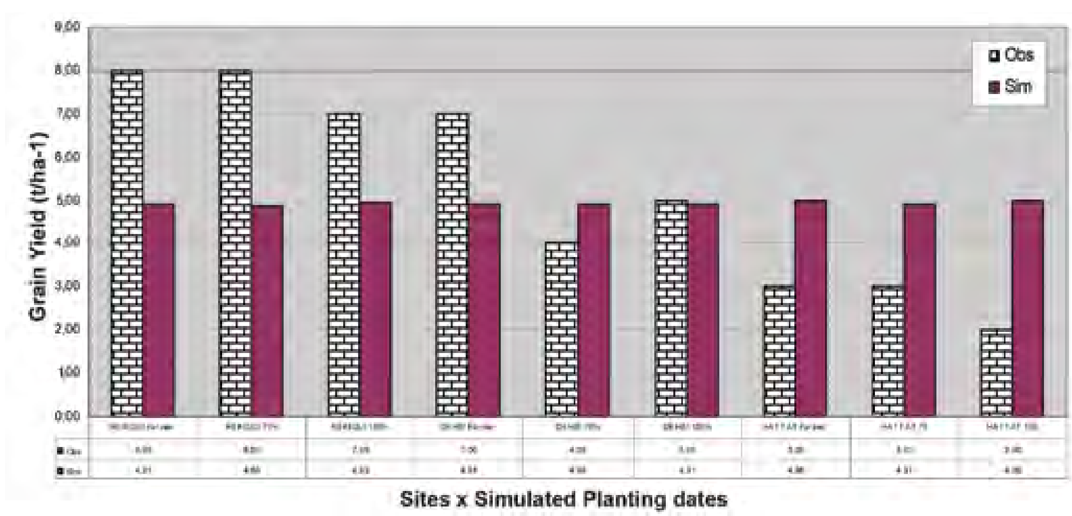

Figure 4.5: Modeling deficit irrigation in on-farm trials, 2006/2007.

Chapter 5: Improved package for drip irrigation and fertigation of citrus

Chapter 5: Improved package for drip irrigation and fertigation of citrus

B. Bouazzama and A. Bahri

5.1 Introduction

In Morocco, citrus is one of the main fruit trees. It is cultivated over an area of approximately 81,500 ha (MAPM, 2007), which represents nearly 10% of the area occupied by fruit trees in the country. In Tadla, citrus orchards cover about 11,461 ha, representing 14.1% of the national citrus area and 11.7% of the total cropped area in Tadla.

Among cultivated varieties, Maroc Late remains the most common nationally because of its productivity and adaptation to most climates. In the Tadla region, it currently covers 3574 ha (MAPM, 2007). The average yield of this variety under traditional surface irrigation systems is about 20 t/ha (ORMVAT. 2005) which is below the potential of the region (over 30 t/ha) (Bouazzama. 2004). Like other crops (alfalfa, cereals and sugar beet), citrus suffered from water shortages over recent years because of more frequent droughts and water scarcity.

In addition to its role in water saving, drip irrigation offers many other advantages, important among which are improved crop yields, better product quality and lower production costs. Because of these advantages, citrus producers are now switching from surface to drip irrigation. This operation (conversion) is encouraged by the Government of Morocco which contributes 60% of the total cost of conversion.

However, a survey conducted in 23 citrus orchards that had converted from surface to drip irrigation, showed that there were still problems associated with irrigation management. The results of the survey showed that the ratio of water supply to crop water requirement ranged from 0.7 to 1.5 in 39%, from 1.6 to 2.3 in 48% and from 2.6 to 2.9 in 13% of the orchards surveyed (Bouazzama and Bahri, 2007).

To promote more efficient water use and so respond to one of the main objectives of the Benchmark project, we conducted an experiment in a farmer's citrus orchard over two years. The principal objective was to introduce an improved technical package for drip irrigation and fertigation at the farm level, taking into account crop water needs and so improve efficiency in the use of inputs.

5.2 Materials and methods

The experiment was conducted in a farmer's citrus orchard in the Bradia area of the project. The trial consisted of applying a pre-established irrigation and fertigation program to one part of the orchard, while using the farmer's usual practice on another part as a check.

Irrigation requirement (IR, mm/day) is given by the equation:

$$IR = Kc * ET_0 - Pe$$

where:
Kc: crop coefficient (Doorenbos and Pruitt, 1986)
ET_0: reference evapotranspiration (mm) calculated at Ouled Gnaou Meteorological Station
Pe: effective precipitation (mm), 80% of rainfall is considered effective.

The quantity of irrigation water (mm/day) per treatment is given by:

$BNI = IR * 1/E * 1/Cu * k$ (mm/day) (Vermeiren and Jobling, 1983)

where:
E: efficiency of drip irrigation considered to be equal to 0.9
Cu: uniformity coefficient (%) measured in situ
k: reduction coefficient calculated as:

$k = Cs + 0.5\,(1 - Cs)$ (Vermeiren and Jobling, 1983)

where:
Cs: soil crop coverage coefficient
Irrigation duration per treatment is:

$T = \frac{BNI}{Pf}$ *n* (h, min) (Vermeiren and Jobling, 1983)

$pf = \frac{n * Q}{A}$ is fictive rainfall

where:
n: number of emitters per tree
Q: emitter average flow (m^3/s) measured in situ
A: area per tree (m^2)

In parallel to the irrigation treatments, ten spring shoots were chosen and marked on trees in both treatment areas at the beginning of the crop growth cycle at the end of March. These observations depend on the production parameters of the variety studied.

In an attempt to ensure more homogeneity between the selected shoots and to limit the effect of other factors (orientation and location on the tree), all the chosen shoots were at adult height and on the southern side of the tree. At the beginning of July, ten fruits were also selected from each treatment and the growth in their diameter recorded. This operation continued until March of the following year. At harvest (beginning of May), the yield per tree and fruit size were measured. Juice and citric acid content were measured in the laboratory.

5.3 Results and discussion

5.3.1 Changes in ET_o

In establishing the irrigation program, we used the monthly mean reference evapotranspiration (ET_0) calculated over a period of ten years (1995–2004) using the Penman-Monteith model (Smith et al., 1991; Allen and al., 1998). Climatic data used were collected from the Ouled Gnaou Station. Figure 5.1 illustrates the average daily change in ET_0 over the year.

We can see that the average ET_0 is moderate at the start of the cycle, reaches a maximum of 6.7 mm/day in July, and then drops again during the rainy season. Figure 5.1 shows that the sum of ET_0 over the trial period was about 1280 mm. Rainfall during this same period was about 292 mm.

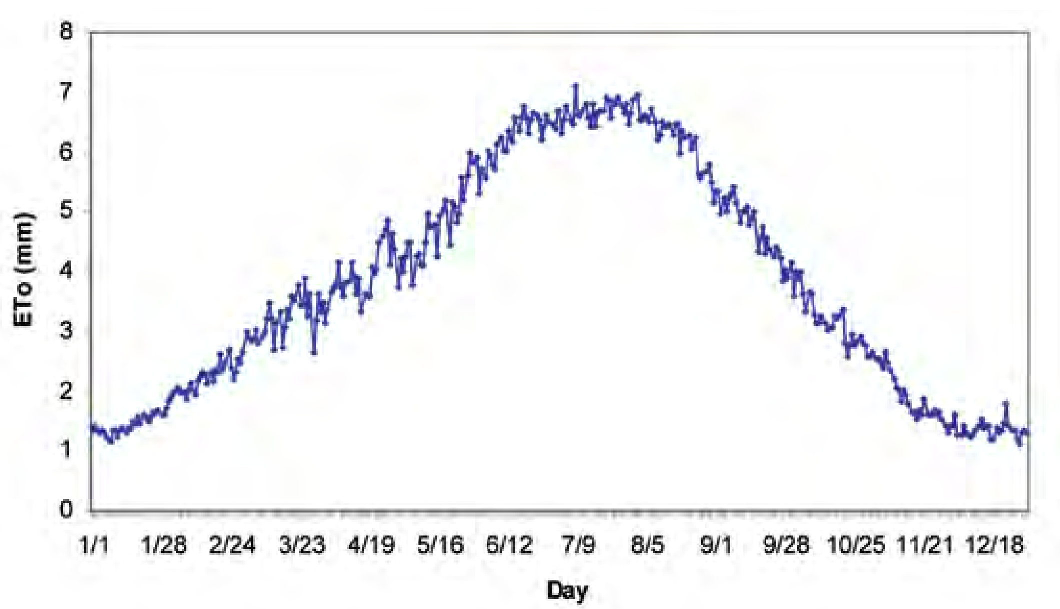

Figure 5.1: Average daily change in ET_o over the year at Ouled Gnaou Station.

5.3.2 Assessment of the installation

Before establishing the improved irrigation program, we tested the system by measuring performance indicators – the uniformity of distribution (CU), the medium flow and the pressure at the end of the ramps. This operation was carried out in the sector controlled by valves. The results are given in (Table 5.1).

Table 5.1: Values of performance indicators.

Indicator	Mean
Uniformity coefficient (%)	91
Average water flow (l/h)	3.96
Average pressure (bar)	0.8 to 1.0

5.3.3 Establishing the irrigation and fertigation program

The improved irrigation program handed over to the farmer shows the daily duration of irrigation to apply during each month.

The results of the evaluation described above together with the architecture of the installation (number of emitters per tree and planting density) allowed the following irrigation program to be developed (Table 5.2).

To determine the fertilizer application plan, we took a composite soil sample from the orchard housing the trial. Three soil horizons were sampled (0–30, 30–60 and 60–90 cm). The laboratory analyses allowed us to determine the amount of fertilizer (kg) to be applied to the trial orchard (1.5 ha) (Table 5.3).

The amounts of irrigation water used during 2005/06 were 9941 m^3/ha and 7153 m^3/ha for the farmer's practice and improved program, respectively. Consequently, 2788 m^3/ha of water were saved by using the improved drip irrigation program.

During the second season, the amounts of irrigation water used were 8963 m^3/ha and 6907 m^3/ha for the farmer's practice and improved program, respectively, and hence the quantity of water saved was 2056 m^3/ha. The difference in water saving seen between the two seasons was due to the difference in rainfall and the farmer's practice which started to change as a result of the trial results obtained during the first year.

Table 5.4 shows the amount of fertilizer applied per hectare. Differences between the two treatments in the type and quantity of fertilizer is due to the fact that the farmer used a fertilizer formula recommended to him by ORMVAT the previous season, while in the improved program we used a formula based on the soil analyses carried out at the beginning of the season (January 2007).

Table 5.2: Improved irrigation program.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET_0, mm	46.1	63.9	98.9	120.5	150.7	187.3	203.8	190.4	138.4	96.9	58.8	42.9
Kc	0.62	0.62	0.67	0.67	0.67	0.72	0.72	0.72	0.72	0.72	0.67	0.67
ETM, mm	28.6	39.6	66.2	80.8	100.9	134.8	146.8	137.1	99.6	69.8	39.4	28.8
Duration, min	27	41	62	78	97	130	141	132	96	67	38	28

Table 5.3: Improved fertigation program.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Ammonium nitrate	33	30	0	0	131	140	179	65	0
Mono-ammonium phosphate (MAP)	8	18	26	35	18	3	0	0	0
Potassium nitrate	0	0	110	156	69	75	87	69	12

Table 5.4: Type and amount of fertilizer applied in each treatment.

Type of fertilizer	Farmer's practice	Improved irrigation program
Ammonium nitrate	309	385
Mono-ammonium phosphate (MAP)	92	72
Potassium nitrate	252	385
Calcium	85	0
Magnesium sulfate	10	0

5.3.4 Soil moisture

Soil moisture measurements at different depths around the emitters allowed us to compare the two treatments and to assess the quality of irrigation. Soil samples were taken under the emitter (0 cm) and 40 cm from the emitter (40 cm to the left and 40 cm to the right of the emitter). Figures 5.2 and 5.3 illustrate the distribution of soil moisture for the two treatments in 20 June 2007.
These figures indicate that:

- Soil moisture decreases with depth in the improved program and thus less water is used.
- Soil moisture varies between 16 and 27% around the emitter using the farmer's practice. In our improved program it varies from 24.8% at the surface to 10% at a depth of 120 cm.

5.3.5 Physiological parameters

Flowering rate and number of fruits

The average values for these parameters in each treatment during the two seasons are given in Table 5.5. Statistical analysis shows that the differences are not significant ($p<0.05$). The values of the parameters in 2007/08 are lower than those during 2005/06. This can be explained by the high level of rainfall during April 2007 (118 mm) which coincided with the flowering stage causing flower losses. Previous studies on the same variety at the Regional Agricultural Research Centre (Centre régional de la recherche agronomique, CRRA), Tadla (Bouazzama et al., 2008), showed that flowering and fruit set were limited by high rainfall.

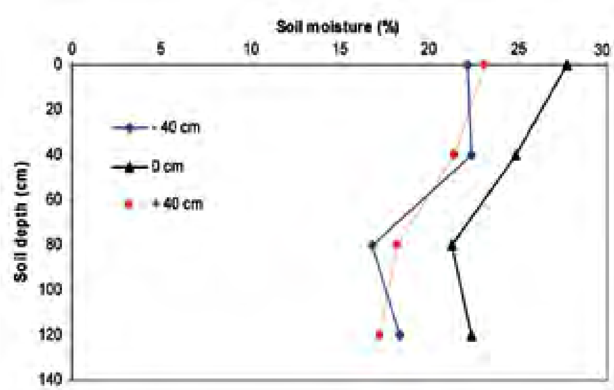

Figure 5.2: Soil moisture profile- farmer's treatment.

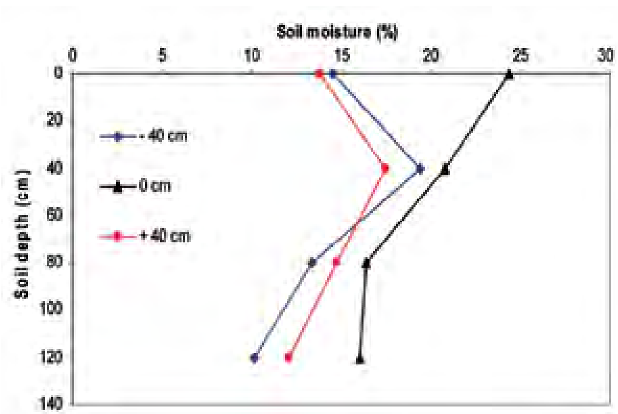

Figure 5.3: Soil moisture profile-improved irrigation program.

Table 5.5: Flowering and fruit set rates for the farmer's and improved treatments.

Parameter	Farmer's practice		Improved irrigation program	
	2005/06	2007/08	2005/06	2007/08
Flowering rate	0.68	0.66	0.78	0.71
Number of fruits (rate)	0.66	0.62	0.73	0.64

Vegetative growth

Monitoring of vegetative growth was limited to the spring shoots. Figures 5.4 and 5.5 show that shoot length was longer using the farmer's practice in each season since more water was used in his treatment.

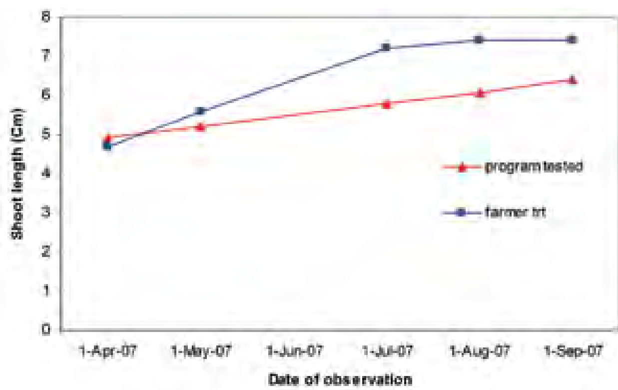

Figure 5.4: Shoot length evolution- 2007/2008

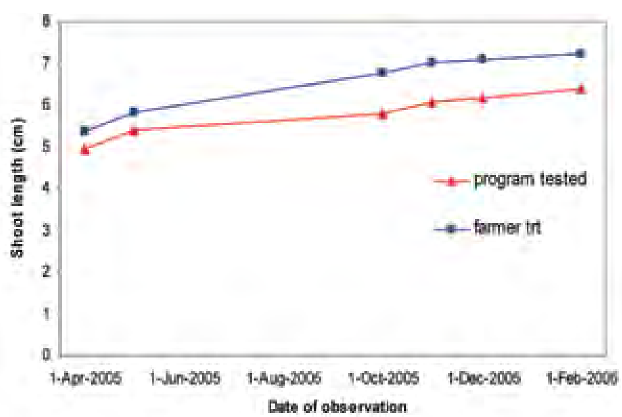

Figure 5.5: Shoot length evolution- 2005/2006

Yield and fruit grade

Statistical analysis ($p<0.05$) (Table 5.6) shows that there is no significant difference in yield between the two treatments (CV varies from 8.2% to 17.4%). For both seasons, the yield obtained using the farmer's practice was higher due to the amount of water applied by the farmer. The values obtained in 2007/08 are better than those recorded in 2005/06 because the fertilization is not applied in this season (05/06). There was a significant difference in water productivity between the two treatments ($p<0.05$). In all cases, our improved program resulted in greater water productivity.

Fruit quality

Statistical analysis ($p<0.05$) shows that:

- for both seasons, there was a significant difference in juice content between the two treatments; but
- there was no significant difference ($p<0.05$) between the two treatments in citric acid content.

These results are confirmed by a previous study on the same variety, carried out at CRRA Tadla (Bouazzama et al., 2008). The juice content increases and the citric acid content decreases with more water (table 5.7)

Fruit grade distribution is shown in Figures 5.6 and 5.7. The differences between the two treatments are marked during the second season (07/08). Small grades dominate on the trees irrigated using the farmer's practice, while large fruits are well represented on the trees under the improved program. It is known that the diameter of fruits increases with more irrigation water but decreases when the tree produces a lot of fruit.

5.4 Conclusions

Applying the improved irrigation program saved 2788 m^3/ha and 2060 m^3/ha of water in the first and second season of the trial, respectively;

Applying more water does not necessarily mean producing significantly more. In the first season, we obtained 31.8 t/ha for the improved irrigation program versus 35.6 t/

Table 5.6: Yield and water productivity per treatment and per season.

Parameter	Farmer's practice		Improved irrigation program	
	2005/06	2007/08	2005/06	2007/08
Average yield (t/ha)	35.6	44.5	31.8	38.1
Water productivity (kg/m^3)	3.58	4.62	4.44	5.18

Table 5.7: Juice and citric acid contents per treatment and per season.

Parameter	Farmer's practice		Improved irrigation program	
	2005/06	2007/08	2005/06	2007/08
Juice content (%)	46.0	51.6	43.0	48.2
Citric acid content (%)	1.80	1.09	2.00	1.12

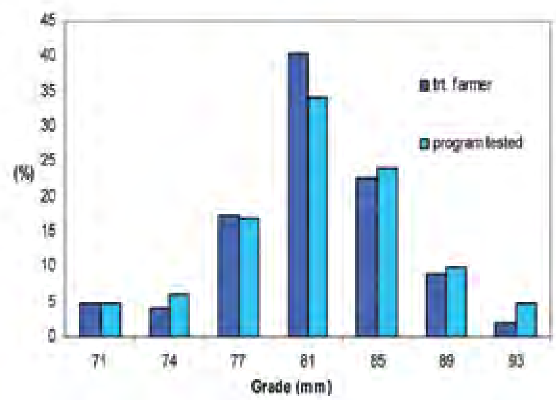

Figure 5.6: Percent distribution of fruit grades in the seasons 2005/2006

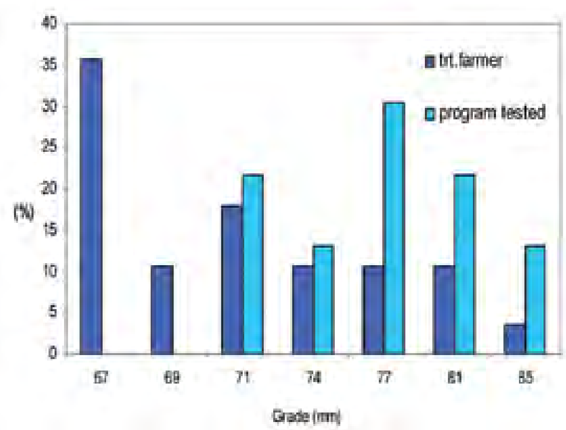

Figure 5.7: Percent distribution of fruit grades in the seasons 2007/2008

ha for the farmer's practice. In the second year, yields improved by 45.1 and 38 t/ha for the farmer's practice and our program, respectively.
Water productivity is significantly higher using the improved irrigation program compared to the farmer's practice.

There is a need for an economic evaluation that will consider the amount of water saved, yield obtained and fruit quality comparing the improved irrigation program to the farmer's practice.

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Chapter 6: Economic evaluation and adoption of improved technologies

Chapter 6: Economic evaluation and adoption of improved technologies

M. Boughlala, M. Boutfirass, A. Bahri, M. Karrou, B Benli and T. Oweis

6.1 Economic evaluation of improved technologies

6.1.1 Introduction

Nowadays, many agricultural researchers incorporate some level of economic analysis in their decisions concerning which alternative technologies or practices to recommend to farmers to improve their incomes. This is in contrast to the previous two decades, when little or no economic criteria were included in the decision-making process. At that time, research recommendations were based only on yield increases. Those recommendations were biased by supposing that this is the only factor farmers consider when making decisions. However, it is clear that other criteria such as costs, returns and risks may impact profitability, and therefore must be taken into account in the early stages of research planning and analysis. In reality, farmers often manage a very complex system of enterprises that may include various crops, animal production and off-farm activities. However, they are interested in the economic performance of the technology. In fact, they attempt to evaluate the net benefits of different interventions and usually take risk into account. They may prefer stable returns to the highest one when risk criteria are considered. To achieve a higher rate of adoption for a new technology, researchers must be aware of the social and economic elements of farming, as well as the biological ones.

In this study, an economic evaluation of water-use efficiency technologies proposed and tested by the agronomic team in the Tadla Irrigated Perimeter was carried out. To capture climatic variability, the analysis was conducted during two contrasting years (dry and wet). Total annual rainfall was 357 mm in 2005/06 (wet year) and 296 mm in 2006/07 (dry year). During the first year, precipitation was well distributed throughout the season. However, the second year was wet at the beginning, dry in the middle and very wet at the end of the season.

6.1.2 Methodology

A field experiment and evaluation was carried out with the two Benchmark communities during three cropping seasons (2005/06, 2006/07 and 2007/08). The five technologies evaluated in this chapter are well described in the biophysical reports (see Chapter 4). The proposed water-use efficiency technologies in this study were:

- Optimal rate of nitrogen. This fertilizer trial consisted of three rates of nitrogen (60 kg N/ha, 120 kg N/ha and 180 kg N/ha) and the farmers' usual practice.
- Improved surface irrigation. Three treatments were compared: 1) farmers' usual irrigation and crop management (Farmer); 2) improved surface irrigation with farmers' usual crop management (Conventional); and 3) improved surface irrigation and crop management package (Improved). This technology was tested by one farmer in Bradia community.
- Wheat varieties adapted to supplemental irrigation. The varieties tested in the two communities included the bread wheats Mehdia and Achtar and the durum wheats Tomouh and Marjana. Achtar variety represents the farmers' usual practice.
- Optimal planting date. Two farmers in each community were selected to evaluate this technique. Two planting dates were tested. Early planting on 1 November and late planting on 2 December. In general, the late planting date represents the farmers' usual practice.

- Deficit irrigation. To evaluate this technology, three on-farm trials were conducted with three farmers in the Bradia community. The options that were tested were: 1) irrigation at 70% of field capacity and 2) irrigation at 100% of field capacity.

Marginal analysis was used to evaluate the proposed technologies. This aims to determine how the net benefits from an investment (new technology) increases as the amount invested increases. The easiest way of expressing this relationship is by calculating the marginal rate of return, which is the marginal net benefit (the change in net benefits) divided by the marginal cost (the change in costs), expressed as a percentage. The marginal rate of return indicates what farmers can expect to gain on average, in return for their investment when they decide to change from one practice to another (Perrin et al., 1988).

The first step in undertaking an economic analysis of on-farm trials is to calculate the costs that vary for each treatment. Farmers will want to evaluate all changes that are involved in adopting a new technology. It is, therefore, important to take into account all inputs that are affected in any way by changing from one treatment to another. The partial budget is a method of organizing experimental data and information about the costs and benefits of various treatments. Not all production costs are included in the budget, but only those that are affected by the alternate treatments.

Yields from on-farm trials are often higher than the yields that farmers themselves obtain using the same treatment. Consequently, average trial yields must be adjusted downward by a certain percentage to reflect the difference between the experimental yield and the yields on farmers' fields (known as the yield gap) from the same treatment. In this study, the on-farm trials yields were adjusted by 10% downwards for grain and 20% downwards for straw.

6.1.3 Results

Dry conditions

Table 6.1 summarizes the enterprise budget and estimates the farmers' production costs per hectare of wheat. Wheat production costs were similar in the two communities, 5097 Moroccan dirhams (MDh) per hectare in the Bradia community and 4421 MDh per hectare in the Ouled Zmam community. Irrigation costs are the major cost items representing 23% of the total cost in Bradia and 26% in Ouled Zmam. So, any technologies that can save water imply a direct reduction in total production costs. The information that exists in this enterprise budget represents and describes the farmers' practices. This information will be used in the partial budget to evaluate the new technologies.

Marginal analysis

The gross field benefits for each treatment are calculated by multiplying the field price by the adjusted yield (Table 6.2). The gross

Table 6.1: Production costs for wheat in the Bradia and Ouled Zmam communities.

Cost item	Bradia		Ouled Zmam	
	Cost (MDh/ha)	% of total cost	Cost (MDh/ha)	% of total cost
Tillage	600	12	500	11
Fertilization	889	17	1010	23
Planting	995	20	970	22
Crop maintenance	833	16	215	5
Irrigation	1150	23	1146	26
Harvest and storage	630	12	580	13
Total cost	5097	100%	4421	100%

field benefit for the farmers' practice was about 11663 MDh per hectare. The highest gross benefit observed was 12,795 MDh per hectare and this was associated with the 120 kg N/ha treatment. The total cost that varies for 60 kg N/ha was negative. It means that farmers use more than 60 kg N/ha (106 kg N/ha).The average N quantity that farmers' use in this region is about 63 kg N/ha. The highest total cost that varies involved the 180 kg N/ha treatment (853 MDh/ha).

would incur an additional cost of 45 MDh/ha (453 minus 408), but would realize a loss of 1459 MDh/ha.

Table 6.4 shows that the marginal rate of return (marginal net benefits divided by the marginal cost) for changing from treatment 1 (60 kg N/ha) to treatment 2 (120 kg N/ha) is about 119%. This means that for every 1.00 MDh invested, farmers can expect to recover 1.00 MDh plus a further 1.19 MDh as profit. So,

Table 6.2: Partial budget for nitrogen trials in the Bradia community.

Cost item	Treatments							
	Farmer		60 kg N/ha		120 kg N/ha		180 kg N/ha	
	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
Average yield (kg/ha)	7205	5133	7297	5233	7572	5667	6820	5233
Adjusted yield (kg/ha)	5764	4620	5837	4710	6057	5100	5456	4710
Gross field benefits (MDh/ha)	11663		11880		12795		11781	
Cost of fertilizer (MDh/ha)	729		413		826		1238	
Cost of labor (MDh/ha)	27		17		33		66	
Total costs that vary (MDh/ha)	0		-326		408		853	
Net benefits (for PB) (MDh/ha)	11355		11901		12387		10928	
Net benefits (for EB) (MDh/ha)	6258		6804		7290		5831	

PB = Partial Budget and EB = Enterprise Budget.

Once the net benefit has been determined (Table 6.2), the next step is to perform a dominance analysis. This is done by sorting the treatments, including the farmers' practice, on the basis of costs, listing them from the lowest to the highest, together with their respective net benefits. In moving from the lowest to the highest, any treatment that costs more than the previous one, but yields less net benefit, is said to be 'dominated on the basis of cost' and can be excluded from the analysis.

Table 6.3 reveals that the farmers' practice and the 180 kg N/ha treatment were dominated and can be excluded from the analysis. By switching from 60 kg N/ha to farmers' practice (106 kg N/ha), an additional cost of 326 MDh/ha is incurred but this would lead to a loss of 546 MDh/ha (6804 minus 6258). The value 6258 MDh is the net benefit from the farmers' practices. The same thing for the last treatment, when moving from 120 kg N/ha to 180 kg N/ha, the farmer

from the treatments tested in this nitrogen experiment, the 120 kg N/ha would be the best recommendation for farmers in this region. However, this level is also very close to the current farmers' practice of 106 kg N/ha.

The results in Table 6.5 summarize the economic evaluation of all the technologies tested in the two communities. For example, in the variety trials the new variety Tomouh was shown to have the best agronomic and economic performance in the Bradia community. In the Ouled Zmam community,

Table 6.3: Dominance analysis for nitrogen trials in the Bradia community.

Cost items	Total costs that vary (MDh/ha)	Net benefit (MDh/ha)
60 kg N/ha	0.00	6804.00
Farmer	21.00	6566.00
120 kg N/ha	408.00	7290.00
180 kg N/ha	453.00	5831.00

Table 6.4: Marginal analysis for nitrogen trials in the Bradia community.

Treatment	Total costs that vary (MDh/ha)	Net benefits (MDh/ha)	Marginal cost (MDh/ha)	Marginal benefit (MDh/ha)	Marginal rate of return (%)
60 kg N/ha	0.00	6804			
120 kg N/ha	408	7290	408	486	119

Table 6.5: Technologies to be recommended in the Bradia community.

Trials	Technologies	Variation in cost (%)	Variation in net benefit (%)	Net benefits (MDh/ha)
Varieties	Tomouh	0	37 +	12,331
Nitrogen	120 kg N/ha	8 +	11 +	7290
Planting dates	Early	0	115 +	5526
Deficit irrigation	Farmer	0	0	7996
Improvement of surface irrigation	Improved	40 +	48 +	13,885

the variety that gave the best results was Marjana. The new varieties, Tomouh and Marjana, are both durum wheat varieties. The final year's data confirmed the previous results that the new durum wheat varieties are more water-use efficient than bread wheat cultivars.

The early planting technique showed, for the second year, very interesting results in the two target communities. But this technology can be recommended only to farmers who have access to wells because water is needed for irrigation at seeding.

The econoioc evaluation showed that the technologies to be recommended in Ouled Zman are durum wheat Marjana and early planting (Table 6.6)

In the deficit irrigation trials, no significant difference between treatments was seen for agronomic performance. Results for grain yield and total biomass showed that 70% FC gave as much as 100% FC and farmers' practice because of the high variability noted among samples. However, the economic evaluation showed that the farmer's practice is the best. These results are in sharp contrast to last years' results and to the literature and should be treated with caution.

Wet conditions

Marginal analysis

Table 6.7 presents the partial budget for surface irrigation technology during the wet year. The gross field benefit for each treatment was calculated by multiplying the field price by the adjusted yield. The gross field benefit for the farmer's practices was about 14,427 MDh per hectare. The highest gross benefits observed were using the improved treatment (20,927 MDh/ha). Farmer's practice was used as a basis for the analysis and, therefore, the total cost that varies for this technology equaled zero. The highest total costs that varies involved the improved treatment (2000 MDh/ha). Table 6.8 shows that the marginal rate of return (marginal net benefits divided by the

Table 6.6: Technologies to be recommended in the Ouled Zmam community.

Trials	Technologies	Variation in cost (%)	Variation in net benefit (%)	Net benefits (MDh/ha)
Varieties	Marjana	0	222 +	6970
Planting dates	Early	5 +	95 +	9665

Table 6.7: Partial budget for surface irrigation improvement trials in the Bradia community.

Cost item	Treatment					
	Farmer		Conventional		Improved	
	Straw	Grain	Straw	Grain	Straw	Grain
Average yield (kg/ha)	7960	6450	8560	7180	9890	9530
Adjusted yield (kg/ha)	6368	5805	6848	6462	7912	8577
Gross field benefits (MDh/ha)	14426		15996		20926	
Cost of surface leveling (MDh/ha)	0		600		2000	
Total costs that vary (MDh/ha)	0		600		2000	
Net benefits (for PB) (MDh/ha)	14426		15396		18926	
Net benefits (for HB) (MDh/ha)	9385		10355		13885	

marginal cost) for changing from treatment 1 (Farmer) to treatment 2 (Conventional) was 162%; and from treatment 2 to treatment 3 (Improved) it was 252%. This means that for every 1.00 MDh invested, farmers can expect to recover their investment plus an additional 2.52 MDh. So, from this experiment, we can conclude that the improved technique would be the best recommendation for farmers in this region.

Results in Table 6.9 summarize the economic evaluation of all the technologies tested in the two communities. For the deficit irrigation, planting dates and nitrogen trials marginal analysis was not needed because changes in costs that vary are equal to zero or negative. For example, irrigation at 70% of field capacity in the deficit irrigation trials involved a reduction in total cost of 10% and an increase in net benefits of 45%. In this case, only dominance analysis is needed and any treatment that has net benefits that are less than or equal to those of a treatment with lower cost that varies is dominated. The marginal rate of return must be always positive. The best recommendations for farmers in the Bradia community according

Table 6.8: Marginal analysis for surface irrigation improvement trials in the Bradia community.

Treatment	Total costs that vary (MDh/ha)	Net benefits (MDh/ha)	Marginal cost (MDh/ha)	Marginal benefit (MDh/ha)	Marginal rate of return (%)
Farmer	0.00	14426			
Conventional	600	15396	600	970	162
Improved	2000	18926	1400	3529	252

Table 6.9: Technologies to be recommended in the Bradia community.

Trials	Technologies	Variation in cost (%)	Variation in net benefit (%)	Net benefits (MDh/ha)
Varieties	Marjana	2 +	30 +	9615
Nitrogen	60 kg N/ha	0	35 +	9986
Planting dates	Early	8 -	55 +	12,869
Deficit irrigation	70%	10 -	45 +	7580
Improvement of surface irrigation	Improved	40 +	48 +	13,885

to the economic evaluations are Marjana durum wheat variety, 60 kg N/ha, early planting date, irrigation at 70% of field capacity and improved surface irrigation. Table 6.9 also shows that the recommended technologies imply a considerable increase in farmers' net benefits (between 30 and 50%) because of the very high agronomic performance of the technologies tested.

In Ouled Zmam community (Table 6.10) Achtar bread wheat variety and early planting date are the treatments to be recommended.

6.1.4 Conclusions

- The economic performance of some technologies changes from year to year due to drought conditions (nitrogen-use technologies). This makes the technology recommendation process very difficult.
- The new durum wheat varieties are more water-use efficient than bread wheat varieties.
- The early sowing technique is one of the water-use efficiency technologies to recommend to farmers in the two communities.
- In all cases, the change in technology offers a rate of return above 100% (considered as a minimum rate of return acceptable to farmers).
- The adoption of the tested technologies implies a substantial increase in farmers' net benefits (between 110 and 222%) because of the very high agronomic performance of the technologies tested.
- Marginal analysis is an important step in assessing the results of on-farm experiments before making recommendations. But agronomic interpretation and statistical analysis are also part of the assessment.

6.2 Adoption improved technologies

6.2.1 Introduction

This part of the report is concerned with a study of the adoption of efficient water-use technologies and the farmers' attitude toward these technologies. This study was carried out with the two Benchmark communities, Bradia and Ouled Zmam. The study included farmers who participated in field days and farmers who hosted field trials. The technologies evaluated were wheat varieties adapted to supplemental irrigation, deficit irrigation, optimal planting date, and optimal rate of nitrogen.

Field days were organized each cropping year during the three years of the project and served as an occasion for interaction between researchers, extension agents from ORMVAT and farmers. During the field day, the host farmer played the lead role in presenting his activities to other farmers (what was tested in his field and how the efficient water-use technologies were performing). This gave farmers an opportunity to learn from and convince each other. Researchers and extension staff assisted farmers in answering questions and clarifying issues. Meetings with farmers and individual contacts were also occasionally organized to exchange ideas on proposed new technologies and to prepare for the installation of trials on the farmer's plots.

6.2.2 Methodology

The efficient water-use technologies discussed in the adoption and impact evaluation are the same technologies already explained in the economic evaluation part of this chapter.

Table 6.10: Technologies to be recommended in the Ouled Zmam community.

Trials	Technologies	Variation in cost (%)	Variation in net benefit (%)	Net benefits (MDh/ha)
Varieties	Achtar	0	0	5195
Planting dates	Early	2 -	48 +	5811

Sampling procedure

The farmers sample included three categories of farmers, those who participated in field days, those who hosted trials and their neighbors. A total of 50 farmers were interviewed. The sample included 40 farmers who participated in field days (including farmers who are neighbors of the field trials farmers). This sample represents more than 50% of the total participants in field days during the three years of the project and 10 farmers who hosted trials.

The team responsible for collecting the data was composed of interviewers from ORMVAT (extension agents) and INRA (technicians). Before starting the survey, the questionnaire was pre-tested and the interviewers were trained on how to use the questionnaire. The training included discussion of the survey objectives, a review of the survey questionnaire and role-playing.

Adoption indicators

Two main indicators of adoption were used in this study:

- **Adoption rate**: This indicator represents the percentage of farmers adopting the technology under consideration. It is an important indicator in measuring technology adoption, especially during the early stages of the project.
- **Degree of adoption**: This is measured using the proportion of land under the new irrigation technique or new crop cultivar, for example.

6.2.3 Results

Characteristics of the farmer sample

The characteristics of the farmer sample are presented in Table 6.11. This table shows that there was little difference between the two categories of farmers for the majority of variables listed. We found no statistical difference in years of schooling between the two categories and the majority were illiterate. Household sizes were also not significantly different. On average, each family was composed of 3.6 adult males, 3.4 adult females and 2.9 children under 15-years old. However, the number of farmers who used underground water for irrigation was statistically significantly different between field day participants and field trial hosts. This difference can be explained by the fact that one of the criteria for choosing plots for the optimal planting date trial was the existence of a well. The size of livestock flocks and the number of tractors owned are generally correlated with farm size.

Table 6.11: Characteristics of sample farmers by categories.

Characteristic	Field day participants	Field trial hosts	Difference between the two categories
Male (%)	100	100	NS
Female (%)	0	0	NS
Age (yr)	57	55	NS
Formal education (%)			
None	72	78	NS
Traditional school	18	16	NS
Primary school	7	4	NS
Secondary school	2	2	NS
Adult females (no.)	3.5	3.3	NS
Adult males (no.)	3.7	3.5	NS
Children < 15	3.0	2.8	NS
Farm size (ha)	5.6	7.4	NS
Wells (%)	22	46	S
Sheep (no.)	10.3	20.5	S
Cattle (no.)	2.3	4.4	NS
Tractor (%)	9	12	S
Number of farmers	40	10	

Note: NS = not statistically significant; S = statistically significant at the 95% confidence level.

Adoption rate and degree of adoption

The results of farm surveys of participants in the demonstration trials showed that the level of adoption of new varieties of wheat adapted to supplemental irrigation in the two communities was very high. Ninety-eight percent of farmers who hosted demonstration trials used new varieties of wheat and 52% of their total wheat area was sown to such varieties (Table 6.12).

These results also indicated that 52% of participants in field demonstrations adopted the optimal planting date technique. The degree of adoption among this group was 67%. In contrast, only 10% of participants adopted deficit irrigation technology. Farmers are apparently not convinced that stressing the crop can improve land and water productivity.

In general, adoption rates and degrees of adoption for participants in field days were very low when compared to the results obtained for participants in demonstration trials. The field participant group faces more challenges in adopting these technologies and progresses more slowly than farmers who hosted the trials.

The results presented in Table 6.13 indicate that just 36% of all participants in field days and neighbors of demonstration trial hosts use the proposed new wheat varieties. The degree of adoption of these varieties for the same group of farmers was about 25%. Obviously, the adoption rates of the optimal rate of nitrogen and optimal planting date were very low compared to rates for wheat varieties adapted to supplemental irrigation. The adoption rate for deficit irrigation technology was zero.

Table 6.14 shows that most farmers found it very easy to adopt the proposed new varieties that use irrigation water more efficiently (85%) and the optimal planting dates (87%). But farmers found it difficult to adopt the optimal rate of nitrogen and deficit irrigation recommendations. These procedures are quite different from those they replace and a special information program is needed to markedly reduce the degree of complexity of these technologies.

In general, the more accessible and simple the information about a technology is, the less time is needed between learning about it and its adoption. For example, by just after the first year of demonstration trials, 85% of farmers had adopted the wheat varieties adapted to supplemental irrigation. But for the optimal rate of nitrogen, which is considered a more complicated technology (as it needs soil analysis and exact rate

Table 6.12: Adoption rate and degree of adoption by participants in demonstrations.

Indicators	Varieties	Optimal rate of nitrogen	Optimal planting dates	Deficit irrigation
Adoption rate (%)	98	26	52	10
Degree of adoption (%)	52	62	67	25

Table 6.13: Adoption rate and degree of adoption by participants in field days and neighbors of demonstration trial hosts.

Indicators	Varieties	Optimal rate of nitrogen	Optimal planting dates	Deficit irrigation
Adoption rate (%)	36	11	5	0
Degree of adoption (%)	25	20	50	0

Table 6.14: Technical feasibility of the proposed technologies (in %).

Degree of feasibility	Varieties	Optimal rate of nitrogen	Optimal planting dates	Deficit irrigation
Very easy	85	8	23	5
Easy	9	13	64	13
Moderate	5	21	9	14
Difficult	1	53	4	68
Very difficult	0	5	0	0

calculation), the majority of farmers started adoption after the second year of demonstration (Table 6.15).

To study the economic impact of the efficient water-use technologies proposed by the Benchmark project, we used the economic water productivity indicator (MDh/m^3). An increase in economic water productivity implies a direct improvement in farmers' incomes. It is also positively correlated with water productivity. The precise impact of the adoption of the proposed efficient water-use technologies on farmers' incomes will not be evaluated in this report.

The results in Table 6.16 indicate that on average the adoption of the technological package increased economic water productivity by 30%. The highest level of economic productivity was with the deficit irrigation technology; this implies that the maximum yield obtained with full irrigation does not always correspond to the maximum economic water productivity.

Table 6.15: Time between learning about the technology and its adoption (in %).

Period	Varieties	Optimal rate of nitrogen	Optimal planting dates	Deficit irrigation
One year	68	12	0	0
Two years	23	56	73	0
More than two years	9	22	27	100

Table 6.16: The impact of adoption on economic water productivity.

	Varieties	Optimal rate of nitrogen	Optimal planting dates	Deficit irrigation	Technological package
Economic water productivity before adoption (MDh/m^3)	2.25	2.25	2.25	2.25	2.25
Economic water productivity after adoption (MDh/m^3)	2.63	2.75	2.55	3.75	2.92
Variation (%)	17	22	13	67	30

6.2.4 Conclusions

The adoption study of improved water-use technologies showed that:

- On average, the adoption rate and degree of adoption for all tested technologies by participants in demonstration trials are promising (average 35%).
- For participants in field days, and their neighbors, adoption rates are lower than for hosts of the trials. One of the reasons for these low rates is the misunderstanding of some technologies.
- Other factors affecting these rates, such as property right aspects, must be studied
- More involvement of the Water Users' Association in the dissemination process is needed.
- ORMVAT and INRA must work more closely together.

Chapter 7: Water policies in Morocco – Current situation and future perspectives

Chapter 7: Water policies in Morocco – Current situation and future perspectives

A. Laamari, M. Boughlala, A. Herzenni, M. Karrou and A. Bahri

7.1 Introduction

The concept of rural development necessarily implies the reduction of current disparities between urban and rural areas. Reduction of rural socioeconomic deficiencies depends directly on sustainable water management, whether for irrigation or for domestic and industrial uses. Water management in Morocco, like everywhere else, is linked to the management of other natural resources, and must address the needs of its three major users – agriculture, industry and the household sector. With two maritime borders (the Atlantic Ocean to the west and the Mediterranean Sea to the north), Morocco is relatively well supplied with water when compared to other countries in North Africa. In addition, the mountains, which cover a substantial part of the country, act as reservoirs. The overall annual rainfall is estimated at 150 billion cubic meters (m^3). However, two constraints must be noted – rainfall variation in time and space. Morocco has always had drought years, but their frequency and severity have greatly increased since the early 1980s. Nine droughts have been recorded over the last 16 years, whereas during the first half of the 20th century, there was, on average, only one drought every ten years. Spatial distribution of rainfall in Morocco is characterized by declining gradients from north to south and from west to east. Certain regions receive 600 to 700 millimeters (mm) per year, while others receive less than 100 mm. The three hydraulic basins of the Atlantic zone (Sebou, Bouregreg and Oum Rabii) supply two-thirds of the potential freshwater.

Climate and landscape determine both the state of vegetation and the natural resources management policy followed by the Government. The total area of the country, 72 million hectares, is divided into arable agricultural land (13%), forest and alpha zone (12.5%), roadway terrain (30%) and uncultivated land (44.5%). It is estimated that 80% of the 150 billion m^3 of precipitation is lost through evaporation and flow into the sea.

Only 14% (21 billion m^3) of the total rainfall is presently believed to be captured, taking into account existing economic and technical means. Currently 11.7 billion m^3 are used, of which 75% is surface water and 25% is groundwater. Water use in Morocco is:

- 86% for irrigation;
- 5.5% for industry, mainly concentrated in the northwestern zone of the country and in the Casablanca-Mohammedia agglomeration; and
- 8.5% for human consumption (potable water), i.e., an annual average of 38 m^3 per capita, or over 100 liters per day for each inhabitant.

The Moroccan economy is still under the effect of the transition from a traditional interventionist government to a more market-oriented economy. Given the importance of the agricultural sector, inertia prevents the attainment of the full and instantaneous benefits of liberalization. More time is therefore needed to ensure better economic performance. In this context, accurate agricultural policies are important for attaining a high level of overall economic performance. Moreover, these policies are critical for determining the levels of growth in both rural and urban sectors. Water's economic performance will be affected by such an economy.

This chapter addresses three main questions related to agricultural policy in the country:

- What are the main water policies?
- Which water management institutions has Morocco developed since independence? and

- To what extent have these measures contributed to water-use efficiency and its rational management?

The main objective of the study is to review and assess the existing agricultural policies related to the water sector in Morocco, including governance issues.

7.2 The water sector in Morocco

7.2.1 Main actors

Legally all water resources are the property of the State, which has the right to intervene and determine their different uses. In practice, water is under the control of different state departments (Figure 7.1). All water policies are developed by the Ministry of Environment, Ministry of Finance, Ministry of General Affairs, Ministry of Interior, Ministry of Agriculture and the Water State Secretary. Now, the General Counsel of Water and Climate is becoming a powerful unit in the development of water strategies.

More than 86% of water is under the control of the Ministry of Agriculture through the regional offices responsible for irrigation water management (Offices régionaux de la mise en valeur agricole, ORMVAs); but water pricing still involves the Ministry of Finance and its Departments. In 1995, legislative reform engaged Morocco in a process of decentralization of water resources management with the creation of six basin agencies that are legal entities equipped with financial autonomy. These agencies are responsible for water policy and the integrated management of the hydrographic basins.

In Morocco, the stabilization of the macro-economy and economic development have been linked to the strategy of developing the water sector. In the Government's last national development plan social issues such as poverty reduction, education and inter-regional gaps were also emphasized. The annual growth rate of the population is estimated at 1.6%, resulting in a projected population of 33.2 million in 2010. The proportion of the population in urban areas is

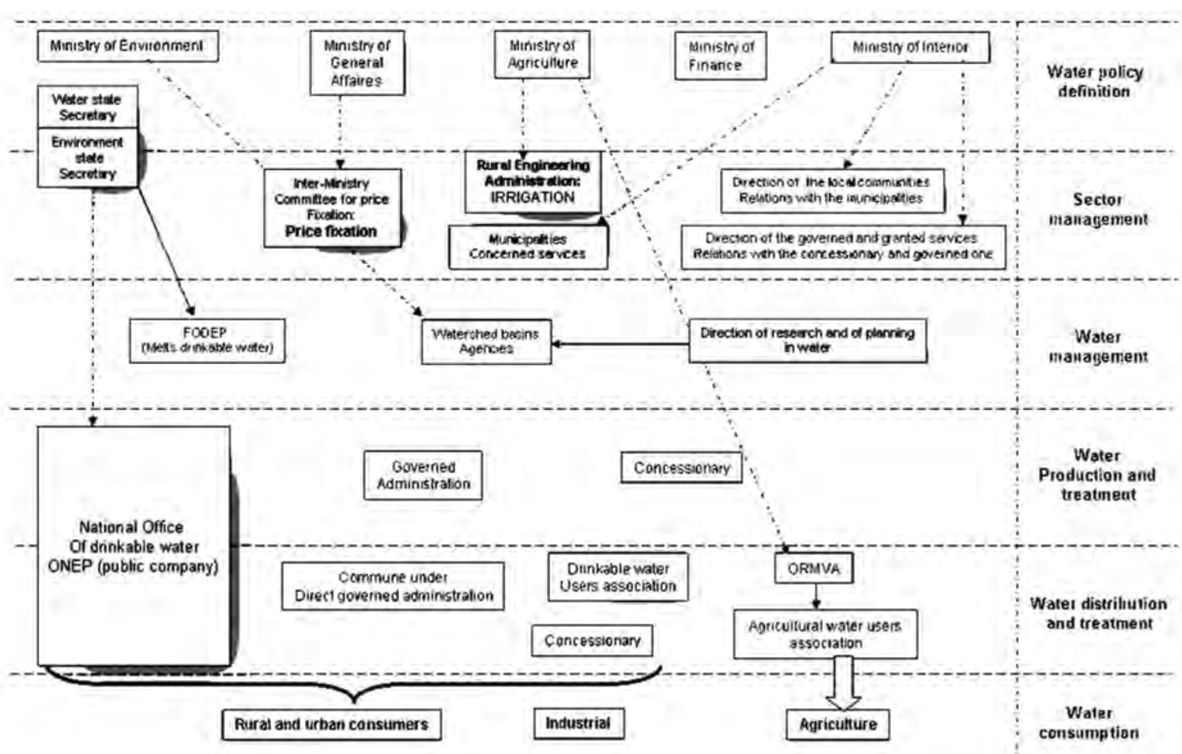

Figure 7.1: General structure of water sector institutions in Morocco.

predicted to reach 62% in 2010 (50% in 1992). Based on such demographic trends, the plan assumes that further needs will arise in sectors such as education, employment, health and sanitation, water resources, roads, housing, and food. The plan sets out specific medium- to long-term objectives for each sector. Targets for the water resources sector are as follows:

- Dams and drilled wells will be constructed to meet anticipated increased demand by 2020.
- Potable water supply will be doubled before 2010 to cope with the 4% increase in demand per year. Figure 7.1: General structure of water sector institutions in Morocco.
- The proportion of the urban population with access to potable water networks will be increased to 94% in 2010 (85% in 1999).
- Access to the public water supply system in rural areas will also be increased. In addition, the privatization of the water resources development sector will be promoted.

The Water Law specifies the establishment of Basin Agencies, which evaluate, plan and manage water resources in the river basins to strengthen the institutionalization of water management. Other principles stated in the Law are 1) water as a public domain, 2) regulation of development, distribution and sale of potable water, 3) improvement of agricultural water development and use, and 4) security against illegal water resources development or management, which causes water pollution, etc.

Morocco is divided into six major river basins, with long-term water resources development policies planned and stipulated in the Integrated Master Plans. These plans are mainly aimed at estimating water demand from different sectors such as potable and industrial water, irrigation and hydropower generation, and determining an optimal integrated scheme for water resources development. In Tadla, the river basin plays an important role in water management. For agriculture, this role is played in conjunction with Tadla ORMVA (ORMVAT) and the Water Users' Association. It is important to stress that river basin interventions in Morocco can differ from one region to another given the sensitivity of the situation.

During a five year period (2000–2004), the National Development Plan defined the objectives of the hydraulic sector as 1) contributing to potable water supply in both urban and rural areas, 2) contributing to provisional supply, 3) rehabilitating and maintaining hydraulic facilities, 4) improving and maintaining water quality, 5) protecting people and property against inundation and floods, 6) developing the hydro-potential for power generation, and 7) equitably distributing water throughout the country and regional development. The objectives of the irrigation sector in the five-year plan are new irrigation development and improvement of irrigation efficiency (rehabilitation and modernization of the irrigation infrastructure). This latter objective fits well with the Benchmark project's main aim of improving water-use efficiency through appropriate crops and technologies.

7.2.2 A constraining natural context

The Mediterranean type climate of Morocco is characterized by considerable spatial and temporal irregularity of rainfall. An overview of rainfall frequency shows that 80% of the country receives less than 400 mm per year. Over the long term, variability in the rainfall pattern is such that it is virtually impossible to detect similar seasons in terms of precipitation. The situation is even more difficult when, after several successive dry years, a good rainy season might become brings its own problems such as flooding and water-logging. As a result, substantial irregularity is seen in the hydrologic regime.

Under such variable conditions it is impossible to fully utilize all surface water resources without controlling the flow of water in the hydrologic network. For the same reasons, agriculture dependent on rainfall is uncertain, and cannot be considered as a reliable source of food security and stability and improvement in farmers' incomes and well-being.

7.2.3 Relatively limited potential

The potentially useful water in Morocco is estimated at 20 billion cubic meters including 4 billion of underground water resources. The agricultural arable land of up to 9 million hectares represents only about 13% of the total land area of 71 million hectares. The permanently irrigable area amounts to only 1.36 million hectares of which 300 thousand hectares are under seasonal irrigation.

7.2.4 A harmonious hydraulic infrastructure policy

To better understand actual water policy and the functioning of water institutions in Morocco, we need to analyze the historical origins of the current laws. The laws and rules governing land and water use in the country today emerged from the historical superimposition of three bodies of laws and rules (Bouderbala and Filali-Meknassi, 1992) – the *Orf*, (indigenous sets of rules and practices), the *Chriaa* (the religious interpretation of Islamic law and rules) and modern legislation that was introduced by the French protectorate and later reinforced by Morocco since independence in 1956.

After independence, Morocco closely linked its economic and social development to the control of water resources. The development of irrigation is within the scope of an overall integrated policy for water resources aimed at optimizing investments and valorizing water resources.

The 1960s marked an important stage in the history of Morocco in the field of the development and valorization of water resources policies. Indeed, with the announcement by the King in 1967 of the objective of 'one million irrigated hectares', a new water policy was implemented and translated over the following decades into numerous and vast hydraulic and hydro-agricultural plans and infrastructure development.

Morocco obtained and established the necessary legal, institutional, technical and financial means to implement this policy and achieve its goals. A rigorous plan for the integrated management of water resources was launched.

From the start, Morocco has based its water policy on two objectives in particular:

- to ensure a balance between the demand for water and its ability to mobilize water resources; and
- to give long-term visibility to the various sectors using water with regard to water resources development and sector allocations of these resources.

This planning has been used as a basis for controlling and managing water resources in all water basins. These strategic planning approaches also formed the basis for the preparation of regional plans for irrigation development.

Guidelines for water management in the water basins define plans for the mobilization and exploitation of utilizable resources at various levels. These are revised every five years and are prepared based on the needs and uses of water – drinking, industrial, irrigation, etc.

The guidelines are drawn up with contributions from all stakeholders (Government Departments involved, local communities, users, controllers, etc.) and are approved by the Higher Council for Water and Climate. Since the promulgation of the 10-95 Law on Water in 1995, the development of the master plans is coordinated by the Basin Agencies, created at the level of the various water basins – hydraulic schemes – in the country. They are promulgated by decree.

The implementation of the master plans for each catchment area and their follow-up are the responsibility of the Provincial Commissions on Water chaired by the '*Wali*' or Governor of the province and composed of regional and provincial representatives of all of the above-mentioned institutions. Under the 10-95 Law on Water, a 'National Water Plan' is launched synthesizing the different basins' plans aimed at implementing measures to rationalize and safeguard the use of the resource.

The importance attached by the authorities to the water sector has increased over the years, especially with the challenges of water scarcity and the need for the valorization and better use of this valuable resource. Thus, in addition to the promulgation of the 10-95 Law on Water, Morocco created a State Department responsible for water in 2002.

7.3 Water legislation

Water was considered as public property and water use rights were recognized prior to the promulgation of the first text establishing the public right to water – the *dahir* of 7 Chaâbane, 1332; 1 July 1914). All judicial texts were amalgamated in a single text; which is the 10-95 Law on Water promulgated in 1995.

7.3.1 The Code on Agricultural Investment

Shortly after the challenge of 'the one million irrigated hectares' was launched, the Code on Agricultural Investment was promulgated by the *dahir* (law) 1-69-25 of 25 July 1969, together with its implementing instruments. This code governs the interventions of the State in hydro-agricultural installations, and the relationship between the State and users of agricultural water in term of rights and obligations. It also defines the contribution of the State and the financial participation of recipients in the investment. Moreover, it defines the bases of water pricing for agricultural use and the conditions of its distribution in the irrigated areas.

The main elements of the Code on Agricultural Investment are:

- **Overall planning of water resources:** It aims at long-term visibility in terms of investment, integration, mobilization, and use of water.
- **Overall development of irrigated areas:** Make the best use of scarce resources (water, land and capital), optimize management costs and consider external and internal management.
- **Management of hydro-agricultural systems**: Collective management of irrigation, and water pricing to ensure sustainability of water services and adequate maintenance and renewal of community networks.
- **Agricultural development:** Support enhancement and creation of mechanisms for consultation, monitoring and implementation

7.3.2 Structure of interventions in irrigation

Ever since independence, Morocco has been aware of the strategic role of irrigation in the economic and social development of the country. In 1960, the State created the National Office of Irrigation (ONI) to harmonize and integrate services related to the development of irrigation under the authority of a single organization. This organization was given a very broad mission nationally, such as to search for and mobilize water resources for use for agricultural purposes. The ONI was particularly responsible for infrastructure and the development of areas previously delimited by decree, undertaking the equipment and mobilization of water for irrigation, land improvement, valorization of production, organization of marketing, distribution of appropriations and subsidies, training of farmers, and promotion of agricultural cooperatives. The tasks related to rural development were under the control of the National Office of Rural Modernization (ONMR).In 1965, ONI and ONMR were merged to create the Office of Agricultural Development or Office de mise en valeur agricole (OMVA).

In 1966, the need for the decentralization of the institutions responsible for irrigation development and their relocation to the areas where they worked, which were the areas with high agricultural potential, justified the replacement of OMVA by Regional Offices of Agricultural Development (ORMVA). Thus on 22 October 1966, seven ORMVAs were created: Moulouya, Tadla, Haouz, Gharb, Doukkala, Tafilalet, and

Ouarzazate. Two others were created later, Souss-Massa in 1970 and Loukkos in 1975. The ORMVAs are public institutions, responsible for civil administration and with financial autonomy. They integrate all the services needed for the development of irrigated agriculture in the nine large-scale irrigated areas. They are also responsible for the construction of hydro-agricultural infrastructure, the use and maintenance of irrigation networks and the technical supervision of farmers.

In addition to the large-scale irrigated areas, irrigation schemes are also implemented by the Provincial Agricultural Directorates (DPA). These institutions are especially concerned with implementing small- and medium-scale irrigation projects and the technical supervision of programs for the promotion of private irrigation. time, and with increasing regional development in the country, the number of DPAs has increased and currently stands at 40.

The Rural Equipment Directorate (DER) was created in 1974 at the national level. Its role was to coordinate and follow up issues related to the control of water, land improvement and rural development. In 1993, the National Program on Irrigation was launched and aimed mainly at increasing the rate of introduction of hydro-agricultural equipment to achieve the 'one million irrigated hectares' targeted for 2000. The DER was part of the Rural Engineering Administration (AGR). This new entity is responsible for coordinating the actions of the Ministry of Agriculture related to the development and management of irrigation, hydro-agricultural equipment and land improvement.

7.3.3 Achievements

Before independence, the area under irrigation hardly exceeded 65,000 ha. In 1960, the total area equipped for irrigation was 150,000 ha, including 97,000 ha with large-scale hydraulics. The objective of the 'one million irrigated hectares' was declared in 1967. The area irrigated by the State increased from 213,700 ha in 1967 to 442,850 ha in 1975 to 748,300 ha in 1990 (Table 7.1). In 1993, a new push was given to hydro-agricultural installations by launching the National Program on Irrigation. This program aimed at extending irrigation to another 250,000 ha and the rehabilitation of 200,000 ha in existing irrigated areas. In 2000, taking into account the areas equipped for irrigation and those which were in the process of installing the equipment, the objective of the 'one million irrigated hectares' was largely achieved and the challenge was met (Table 7.1).

Currently, the public irrigated areas stand at 1.016 million ha, including 682,600 ha in large-scale irrigated areas and 334,100 ha in areas with small- and medium-scale hydraulics, increasing at an annual rate of almost 20,000 ha. These efforts result from significant investment made by the State in irrigation programs representing 43 to 77% of public investments in agriculture during the years from 1970 to 1990. 1965 to 2004, Morocco invested nearly 32 billion MDh in the establishment of hydro-agricultural installations including more than 87% for large-scale hydraulics. There has been a very substantial growth in the area equipped for irrigation since the 1960s (Table 7.1).

The private sector has also made considerable efforts in the irrigation of arable land. This effort has increased over time, particularly after the 1980s, with the incentives given by the State, the episodes of drought and the growing importance of export crops. Currently, private irrigation handles an area of 441,430 ha, in addition to the areas already equipped by the State.

Thus, the total irrigated area (State and private) is about 1,458,160 ha of which 81.1%

Table 7.1: Growth in the areas equipped for irrigation.

Years	1960	1965	1970	1975	1980	1985	1990	1995	2000	2004
1000 ha	150	172	273	443	564	642	748	871	974	1017

is surface irrigation, 9.8% is by sprinkler and 9.1% is drip irrigation. Most of the drip-irrigated areas are privately owned (table 7.2).

Large-scale irrigation (LSI): Adjustment of scale

Large-scale irrigation is synonymous with the nine large public irrigated areas supplied mainly from the dams and geographically defined in the terms of the Code on Agricultural Investment. These irrigable areas extend from 30,000 to 250,000 hectares. They are the Moulouya, Tadla, Haouz, Doukkala, Gharb, Tafilalet, Ouarzazate, Loukkos, and Souss-Massa Irrigated Perimeters.

Until independence, the use of water in the large hydraulic areas (Nfis, Beht and Tadla) was related to the construction of dams built mainly to satisfy the country's energy needs. Irrigation equipment was limited to the primary canal network and in the best of cases, to a tertiary canal network. Internal land management was left to the farmers using irrigation.

With the new emphasis on hydro-agricultural installation in the 1960s, planning of integrated installations was adopted at the same time as the high priority given to the construction of dams and hydro-agricultural equipment. The installations carried out by the State also integrate: (i) the implementation of equipment, from mobilization, main water supply and distribution networks to internal management including land improvement and the adoption of the irrigation network; (ii) the rural infrastructure operations; and (iii) the installation of infrastructure and support services for agricultural development, in addition to studies and project development and implementation.

Thus, the large hydraulic areas benefited from the installation of modern techniques for the mobilization, transport and distribution of irrigation water and its use at the farm level. This development is characterized by high rates of crop intensification and high yields. However, significant differences are seen among these areas in the basic type of infrastructure and in the irrigation method.

According to the Code on Agricultural Investment, the State, through the Ministry of Finance, is responsible the whole external and internal equipment. , the recipients, while preserving their right of ownership, are requested to manage their land following a set of standards, which take into account national production needs. These standards relate to crop rotation schemes, farming techniques, irrigation methods, water use, etc. Moreover, recipients are obliged to contribute 40% of the balanced average cost of the irrigation equipment plus a royalty for the use of irrigation water, which covers the operations and maintenance costs of the network. The components and means of implementation and revision of this tariff system are clearly defined.

Measures in the Code provide for the safety of long-term production and investment initiatives in the farmers' land assets. Other measures are designed to conclude crop production contracts, to guarantee prices, to grant subsidies for the purchase of farm equipment and the intensification of agricultural production, and to support the agricultural co-operative movement. They lie within a coherent macro-economic

Table 7.2: Areas equipped for irrigation (in hectares).

Type of irrigation	Mode of irrigation			
	Gravity	Sprinkler	Drip	Total
Large hydraulics	535,927	119,193	27,480*	682,600
Small- and medium-scale hydraulics	327,230	6,900	–	334,130
Private irrigation (in addition to the areas already equipped by the State)	320,110	16,230	105,090	441,430
Total	1,183,267	142,323	132,570	1,458,160

scenario likely to guarantee the stability and the sustainability of hydro-agricultural installations.

However, since the beginning of the 1990s, changes in the socio-political and economic context in Morocco, together with an international environment characterized by free world trade, have led the State to gradually liberalize some economic sectors and to adopt a policy of disengagement and to focus on its role as a regulator. The agricultural sector, in common with other sectors, has been affected by this disengagement. Crop rotations are no longer obligatory and the production of some commodities is experiencing a progressive deregulation. Irrigated agriculture, particularly in the large hydraulic areas, currently has to adapt to this new reality and to take up the challenge of competition and competitiveness. The opening of the sector to private initiatives is more than ever a prospect

The large hydraulic area currently covers 682,600 ha, whereas it was only 97,000 ha in 1960, that is to say a rate of growth of 13,300 ha/year. For technical and especially socioeconomic reasons (relatively low capital cost, use, educational level and technical level of farmers and of labor, local equipment, etc.), the decision was made to limit surface irrigation to the level of 2005, that is 535,920 ha (78.5%).

The first collective areas equipped with sprinklers were established in the 1970s. There was a quick expansion mainly in Doukkala, Loukkos, Moulouya, Souss-Massa, and Gharb Irrigated Perimeters. But this decision was questioned because of the cost of the energy needed to pressurize the water; which became very expensive because of rising energy prices. The area currently equipped with sprinkler irrigation is about 119,200 ha.

The development of drip irrigation in the large hydraulic areas is only just beginning with the conversion of existing surface irrigation systems. The area converted to drip irrigation rose at the end of 2005 to 27,480 ha (18,130 ha of which were previously equipped with gravity and 9,350 ha with sprinkler systems).

In addition to the efforts made to expand irrigation, the large irrigated areas have benefited from significant programs and measures aimed at improving the performance of the sector. Examples include the Projects for the Improvement of Large-Scale Irrigation (PAGI-1 1987–1993 and PAGI-2 1993–2000) and the Program for the Rehabilitation of Large-Scale Irrigation, which started in 2001 for a six-year period. These programs dealt with the improvement of the operational effectiveness of the technical, administrative and accounting aspects of the ORMVAs, the rehabilitation and modernization of irrigation infrastructure and pricing readjustments.

Involvement of farmers' organizations in water management

The proposal to make publicly managed large-scale irrigation systems more flexible and responsive to local needs involves the promotion and involvement of farmers' associations in water allocation and management. While such farmer-based participatory organizations already exist in small- and medium-scale irrigated areas, they are yet to be created in the large-scale irrigation schemes. In 1990, the government revised the legislation on Water Users' Associations (WUAs) (law 02-84) to promote WUAs in all large-scale irrigated areas. The object was to involve farmers in water allocation and management, fee collection and irrigation systems maintenance. The aim was to create a total of 3,432 WUAs (532 in LSI areas and 2,900 in SMSI areas) and to revise water rates in LSI to cover the full operational and maintenance costs, and use WUAs as mechanisms to improve collection (Doukkali, 2005). However, even a decade after the law on WUAs was implemented, only 1,045 WUAs (445 in LSI areas and 600 in SMSI areas) have been created (Kingdom of Morocco, 2001). In reality, WUAs do not have much responsibility for water management and the maintenance of irrigation systems. All tasks remain under the control of the ORMVAs. The ORMVAs still control the distribution and allocation of water from the principal canal to the individual farms. They are still responsible for the maintenance of the entire irrigation system (maintenance program, budget, rehabilitation of the irrigation system, installation, roads, and clearing the secondary and tertiary canals). The ORMVAs collect irrigation water fees and plan the water distribution schedule. Their other activities include seed supply, fertilizers, sugar processing, and milk cooperatives. Their major role slows down the process of participation by WUAs in agricultural water management. It is clear that the ORMVAs do not want to lose their authority over water but this attitude goes against the option of liberalization.

Creation of WUAs seems not to be an option for transferring power to water users. WUAs are, also, not operational because of the lack of confidence between members and their representatives. Many factors intervene such as politics, elections and individual power. So users are less confident and board members can use WUAs as a bridge to achieve other objectives that are not necessarily related to the main objectives of the association.

Although they are part of the irrigation reforms adopted by Morocco, WUAs have no impact on water management. They are not well empowered to really manage water for agricultural irrigation. This situation is becoming more complicated by the involvement of river basin agencies (van Vuren et al., 1995) in the distribution of water among the different sectors.

Small- and medium-scale irrigation (SMSI)

In Morocco where irrigation is a secular practice, small- and medium-scale irrigation is a very old system for which water users have inherited a rich indigenous tradition. Irrigation is also a form of mechanism and social organization for the development and management of SMSI areas. SMSI relates to a multitude of areas distributed all over the territory with much smaller areas than those of the large-scale hydraulic schemes, varying from few hundred to a few thousand hectares. The water used in SMSI has various origins that could or could not be regularized – small dams, small reservoirs, deviation from larger water flows, collection of water from springs, *khettaras*, pumping from the water table, flood water. The management of these areas, in comparison to large-scale schemes, is more of the participatory type. SMSI is generally directed towards agricultural production that is primarily geared to local consumption.

Nowadays, the State is taking a growing interest in SMSI. This sector represents 35% of the national potential for sustainable irrigation, that is 484,000 ha, and 300,000 ha of seasonal irrigation. In addition, its geographical location between mountains and plains and large irrigated areas and dry zones, gives SMSI a great socioeconomic importance. Its development allows the readjustment of the disequilibrium in water supply over most of the territory and satisfies the imbalance generated by the development of the large irrigated areas and the cities. SMSI areas constitute true development goals generating wealth in places with limited productive potential.

In 1960, SMSI hardly accounted for a total area of 53,000 ha. The new hydraulic policy and the hydro-agricultural impetus towards the end of the 1960s largely benefited the sector, which recorded rapid expansion in area from 90,100 ha in 1970 to 332,300 ha in 2000. Currently, the total SMSI area is about 334,100 ha with only 6,900 ha irrigated by sprinklers. In general, surface irrigation remains the main technique practiced in SMSI areas (98%).

Most of the State's effort towards the development of SMSI was focused on the rehabilitation and modernization of traditional areas (SMSI-1 and SMSI-2 programs). Moreover, an emphasis was placed on the promotion of participatory management in irrigation, which aims to give famers the effective responsibility for water use, resource exploitation and the equipment.

Recently, the Ministry of Agriculture has adopted a new vision for SMSI development.

This vision is based, on one hand, on an integrated rural development approach where SMSI is seen as the tool to maximize the synergy between agricultural and rural development (construction of communal infrastructures – tracks, drinking water, electrification, schools and dispensaries), and on the other hand, on the reinforcement of participation by the recipients in the definition of all their needs including investment and management of the equipment. This has been implemented in a new generation of integrated rural development projects centered on SMSI (Dri-SMSI), where rural development funds play a paramount role in integration.

Within this framework, a total of 62,700 ha were rehabilitated and the development of traditional SMSI areas was considered. Among these, 46,000 ha were identified. A first phase of this program dealing with 9,450 ha is under development in the provinces of Azilal, Khénifra and Haouz.

Private irrigation: towards modernization

Parallel to the efforts made by the State for the extension of SMSI and large hydraulics, the private sector (farmers and private companies) has also played a part in establishing hydro-agricultural installations. Generally, private irrigation is characterized by the fact that the financing of the investment and the costs of exploitation and maintenance are the responsibility of the owner or owners. Although private irrigation has existed in Morocco for a long time, its development has grown since the 1980s with the increased frequency of droughts and the engagement of the State in providing assistance to farmers for the improvement of their farms. When even the wet rainfed zones characterized by high agricultural production were affected by drought, irrigation became crucial even there and the number of SMIS installations by farmers increased.

At present, private sector hydro-agricultural installations cover an area of more than 441,400 ha, including 320,110 ha under surface irrigation, 16,230 ha with sprinklers and 105,090 ha under drip irrigation. There is the potential for adding 185,180 ha (including 27,480 ha of drip irrigation and 15,930 ha with traditional sprinklers) to be located inside the irrigation areas already equipped by the public authorities.

The private irrigation sub-sector is partly equipped with modern equipment, mainly because of financial incentives offered by the State. Indeed, the State has tried to progressively disseminate new irrigation technology. The experimental stations as well as the large private farms – orange orchards, vegetable and fruit farms – have contributed significantly to the diffusion of new technologies.

Efficient water use

In the context of the increasing scarcity of national water resources, accentuated by increasingly frequent and acute droughts, Morocco has given high priority to improving the efficiency of irrigation systems. Furthermore, the State has been compelled to shift its focus from water development and irrigated agriculture to the most challenging frontiers of water reallocation and integrated water resources management from the perspective of the whole economy (Ait Kadi, 1998).Since the beginning of the 1980s, institutional, technical, pricing, and extension programs have been undertaken with the objective of ensuring better use and valorization of irrigation water.

Due to the conjugation of these actions, remarkable progress has been made in the development and improvement of the technical and managerial capacity of those responsible for irrigation networks (ORMVAs), and in the increased responsibility of agricultural users in the management of these networks (AUEA), the rehabilitation and conservation of the infrastructure and the promotion of modern irrigation techniques such as drip irrigation.

The large potential for saving water at the farm level, and the encouragement of the adoption of modern techniques of irrigation since the 1980s has led to the increased interest of the authorities. This interest has resulted in encouragement, financial incentives, support, and technical supervision of the farmers.

Decrees related to the rights and exemption from import taxes of certain types of irrigation equipment and materials (drip irrigation, drilling. surveying, some pumping equipment, sprinklers, mobile pivots) were promulgated between 1982 and 1984. Since 1985, a system of financial incentives for hydro-agricultural and agricultural land improvement was set up with subsidies ranging from 10% to 30% (Decision no. 1305-83 of 1 February 1985). In 1999, in addition to these subsidies, financial assistance in the form of a 'premium to the investment' was instituted for five years (Decision no. 684-99 of 8 July 1999) to help farmers acquire installations allowing them to save water (drip irrigation, laser land leveling).

These measures resulted in an increase in the area equipped with modern, water-saving irrigation technologies to nearly 130,135 ha (97,975 ha with drip irrigation and 32,160 ha with sprinkler irrigation) in 2002. In this year, the Department of Agriculture implemented a new strategy for irrigation water saving to encourage modern irrigation techniques. New incentives were set up (Decision no. 1994-01 and 1995-01 of 9 November 2001 related to drip irrigation and supplemental irrigation, respectively). This system aims to promote water saving and is characterized by raising the subsidy rates from 30 to 40% of the total costs of the project carried out by farmers. Moreover, these two decrees allow the extension of subsidies on installations to the whole set of project components, including water mobilization and the distribution of water at the crop plot level.

With the implementation of this incentive system, a new program of extending drip irrigation to an additional 114,000 ha (of which 110,000 ha are conversions from existing irrigation systems) and supplemental irrigation (30,000 ha) was launched. Water saving was estimated at 400 million m^3 per year. An amount of MDh1.4 billion was reserved to support the implementation of this program. At the end of 2005, the total area under modern water-saving technologies showed a marked expansion reaching 164,730 ha including 132,570 ha under drip irrigation.

7.4 Impact of irrigated agriculture in Morocco

Irrigated agriculture in Morocco, although occupying only 15% of the agricultural area contributes an average of 45% to the agricultural added-value and 75% of agricultural product exports. This contribution is even more marked during dry years, when production in the rainfed zones is severely affected. During 1993/1994, a wet year, the contribution of irrigated land was 35% of the total agricultural added-value. In 1994/1995, a dry year, this contribution rose to 70% of added-value.

The intensification of agriculture, made possible by irrigation and the use of adapted inputs such as certified seed, chemical fertilizers and mechanization, has allowed a substantial increase in yields. Thus, the average annual increase in agricultural production in the irrigated areas since 1960 is 7.9%. The most significant increases are related to dairy and meat products (27%), vegetable and fruit farming (17.5%), cereals (17.4%), citrus fruits (17%), and sugar (6.2%). The production levels reached have largely satisfied national needs in basic foodstuffs and contributed to the development of exports.

The contribution of the irrigated areas to the national economy is illustrated by its importance and its stability. It amounts, on average, to 2.9 million tonnes of sugar beet (99% of national production), 1.2 million tonnes of sugarcane (100%), and 1.3 million tones of citrus fruit (100%). In the same way, irrigated agriculture contributes 75% of fodder crop production, 75% of dairy production and 26% of the national red meat production.

The impact of hydro-agricultural installations on rural development can be appreciated through the growth in farmers' incomes, employment, road infrastructure, and access to other communal public services like drinking water and electrification. In the Moulouya Irrigated Perimeter, net incomes increased by 9 to 13 fold (4 to 6 times in real terms). Thirty-eight percent of the total benefit from irrigation is accrued by owners, 37% by farm labor and 5% by consumers. In the Doukkala Irrigated Perimeter, farmers' incomes increased 5 to 8 times compared to before the introduction of irrigation and exceed 15,000 MDh/ha.

Irrigated areas currently provide more than 120 million working days a year, which is approximately 1,065 million jobs including 250,000 permanent workers in addition to the jobs created by upstream and downstream activities. In addition, networks of roads and rural paths were created or reinforced at the time of hydro-agricultural installation; they have decreased the physical isolation of these places. The regrouping of housing has created conditions favorable to the installation of socioeconomic infrastructure (electrification, drinking water, sanitation, schools, etc.).

The development of irrigation has had significant effects on the national economy. Indeed, upstream activities – irrigation infrastructure and related work – have had significant repercussions on public services, industry and other services. On average, 25% of the investment is allocated to labor in irrigation extension programs and nearly 60% in rehabilitation programs. But, it is especially in downstream activities that the diversification and stabilization of production made possible by irrigation has allowed the development of significant agro-industrial plants for processing, conditioning and transformation of agricultural products. Examples include the establishment of 13 sugar refineries with a total annual capacity of about 4.7 million tonnes of sugar beet and cane, 13 dairy production plants with a capacity of about 500 million liters of milk per year and hundreds of processing, conditioning, cold storage and canning facilities for fruit and vegetables with a capacity of over 1 million tonnes annually.

7.5 Irrigation and water pricing

The Agricultural Investment Code is a legal and institutional framework for significant recovery of both investment and operating costs in irrigation. It calls for full recovery of O&M costs and up to 40% of initial investment costs. There are tow types of charges:

- A land improvement levy. A fixed improvement levy, which covers 30% of the original investment cost, is applied. The first five hectare of holdings of less than 20 hectares are exempt from this charge. Land improvement levy may be paid over 17 years at an annual rate of 4%;
- A volumetric charge. A volumetric charge is intended to cover 100% of operational and management costs, 10% of original investment cost and 40% of replacement cost. Thus, this variable cost is computed as follows (Ait Kadi no date):

$$VC = (OE + ME + 0.01\, I + 0.40\, R\,) \,/\, (\, V * \mathrm{PF}) \quad (1)$$

Where:
OE = present value of total operation expenditures;
ME = present value of total maintenance expenditures;
I = original investment cost;
R = present replacement cost;
V = annual volume of water delivered; and
PF = present value factor

OE and *ME* expenditures are fixed as a percentage of the initial investment cost according to given engineering standards. *VC* is computed for each irrigation sector as completed. The Code allows progressivity in paying charges during the early years of irrigation. This progressivity is over 5 years with a 20% step for annual crops and it runs over 10 years with a 10% step for orchards. In addition, discount coefficients can be applied to take into account different conditions of water delivery. A farmer is charged for a minimum volume of water equal to 3000 m^3/ha per year. The farmer is obliged to pay for this amount of water whether he uses it or not. Different water charges are used according to the irrigation applied and to the region (Figure 7.2).

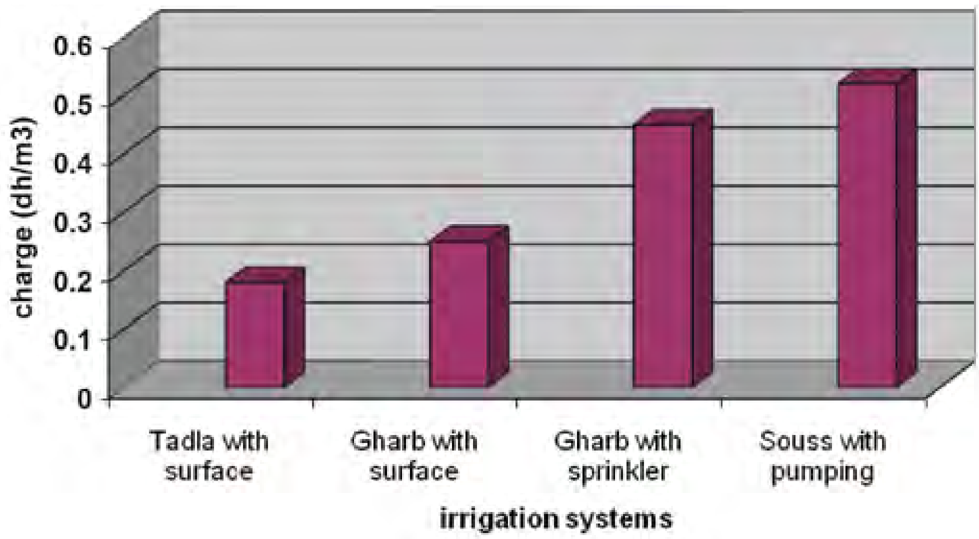

Figure 7.2: Water charges in selected regions of Morocco.

In 1980, as Morocco was shifting to the Structural Adjustment program, a decision was made to double water prices across the country.

The marginal and investment costs of water are higher when the dam is far away from the irrigated area and groundwater reserves are poor. The opportunity cost should be introduced and accorded greater weight because non-traditional water sources must be explored and increased water treatment, transfer and pumping becomes necessary. These measures are not matched by cost recovery and are not sustainable from a public expenditure point of view. Urban tariffs on average cover barely 50% of the full marginal cost of water, and irrigation tariffs under 10% of the marginal cost, including construction of dams and transfers.

In practice, water pricing as implemented in Morocco has mostly taken the form of water tariffs to recover at least the system operation and maintenance costs from users, although not always in their totality. Water fees are applied for both surface water diversion and groundwater pumping.

For each policy, direct and indirect and total effects were analyzed. Water productivity is strongly influenced by these policies, with direct effects modified by general equilibrium (Roe et al., 2005).

7.6 Green Morocco strategy (GMS)

Since the early 1980s, Morocco has developed different strategies to reinforce the agricultural sector in the face of the degradation of natural resources, market competition and to alleviate poverty.
The main objectives of GMS are the development of more strategic crops, well adapted to market mechanisms, by involving private investment and ensuring equity, and the development of a new approach oriented to poverty alleviation for specific zones and specific communities. One of the most important challenges to be targeted by GMS is the implementation of new institutional reforms to face water deficit.
The GMS strategy is based on the delegated management of water, particularly for irrigation, collection, treatment, and eventually hydraulic investment. This new policy was presented and discussed a few years ago at the Agadir congress. It will allow targeted water pricing and water distribution according to real needs.

7.7 Conclusions: Future perspectives?

The worldwide tendency towards water resources development can be seen as an evolutionary process through the setting up of targets for access to safe drinking water and basic sanitation in the Millennium Development Goals and the Johannesburg Plan of Implementation, the Hague Declaration, the WCD (World Commission on Dams) report, and the subsequent international conferences such as the Third World Water Forum or Evian G8 Summit. International organizations such as the UN agencies, the World Bank, the African Development Bank, and the EU, also follow these principles and incorporate them into their strategies. The important point to be considered here is that there is widespread consensus on the importance of securing potable water. Moreover, 1) decentralization of water services, 2) demand control including appropriate pricing, 3) decision-making by all stakeholders, 4) mainstreaming gender, 5) conservation of the environment, and 6) integrated water management, which embraces all of these elements taking into account the finite nature of fresh water resources and the protection of the ecosystem, are also considered important. The global focus has been shifting from water resources development and related infrastructure to policies and strategies based on integrated water management.

At the present stage of irrigation development in Morocco, three challenges remain to be met:

1. The valorization of controlled volumes of water not yet exploited in irrigation due to the lack of hydro-agricultural equipment and infrastructure, commonly called 'water shuffle' between the dams or reservoirs and the hydro-agricultural infrastructure and equipment of the irrigated areas. This shuffle concerns up to 108,440 ha of which more than 85,700 ha are located in the Gharb Irrigated Perimeter.

2. The under-valorization of this potential results in a significant loss in economic earnings that should not be tolerated. Hence, there is a need for exploring all possible ways and means to facilitate the financing of this operation. In addition, in exploring better public–private partnerships, the country is engaged in the implementation of two pilot irrigation projects: a project to safeguard a 10,000 ha citrus area in El Guerdane, Souss and a project in the Central Zone of the third irrigation section in the Gharb area covering 26,300 ha.

   In spite of the relatively satisfactory performances of the irrigation systems in terms of water-use efficiency, the scarcity of the resource and the continually increasing requests from the various water users fuel the search for ingenious ways to better save and use water more efficiently.

   To achieve this objective certain actions need to be taken:

   - the continuation of efforts to rehabilitate
   - the equipment of some irrigated areas the reinforcement of maintenance programs for equipment and infrastructure that is dependent on the development of financial resources from water servicing, which in turn depends on improvements in the pricing mechanisms for irrigation water, on the level of royalties recovery and on the judicious and exclusive allocation of these financial resources to water servicing; and
   - the large-scale dissemination of techniques for high yields under irrigation to realize substantial water savings. This is particularly true for drip irrigation.

   These are the main axes of the new strategy of the Department of Agriculture with regard to the improvement of the performance of irrigation systems in water saving.

3. The third challenge, but not the least, concerns the development of irrigation in terms of the improvement in the productivity of irrigated land. Indeed, in spite of relatively good performance in term of increased productivity, there can be a substantial reduction in the gap between the current level of productivity and the potential. This gap is about 20%. Taken in this perspective, the valorization of water by irrigation and water-use efficiency may bring considerable profits.

Profits from better productivity and better valorization of water can also be achieved by means of greater crop diversity and by the introduction of new crops with high added-value such as fruit orchards, vegetables and industrial crops.

It is worth mentioning the committed efforts in these fields. Indeed, such programs of rehabilitation have so far covered 170,000 ha, and the pricing readjustments implemented have made it possible to compete with the level of pricing applied in the large areas. Progress remains to be made in the collection of water royalties, which so far have not reached the levels needed to carry out the maintenance necessary for the sustainability of water systems.

The authorities have put a lot of effort into the introduction of water-saving technologies in the best agricultural environment. A particularly significant step towards the extension of water-saving technologies to a broader horizon has just been made with a new incentive system implemented in 2002 and the launching of a program for the promotion of drip irrigation on 114,000 ha. This long-term program aims to equip an additional 200 000 ha for drip irrigation to reach, in the long term, a total area of 450 000 ha.

In the past, the public sector dominated the irrigation sector, justified by the socioeconomic conditions in the rural world and by the options chosen by the State regarding economic and social development objectives. But there is now a shift towards the disengagement of the State, the abandonment of obligatory practices and crop rotations and the interventionist policy in agricultural production in the irrigated areas. In fact, the engagement of the public sector is currently overwhelmed by the development of national and international (free trade, competition) economic contexts.

It has, thus, become imperative to re-examine the legal and institutional framework governing the irrigation sector. This framework presents many limits in the current context and needs to be adapted to field realities, but if enriched by new provisions, it will be able to support private initiative and investment in the sector. Indeed, opening to the private sector will permit the acceleration of investment and improve the technical performances and the competitiveness of irrigated agriculture.

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Chapter 8: Potential use of treated wastewater for supplemental irrigation of cereals Algeria

Chapter 8: Potential use of treated wastewater for supplemental irrigation of cereals Algeria

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8.1 Background

Algeria has an area of 2,381,740 km²; more than 80% of which is desert. It is the second largest country on the African continent and the 11th largest country in the world in terms of total area. The coastal lowlands and mountain valleys are characterized by a Mediterranean climate, mild winters and moderate rainfall. In the Tell-Atlas area, with a high population density, temperatures average between 21 and 24°C in summer and drop to 10 to 12°C in winter. Average temperatures and precipitation are lower in the intermountain High Plateau region. The desert is hot and arid. Most of the country experiences little seasonal change but considerable diurnal variation in temperature. Rainfall is fairly abundant along the coastal part where it ranges from 400 to 670 mm annually. The amount of precipitation increases from west to east and is heaviest in the northern part of eastern Algeria. The largest river in Algeria, the Chelif, flows 725 kilometers from the Tell-Atlas into the Mediterranean Sea.

Algeria is blessed with an adequate availability of many natural resources with one notable exception – water. Being part of the Mediterranean region, Algeria is presently looking at improving water availability by adopting a new water resources policy and new alternatives addressing water scarcity. Treated wastewater represents a promising alternative that is increasingly available with the development of cities, tourism and industry. In the agricultural sector, reuse of wastewater adds to the value of water resources. However, the protection of public health and the environment are also concerns associated with the reuse of wastewater. Therefore, it is essential that the development of wastewater reuse in agriculture and other sectors be based on scientific evidence in terms of its effects on the environment and public health. That is why there is a need for an assessment of water quality in parallel with investigating the possibility of using wastewater in cereal production in rainfed agriculture. The use of treated wastewater is an option for enhancing crop productivity in rainfed areas. This can be achieved through the application of wastewater as a source of supplemental irrigation, which is done by applying small amounts of irrigation at critical crop growth stages. Supplemental irrigation has the potential to produce several-fold increases in crop productivity per unit of applied water under rainfed conditions.

Algeria's population is estimated at 33 million. The population increases at an annual rate of 1.2%. More than 90% of the country's population is concentrated along the Mediterranean coast, which constitutes only 12% of the country's land area. Therefore, the overall population density of 14.2 people per square kilometer is deceptive. About 59% of Algeria's population is urban. Drought conditions have led to the internal migration of farmers and herders to the cities to seek alternate employment. High unemployment encourages emigration.

This report explores the different aspects of using treated wastewater as a source of supplemental irrigation for enhancing productivity under rainfed conditions in Algeria.

8.1.1 Agricultural sector

Algeria's agricultural sector, contributing about 8% of gross domestic product (GDP) and employing 14% of the workforce, is unable to meet the food needs of the population. As a result, around 45% of food is imported. The primary crops are wheat, barley and potato. Farmers also have had success growing dates for export. Cropping is concentrated in the fertile coastal plain of the Tell.

The total area of Algeria is 238 million ha, including 200 million ha of desert, 20 million ha of steppe and 12 million ha of mountains. The area suitable for agriculture is 47 million ha with 8 million ha of arable land, including 0.6 million ha of irrigated land.

The major constraints faced by the agricultural sector are:

- Water deficit for irrigation, due to the irregular spatio-temporal distribution of rainfall and the low remobilization of the resource.
- Salinity and soil sterilization.
- Significant overgrazing.
- Erosion, etc.

A National Program for Agricultural and Rural Development (PNDAR) was implemented in 2000 to safeguard natural resources and to bring a new economic dynamics to increase farmers' incomes and fight poverty.

8.1.2 Water resources

The total annual available water resources in Algeria are 19.4 billion m^3, whereas the mobilizable resources are only 12 billion m^3, with 6.8 billion m^3 in the north and 5.2 billion m^3 in the Saharan area. These numbers correspond to an annual per capita water availability of 600 m^3 by 2020. These estimates refer to conventional water resources, without taking into account the contribution of desalinated water. Thus, Algeria falls into the category of countries with low available water resources, taking the threshold of scarcity as an annual per capita water availability of 1000 m^3 (Beckerman, 1992; Falkenmark and Widstrand, 1992).

Among the available scarce water resources, non-conventional ones, in particular treated wastewater, are an alternative source that can narrow the gap between freshwater demand and supply. However, the mobilization of such non-conventional water resources is rather slow and expensive. So, there is a need to make the best use of treated wastewater in agricultural production systems.

Rainfall

Rainfall in Algeria is characterized by its great spatio-temporal irregularity on arable land (AL). This land is divided into three classes based on average rainfall:

1. 1.8 million ha, representing 24% of the AL, receive more than 600 mm of rain/year allowing intensive agriculture without irrigation, especially when precipitation is well distributed.
2. 3.2 million ha or 42% of AL are located in areas of 400 to 600 mm rainfall, allowing the cropping of cereals, rainfed fodder and fruit trees.
3. 2.6 million ha or 34 % of AL are located in areas where average rainfall is lower than 400 mm. In these areas, agriculture constitutes a high-risk activity.

It can be seen that 76% of the AL is located in unfavorable agro-climatic zones where water constitutes a major constraint and a limiting factor to agricultural production.

Water use

The water resources currently used are estimated at nearly 4,250 billion m^3; water consumption is as follows:

- Agriculture = 2.550 billion m^3
- Domestic + industry = 1.5 billion m^3
- Production of electrical energy = 0.2 billion m^3

Table 8.1 summarizes the distribution of water among the different sectors.

Water distribution according to the source:

- Big dams: 932 million m^3 or 24% of the total;
- Small reservoirs: 28 million m^3 or 1% of the total;
- Wells: 2044 million m^3 or 51% of the total;
- Springs: 950 million m^3 or 24% of the total.

8.1.3 Water services and tariffs

The tariff

The water tariff is stipulated by Law no. 05-12 of 4 August 2005, published in the Official

Table 8.1: Distribution of water consumption (hm^3).

Type of activities	Underground water		Surface water	Total	%
	North	South			
AEP and Industry	1000	200	300	1500	35.3
Agriculture	–	–	150	150	3.5
– Large areas (GP)	900	–	200	1100	25.9
– Small areas (PMH)	–	1300	–	1300	30.6
Energy	–	–	200	200	4
Total	1900	1500	850	4250	100
Percentage	44.7	35.3	20.0		

1 hm^3/year is equivalent to 1,000,000 m^3/year. AEP = drinking water supply (l'alimentation en eau potable).

Journal of the Democratic and Popular Algerian Republic, no. 60.

The tariffs are based on:

- The type of user.
- The tariff zone.
- The volume of water provided.
- The nature and quality of the water.

Industrial and domestic water

The water tariff is based on the rate, which takes into account the cost of water in each tariff zone and the volumes used and consumed.

Domestic and industrial water users are divided into four categories:

- Households: Category I.
- Institutions, administrations, communities and publicly-owned establishments: Category II.
- Craftsmen and public sector services: Category III.
- Production facilities and tourism: Category IV.

The country is divided into 10 tariff zones, and each zone corresponds to a tariff unit.

Water services

The use, management and sustainable development of water resources aim to ensure a regular supply. The objectives are:

- Providing a water supply by mobilizing and distributing water in sufficient quantity and of the required quality, to satisfy the needs of the population and the watering of livestock and to meet the demands of agriculture, industry and other economic activities and social users of water;
- Safeguarding public health and the protection of water resources and aquatic environments against the risks of pollution by the collection and purification of domestic and industrial used water as well as rainwater and run-off water in urban zones;
- The valorization of non-conventional water of all kinds to increase water supply possibilities.

Agricultural water

The tariffs for agricultural water use are established according to a binomial formula based on the maximum subscribed flow and the actual consumed volume. The water tariff rates applied in different regions are presented in Table 8.2.

Tariffs applied to agricultural water supply for use in irrigated areas other than those quoted above, are fixed as follows:

Table 8.2: Water tariff rates applied in the large Irrigated Perimeters (Algerian Dinar, DA).

Irrigated Perimeters	Volumetric m^3	Fixed l/s/ha
Sig	1.20 DA	250 DA
Habra	1.20 DA	250 DA
Mined	1.00 DA	250 DA
Low Chélif	1.00 DA	250 DA
Chélif medium	1.15 DA	250 DA
High Chélif	1.25 DA	400 DA
Western Mitidja	1.00 DA	400 DA
Hamiz	1.25 DA	400 DA
Saf Saf	1.00 DA	400 DA
Bou Namoussa	1.20 DA	400 DA

- Volumetric payment: 1 DA per cubic meter.
- Fixed payment subscribers: 250 DA per l/s per hectare.

8.2 Production and use of waste water

8.2.1 Introduction

In Algeria, the use of treated wastewater for irrigation is in an embryonic state and is practiced only in small areas and often on an experimental basis. In fact:

- The total area irrigated by treated wastewater is 2300 ha (MADR 2004, 2006).
- The total volume of wastewater at the national level is 731 million m^3 (Source: Ministry of Water Resources).
- The total area irrigated by untreated wastewater is around 5400 ha (MADR 2004, 2006).

Most areas irrigated by this non-conventional water are concentrated in the northern provinces (*wilaya*).
The tendency to expand the use of untreated wastewater at the expense of public health can be explained by two decades of drought, which negatively influenced the behavior of some users attracted by the speculative aspects of irrigated crops. Following information fallows:

- Urban population: 26 million.
- Quantity of wastewater generated: 731 hm^3/year.
- Collected wastewater: 485 hm^3/year.
- Intercepted wastewater: 337 hm^3/year, of which.
- Wastewater intercepted but not purified: 155 hm^3/year.
- Purified wastewater: 182 hm^3/year.
- Volume of potentially re-usable wastewater: 510 hm^3/year.
- Wastewater purification stations (STEP) to be constructed have been identified
- Total cumulative STEP until 2030: 696

8.2.2 Objectives until 2030

The government had put the following objectives:

- Continue the planning and construction of STEP.
- Guarantee a potential reuse of 52% of wastewater in the large irrigated areas and the rest in the small- and medium-scale irrigated areas.
- Develop purification systems adapted to the requirements for the success of purified wastewater projects.
- Give priority to the interception and reuse of wastewater discharged into the sea.
- Establish the methodology for feasibility studies on the success of using treated wastewater.
- Establish an inter-ministerial committee responsible for wastewater use.

8.2.3 Status treatment plants (STEP)

The number of stations for the purification of domestic wastewater in East Algeria is 45. The status of these stations:

- 10 STEP to be rehabilitated (surveys are completed).
- 11 STEP to be rehabilitated (2nd phase; study is launched).
- 03 STEP in the process of rehabilitation.
- 03 STEP under development.
- 18 STEP in operation.

The total volume of treated wastewater does not exceed 75 million m^3 a year, which is nearly 12% of the total volume of wastewater.

Total potential volume of treated wastewater for use in irrigation is estimated at 39,864,000 m^3/year, representing around 50% of the total volume of wastewater.

The quantity of wastewater said to be used in irrigation remains disproportionate compared to the area actually irrigated (2376 ha) by wastewater (DDAZASA 2005).

8.2.4 Wastewater reuse policy and standards of water quality

- A draft executive decree related to ‘the final concession of treated wastewater uses for irrigation’ is in the process of preparation for adoption.

- Law no. 05-12 of 4 August 2005 institutionalized, in articles 76 and 77, the concession of treated wastewater use for irrigation purpose.
- The articles of the decree stipulate that 'the uses of purified wastewater resources' for individual or collective agricultural use and for industrial uses, must be the authorized by the relevant administration. The procedures and the conditions of authorization are defined by the law.

8.2.5 Wastewater treatment

The treatment plants established so far are insufficient and sometimes their rehabilitation is not considered a priority. A more serious problem is that they have practically no effect on water quality, because they are not operational.

Table 8.3 lists the wastewater treatment plants managed by the National Office of Water Decontamination (ONA, Office National d'Assainissement) that can provide water for irrigating on-farm experiments.

8.2.6 Wastewater treatment potential and reuse in agriculture

The use of non-conventional water resources such as treated wastewater and desalinization is not yet common practice in Algeria.

Wastewater treatment is neglected and there is no effective reuse of treated wastewater in Algeria. The concept of the reuse of treated wastewater, which could have a tremendous impact on water supply, has not yet been applied. However, a few trial plots have been designated to explore this possibility.

Wastewater production and reuse options in the Khemisti area

A survey of the ecological, socioeconomic and agricultural aspects of wastewater use was conducted in the Khemisti region. The main findings are summarized below.

Ecological impact

- Negligible impact on the physico-chemical qualities of soils;

Table 8.3: List of wastewater purification stations.

Wilaya	Site location	Effective flow in m³/day	Proximity to arable land	Does irrigation already exists (Yes/No)
Constantine	18 km from Constantine	16,000	moderately close	No
Souk Ahras	4 km from Souk Ahras	13,000	close	No
Chelghoum El Aid	Wadi El Athmania	2,700	moderately close	No
Maghnia	2.3 km on left bank of Wadi ouedjou	7,000	moderately close	No
Ain El Hadjar	1.8 km	2,000	moderately close	No
Touggourt	Periphery of Touggourt	10,000	near palmerais	No
Sétif	Ain Sfiha	12,000	surrounded by arable land	No
Tizi Ouzou	5 km from Tizi Ouzou	15,000	surrounded by arable land	No
Boumerdes	2 km from city	5,000	surrounded by arable land	Yes, olives arboriculture
Thenia	2 km from city	3,000	surrounded by arable land	No

- Enriches soils by providing essential nutrients;
- Report of groundwater contamination risks; the station requires modification and some additional wastewater treatment processes;
- Little mobilization and exploitation of water potential.

Socioeconomic impact

- The area is characterized by a lack of knowledge of the potential of natural resources, the existence of extensive production systems with a high percentage of fallow, very strong disparities in livestock numbers, significant inadequacies in farm management, and a low level of diffusion of innovative technologies;
- Low level of technical performance, and very strong sensitivity of outputs to climatic risks, reflecting a low level of technical control;
- Low level of agricultural incomes, in particular of very small-scale farming and collective farms that do not have livestock;
- Some technical and economic progress in performance, though not very significant, due to the National Program on Agricultural Development (PNDA), which has had net impacts (diversification of farming systems, irrigation, equipment);
- Quantity of mobilizable wastewater is only enough to irrigate a limited area: 40 to 50 ha, by supplemental irrigation;
- Lack of precise knowledge of the area currently irrigated with used water, and this in spite of prohibition of the use of this resource; Consequently,
    - The current technical and socioeconomic impacts limit the use of wastewater;
    - The potential foreseeable impacts after rehabilitation of the station, collective management and control of the water resource, are relatively significant;

    Then, there is a need for
    - The rehabilitation of the station;
    - The installation of an organizational structure for the collective and interdependent management of the water resource;
    - Equity in access to potential wastewater for irrigation (0.5 to 1 ha/ family);
- The extra income of 26,000 to 52,000 DA per household comes from increasing wheat production from 7.5 to 15 quintals/ ha, plus a considerable contribution to family food from vegetable and milk production.

Gender

Report on the situation of women who are prevented taking initiatives to access external resources – information, credit, subsidies and other State aid, employment opportunities;

- Women contribute significantly to the productive activities of the household (livestock production);
- Very strong degradation of the know-how of women (craft industries, in particular working with wool);
- High recognition of the situation of women and young people who are confronted by unemployment and difficulties of acceding to high responsibility in various State action programs.

Reuse of wastewater for supplemental irrigation project background and design

Issues

Over the last 25 years, Algeria has experienced a period of intense and persistent drought, characterized by a significant rainfall deficit of 30% over the whole country (during the year 2001/2002, this deficit was 50%).

The Algerian climate is characterized by its aridity; so the majority of the arable land is located where water is frequently scarce.

The negative impact of climate change and, in particular, the rainfall deficit recorded over recent decades has resulted in a reduction in the volume of stored water, thus limiting the amount available for irrigation. The priority in the allocation of water is given to drinking water supply. This has involved a reduction in the quota reserved for irrigation and hence a constant reduction in irrigated areas.

The demand for water for drinking and by the industrial sector is 2.4 billion m^3/year for a population of 30 million, while the availability is only 1.6 billion m^3/year; and the requirement in 2010 is estimated at 3.6 billion m^3/year for a population of 40 million.

The solution to this situation is to seek out and plan for other alternatives to mobilize, manage and develop as well as possible this scarce resource.

Since the mobilization of new resources is very slow and expensive for the State and for communities, the obvious, economic and fast solution consists of recovering used water for reuse in agriculture and the development of a significant hydraulic infrastructure.

As our chosen study area is known for its conventional water deficit, it was considered an interesting site to study the possibility of the reuse of wastewater in supplemental irrigation.

Choice of the site

In order to highlight the benefits of the treatment process and the reuse of water on the ecosystem, we needed to choose a suitable site in terms of environmental technical, social and economic conditions.

For all these reasons, the choice fell upon the small rural district of Khemisti (Tissemsilt Wilaya), located in the northwestern region of Algeria, where 22,812 inhabitants rely exclusively on the monoculture of cereals together with cattle and where a wastewater recovery plant was recently established.

Domestic wastewater is collected from the small town of Khemisti. This brings with it the risk of ecosystem degradation, groundwater pollution and the exposure of the population to disease. The treatment plant was set up with the specific aim of recovering and treating this water before disposal, without considering its reuse. However, wastewater treatment plants carry out only rudimentary processing, limited to simple chlorination. The project aimed to use this treated wastewater in agriculture.

Once implemented, new production systems (expanded to other food crops and marketable commodities) will certainly involve rural women because of the development of new agricultural activities – small ruminant breeding, handicrafts and possible product diversification.

The selected area is characterized by low variable rainfall, with an annual average below 350 mm. Groundwater resources constitute most of the water reserves. However, their exploitation remains difficult and expensive for the community. To achieve this goal, it is necessary to carry out an agro-ecological survey of the study area.

Soils

The soils of the study area are calcareous with a clayey texture upstream and a loamy-clayey texture downstream of the terraces. They are suitable for growing field crops, vegetables and adapted fruit trees, except under some conditions upstream, where there is swelling clay. In these conditions, soil moisture has to be high enough to avoid soil cracking.

Water quality

The main data concerning the physico-chemical characteristics of wastewater are presented in Table 8.4.

The analysis of raw waters and water treated by decantation, at the basin level, shows no risk of toxicity due to heavy metals, chlorine and sodium on crops in the near future. There is also no soil degradation due to salinization or sodicity.

Salinity and sodicity

The SAR (sodium adsorption ratio) as low as 2.41 for raw water and 1.66 for treated water, shows there is no risk of degradation of the soil structure or porosity due to sodicity.

The electrical conductivity (EC) of water (3.9 and 2.59 dS/m) appears, on the other hand, relatively high for crops sensitive to salinity, particularly for some vegetables and fruit

Table 8.4: Physico-chemical characteristics of wastewater.

Physico-chemical analyses			Heavy metals		
	Raw water	Treated water	Elements (ppm)	Raw water	Treated water
pH	7.45	7.81	Zn	trace	trace
EC dS/m	3.09	2.59	Cu	trace	trace
K me/l	1.52	1.19	Fe	15	10
Na me/l	14.24	10.94	Mn	5	4
NH4 me/l	129.6	144	Cd	zero	zero
Ca me/l	5.75	4.75	Pb	zero	zero
Mg me/l	74.16	80.02	Co	zero	zero
SO4 me/l	1.82	1.57	Cr	zero	zero
Cl me/l	7.29	7.65			
HCO me/l	12	10.5			
SAR	2.41	1.66			

trees in which yields can be reduced by up to 25%.

Bacteriology analyses
Studies of the indicators of fecal contamination form the basis of bacteriological water testing. The maximum level allowed for the microbiological content of irrigation water authorized by WHO is 1000 total coliforms (TC)/100 ml.

The concentration of microbes in the untreated wastewater in our study (fecal coliforms, total coliforms, activated sludge reactor and CO) is high. However, after chlorination with 2.5 g/m^3 calcium chloride for 24 hours, the microbial load decreased to 1609 TC/100 ml. Measuring the load of (sulfur reducing) bacteria is preferred in this case, because their level indicates the effectiveness of disinfection in reducing the content of micro-organisms. They are also considered as indicators of fecal contamination.

The results revealed a load of anaerobic bacteria (sulfur reducing) of 300/20 ml and a concentration of fecal streptococci of 141/100 ml. It is recommended that the settling time at the reservoir level is increased to improve the bacteriological quality of used water.

8.2.7 Effect of supplemental irrigation with treated wastewater on wheat yields at the Khemisti site

The objectives of this study were to:

- Evaluate the effects of supplemental irrigation on crop development and grain yield; and
- Determine the impact of applying treated wastewater effluent on soil characteristics and plant nutrition

Materials and methods

Field experiments were conducted for two consecutive years (2006/07 and 2007/08) at two sites in Khemisti commune in Tissemsilt Wilaya (altitude: 900 m), characterized by its arid climate with hot summers and cold winters and annual rainfall ranging from 250 to 350 mm, of which about 90% is received from December to April.

In this study, three irrigation regimes of treated wastewater using sprinkler irrigation were tested. The amount of water applied in each supplemental irrigation was 50 mm. One irrigation was given in May (T2) or in March (T3) or two irrigations in March and May (T4). The check or treatment T1 was conducted under rainfed conditions.

Two varieties of durum wheat were used. The first, WAHA, is widely used by farmers and the second is a newer variety, Boussalem, selected at the Sétif ITGC (Institut Technique des Grandes Cultures) station and of ICARDA/CIMMYT origin. The experimental plot area was 1 hectare per farmer.
The experiment was conducted using a completely randomized block design. Analysis of variance (ANOVA) was used to determine the effect of each treatment and their interactions. When the F ratio was significant, a multiple mean comparison was performed using Fisher's Least Significance Test ($p = 0.05$). Statistical analyses were performed using the STATITCF program.

The agronomic parameters measured were the number of spikes/m², the number of kernels/spike, 1000 seed weight and grain yield (kg/ha). In this report, only the grain yield is presented.

Results

Table 8.5 and 8.6 show the effect of supplemental irrigation at different growth stages of wheat on the yield of the two varieties, WAHA and Boussalem grown at two sites (experimental station and farmer's field). In general yields at the station are higher than those obtained at the farm level during both years of study (2006/07 and 2007/08), showing the yield gap due the poorer management used by the farmer. All irrigation treatments gave higher yields than that obtained under rainfed conditions. There was no significant difference in yield between the plot that received one irrigation in March and the one that was irrigated in May. However, two irrigations applied in March and May significantly increased productivity. In a dry year (2007/08), the yield obtained with two irrigations (March and May) was three-fold that under the rainfed and one irrigation in March or May treatments.

8.2.8 Conclusions and recommendation

From this study we can conclude that:
- The effect of using wastewater in irrigation on the physico-chemical characteristics of the soils with a rough texture is low. More work is needed to study the effect on heavy (clayey) soils;
- Soil nutrient content (N and P) is improved when wastewater is used in irrigation;
- There is a risk of contamination of deep aquifers with wastewater;
- There is a risk of microbial contamination if treated wastewater is used by humans and livestock. In fact, it was noted that the microbiological quality of water treated by the existing purification station and non-treated water were similar.
- The availability of wastewater remains low and cannot irrigate more than 50 ha. However, its use in supplemental irrigation can significantly increase yields of cereals and farmers' incomes. From the survey, it is estimated that water can be allocated to irrigate 0.5 to 1 ha per farm in this district.

The following may be recommended:
- Because of the positive effect of supplemental irrigation and the

Table 8.5: Effect of irrigation with treated wastewater on wheat yields for WAHA variety over two years: 06/07 and 07/08.

Years	2006/2007			2007/2008		
Treatment	Grain yield (kg/ha) CA	Grain yield (kg/ha) CS	Average grain yield (kg/ha)	Grain yield (kg/ha) CA	Grain yield (kg/ha) CS	Average grain yield (kg/ha)
Rainfed T1	1423	1923	1673	528	439	510
T2	1706	1871	1788	658	681	670
T3	1740	1953	1846	715	655	685
T4	2003	4359	3181	1430	2218	1824

CA: farmer's field, CS: experimental station.

Table 8.6: Effect of irrigation with treated wastewater on wheat yields for Boussalem variety over two years: 06/07 and 07/08.

Years	2006/2007			2007/2008		
Treatment	Grain yield (kg/ha) CA	Grain yield (kg/ha) CS	Average grain yield (kg/h)	Grain yield (kg/ha) CA	Grain yield (kg/ha) CS	Average grain yield (kg/ha)
Rainfed,T1	1625	1344	1485	354	729	542
T2	1738	1512	1700	576	1435	1006
T3	1673	1943	1808	665	1590	1128
T4	2254	3793	3023	1332	1964	1643

CA: farmer's field, CS: experimental station.

low quality of water obtained from the existing purification station, it is recommended that the station is rehabilitated to guarantee water quality and protect the population and livestock from microbial contamination. When this is done, more experiments on supplemental irrigation are needed.

- A participatory approach to the management of the treated wastewater resource should be established.
- The community should be trained to use treated wastewater in irrigation.

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Chapter 9: Adoption and impact of supplemental irrigation in wheat-based systems in Syria

Chapter 9: Adoption and impact of supplemental irrigation in wheat-based systems in Syria

A. Bader, N. Jouni and K. Shideed

9.1 Introduction

Agriculture in Syria depends on a wide base of varied natural resources extending over five agro-ecological zones differing in total precipitation, soil structure, and water resources such as rivers, springs, dams, and groundwater which supplies water for about 851,000 ha (61% of the total irrigated areas). However, precipitation is considered as the main source of the water needed to establish the widespread rainfed system of agriculture, which occupies 70% of the cultivated area in Syria (Ministry of Agriculture, 2006).

In Syria, wheat is the most important winter crop and is grown on about 1.8 million hectares (about 32% of the total cultivated area). This area includes two farming systems – irrigated and rainfed (45% and 55% of the wheat area, respectively). Statistics show that the productivity of irrigated wheat has increased over the last five years due to new irrigation technologies.

However, new irrigation technologies have low levels of adoption. They cover only 17% of the total irrigated area (about 236,000 ha). The degree of adoption of sprinkler systems was estimated at 69%, greater than that of drip irrigation at 31% (Ministry of Agriculture, 2006).

As wheat is the major user of cultivated land and also of water resources among all winter crops, it was considered as the basic crop in this project undertaken by ICARDA as a joint program in Syria.

9.1.1 Objectives

- Studying the adoption indicators of supplemental irrigation and new irrigation technology in wheat-based systems.
- Identification of the factors restricting adoption.
- Estimating the impact indicators of adoption.

9.1.2 Characterization of the study area

The three most important provinces applying supplemental irrigation in wheat-based systems in Syria have been involved in the project. These are Aleppo in the northwest of the country, Dara'a in the south, and Hassakah in the north east. They account for about 61% of the total production of wheat in Syria (Table 9.1).

Table 9.1: Total production of wheat in the study area during the year 2006.

Province	Production (ton)	% of total country production
Dara'a	99,091	2
Aleppo	1,002,093	20
Hassakah	1,897,934	39
Total of the study area	2,999,118	61
Total of the country	4,931,525	100

In addition, these important provinces account for about 66% of the total area planted to wheat (Figure 9.1)

Another important point is that over the last decade these provinces hosted irrigation field trials conducted by ICARDA and the National Agricultural Research Program (NARP) represented by the Administration of Irrigation Research. These trials focused on supplemental irrigation, deficit irrigation, water timing and scheduling in wheat with various levels of fertilizer and several varieties. The villages involved in these trials were already included in the sampled community, and fifteen villages were selected to be surveyed. Five villages were selected from each province in agro-ecological zones 1 and 2.

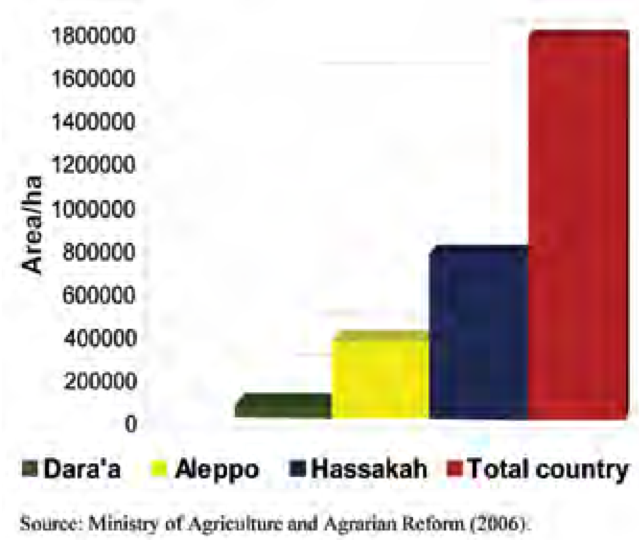


Figure 9.1: Area planted to wheat in the study area during the year 2006.

Farmers in the study area have various sources of water. In Aleppo and Hassakah provinces, they depend mainly on groundwater where they own wells. The discharge of farm water is 10–130 m^3/h and 30–295 m^3/h in the two provinces, respectively. However, farmers in Dara'a province depend on two sources of water, wells and canals which have been established by the government to draw water from dams to farmers' fields. Discharge from wells in Dara'a is 22–80 m^3/h, while the discharge from canals is 18–84 m^3/h.

Both farming systems – rainfed and irrigated – exist independently in the study area. However, some farmers grow wheat as both irrigated and rainfed simultaneously, depending on water availability. The average precipitation varies in the study area. It was 376 mm, 350 mm and 291 mm in Aleppo, Dara'a and Hassakah, respectively, while it was 398 mm in zone 1 and 293 mm in zone 2.

As a Mediterranean country, Syria is characterized by a low annual level of precipitation, unfavorably distributed over the growing season, with great year-to-year fluctuations, which make the prediction of annual rainfall very difficult (Oweis, 1997). So, if farmers depend only on precipitation, they are taking a risk with their production. Therefore, they mostly depend on supplemental irrigation to support crops, especially wheat, when precipitation fails to supply the needed water.

9.2 Methodology

During the initial stages of the project, a check list including all relevant thoughts and important points was developed with the participation of ICARDA scientists and a team from the General Commission for Scientific Agricultural Research (GCSAR) to cover all options that will lead to achieving the project goals in Syria. The check list included the technical and socioeconomic information needed to understand the farmers' irrigation practices, cropping patterns, water sources and allocation, adoption of new technologies and recommendations, and farmers' concepts about water management, as well as farm management and production costs.

A rapid rural appraisal (RRA) was included in this check list and carried out with the participation of various levels of the community (farmers, extension agents, researchers) in irrigated and rainfed areas. At the subsequent stage, a primary questionnaire was designed, and a pre-testing survey was carried out. The results of the pre-testing stage helped in gaining more understanding of the community situation, and in bringing out other new points, which had to be added to the questionnaire later.

9.2.1 Sample size and allocation

The three provinces included in the survey were described. Results showed that each province could be distinguished by its specific characteristics based on farm size, cropping patterns and water resources. This led the study team to adopt a stratified sampling approach, since it helped to consider each province as a uniform stratum. The stratified sample is the one obtained by separating the population elements into non-overlapping groups, called strata, and then selecting a simple random sample from each stratum.

Following the stratified sampling approach, sample size was calculated according to the variance in farm size (calculated from the pre-testing data). On this basis, 490 farmers were interviewed throughout the study area in the three provinces.
The calculated sample size was allocated to various levels:

1. First level is the province.
2. Second level is the agro-ecological zone.
3. Third level is the village, and
4. Fourth level is the source of water, as shown in Figure 9.2.

The sample allocation resulted in 265 farmers located in eight villages in zone 1, and 225 farmers located in seven villages in zone 2, as shown in Table 9.2.

9.2.2 Data collection

The questionnaire used in the study aimed to collect the following data:

- Participation of farmer in previous trials and activities on irrigation.
- Soil type and characterization.
- Agricultural rotation and cropping pattern.
- Land tenure.
- Farm water sources.
- Production costs.
- Farm water use.
- Irrigation system infrastructure on the farm, and its cost.
- Application of supplemental irrigation and adoption of new irrigation technologies.

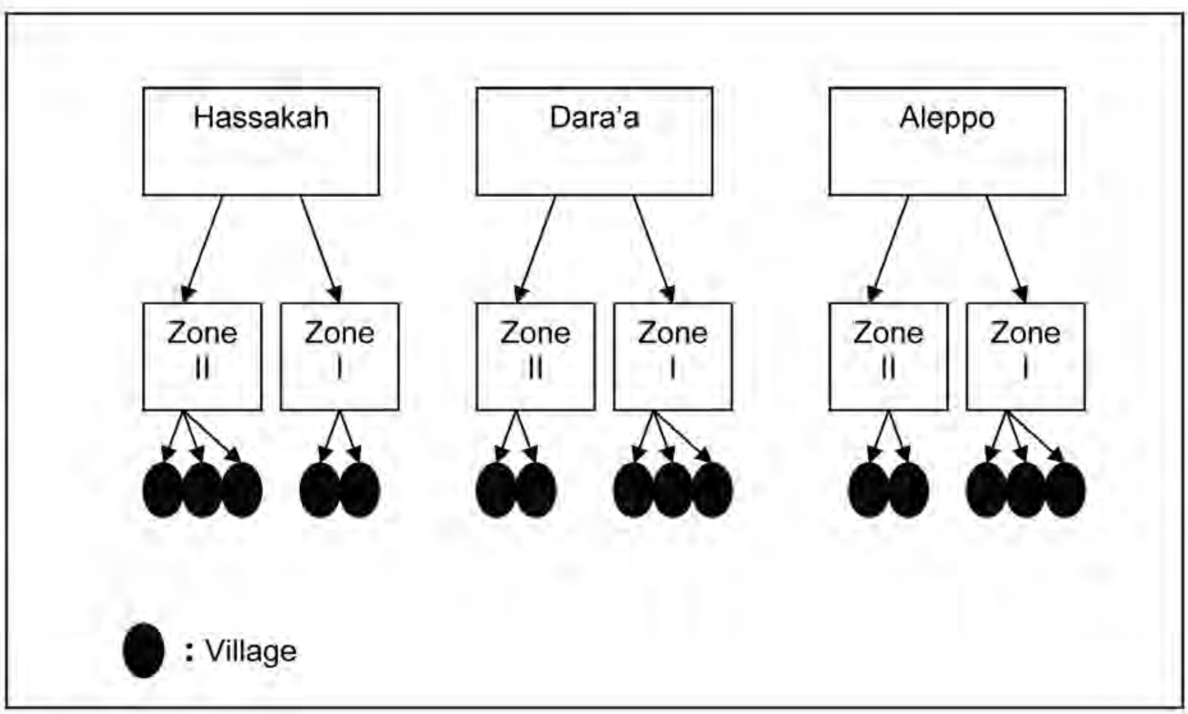


Figure 9.2: Sample allocation.

Table 9.2: Sample allocations by province and agro-ecological zone (AEZ).

Province	Aleppo		Dara'a		Hassaka	
AEZ	I	II	I	II	I	II
Sample size	175	56	55	104	35	65
Province total	231		159		100	

AEZ: agro-ecological zone.

- Obstacles to the adoption of technologies.
- Income sources.
- Household structure and farmer's socioeconomic characteristics.
- Information sources.
- Farmer's self-concepts.

The group of 490 farmers was interviewed in the three selected provinces. The field survey also included measurements of water discharge from both sources – wells and canals.

Data analysis was carried out using the SPSS program (Statistical Package for the Social Sciences) at two main levels, province and agro-ecological zone (1 and 2), and at a third level, the water source, when dealing with production and irrigation indicators.

9.3 Results and discussion

9.3.1 Land tenure and cropping patterns

The average total farm size in the sample was 14.7 ha, not all of which was owned by the farmer; the average owned area was 12.7 ha. The area not owned was mainly rented or partly-shared. The survey showed that total and owned areas were larger in zone 2 (Table 9.3).

From Table 9.3, we can infer that the renting level in Aleppo and Dara'a is higher than in Hassakah, and also in zone 1 when compared with zone 2. This is because of the small size of holdings in these areas, prompting farmers to find an additional source of income. It is also clear that the level of sharing is low in the study area, although it is somewhat higher in Dara'a, Aleppo and in zone 1. This reflects the farmer's concept of economic investment and usage of production resources, and perhaps also the social relationship between community members.

In the survey area, winter crops occupy 63% of the total cultivated area in our sample, while summer crops account for about 24%, fruit trees for 2% and 11% of the total land is under rainfed systems (Figure 9.3). Some farmers overlap rainfed systems with irrigated

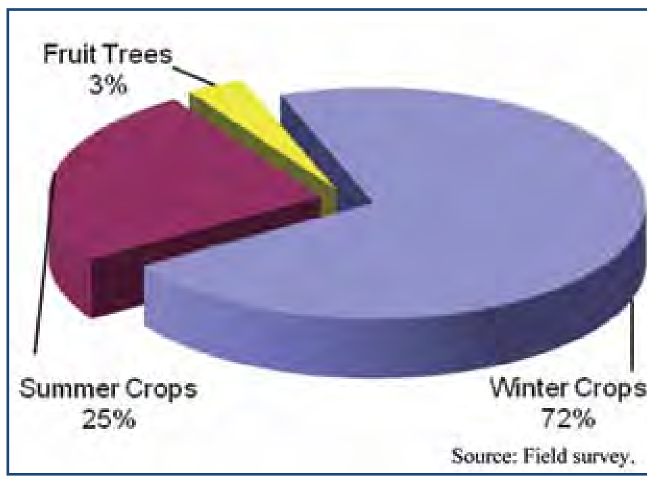


Figure 9.3: Cropping patterns in the study area.

Table 9.3: Land tenure information calculated by the survey.

Land tenure		Aleppo	Dara'a	Hassakah	Area (ha) Zone 1	Area (ha) Zone 2
Total	Area	9.8	9.7	34	11	19
	Total farmers	231	159	100	265	225
Owned	Area	8.6	8.5	34	9	19
	Number of farmers	227	144	90	254	207
Rented	Area	5	7	30	7	11
	Number of farmers	65	44	14	81	42
Shared	Area	4	3	60	3	13
	Number of farmers	9	8	1	12	6

Source: Field survey.

systems. Wheat is considered the dominant crop and occupied 12% of the cultivated area, which is 37% of the area under winter crops. On the other hand, cotton is considered the most important summer crop, and it occupies 21% of the area under summer crops (7% of the total cultivated area). This is in spite of the restrictive policies limiting the area allocated to cotton due to water resources and usage.

Although the three provinces have wheat as a major crop, they differ in other crops. Wheat forms 11%, 9%, 48% of the total cropped area in Aleppo, Dara'a and Hassakah, respectively. Other than wheat, Aleppo is characterized by barley, cotton, sugar beet, potato, olive, fruit, vegetables, and other crops such as cumin, maize, some legumes and others. While Dara'a is characterized by chickpea (more important than wheat accounting for 11% of the cultivated area), melon, potato, legumes, fruit, vegetables, grapes, olive, tobacco and stone fruit. Hassakah is characterized by cotton, barley and some other crops such as some legumes and maize.

The relative importance of winter crops in the cropping pattern in zone 1 decreases in comparison with zone 2 (60% versus 65%). However, summer crops are more important in zone 1. This is due to the large average farm size in zone 2, and the importance of using water for growing winter crops. The shortage of water in zone 2 restricts raising summer crops, which consume more water than winter crops. There was no difference in their relative importance of fruit trees.

Wheat is included in almost all crop rotations. The main rotations in Aleppo are wheat–legumes, wheat–cotton–potato and wheat–potato–sugar beet–cotton, representing 20%, 18% and 11%, respectively. In Dara'a, the main rotations are wheat–vegetables, wheat–legumes and wheat–fallow, accounting for 50%, 19% and 12%, respectively. However, in Hassakah there are five types of agricultural rotations which are wheat–cotton, wheat–cotton–legumes, wheat–legumes, cereals–cereals, and wheat–cotton–maize–potato accounting for 92%, 6%, 1%, 1%, and 1%, respectively.

9.3.2 Farm water resources and irrigation infrastructure

The main sources of water are wells for groundwater and canals for surface water. In Aleppo and Hassakah, wells are considered the main water source in the area surveyed. However, in Dara'a, wells are the water source for 45% of farmers, while canals provide water for 67% of farmers, and 15% of farmers have both sources of water on their farms. The average number of wells on the farm is one in the three provinces, but varies from one to three in the sample, with no significant differences. But, the percentage of owners of wells differs significantly within zones and insignificantly within provinces, as shown in Table 9.4.

Fifty percent of farmers in the sample, who depend on groundwater for irrigation, said that water levels had fallen over the past few years. The majority was in Aleppo (60%), 49% in Hassakah and only 11% in Dara'a. The critical period when water levels decline occurred between June and August, while it was concentrated in May in zone 2, and July and August in zone 1. The average fall in groundwater levels per year is illustrated in Table 9.5.

Table 9.4: Percentage of well owners according to number of wells owned.

Number of wells	Province			Zone		Total
	Aleppo	Dara'a	Hassakah	I	II	
1	77	89	82	82	76	80
2	18	9	13	16	14	15
3	5	2	5	2	10	5

Source: Field survey.

Table 9.5: Average fall in groundwater levels.

Fall in water level	Province			Zone		Total
	Aleppo	Dara'a	Hassakah	I	II	
Average (m/year)	0.49	0.19	0.19	0.36	0.44	0.39

Source: Field survey.

The average fall in groundwater levels per year was 0.39 m in the sample. It approached 0.19 m in Dara'a and Hassakah, while it was 0.49 m in Aleppo. These differences relate to the physical conditions of the groundwater basin, farmers' irrigation behavior and the water renewal ability. It is interesting to note that water decline in zone 2 is greater than the decline in zone 1 (0.44 m vs 0.36), indicating greater water withdrawal in zone 2 compared to zone 1, where crop water requirements are lower as illustrated in Figure 9.4.

Farmers have been drawing water for periods ranging from 2 to 65 years, while the average age of the wells is 21 years. In zone 1, the period of use ranges from 2 to 50 years, and the average age of wells is 21 years, while in zone 2 the period of use ranges from 1 and 65 years, and the average age of wells is 20 years. The cumulative percentage of the age of wells shows that farmers in zone 2 invested in irrigated agriculture before those in zone 1. This may be because of rainfall deficiencies in zone 2, where rainfed farming systems have a high degree of risk, relatively higher than in zone 1. On the other hand, according to the age of wells, investment in irrigated agriculture using groundwater started earlier in Aleppo (23 years) than in Dara'a (19 years), and even later in Hassakah (17 years).

Two types of wells are found in the study area – artesian and chuckhole in Aleppo, but only artesian in Dara'a and Hassakah. Artesian wells are more recent (up to 20 years), while chuckhole wells are older (up to 27 years).

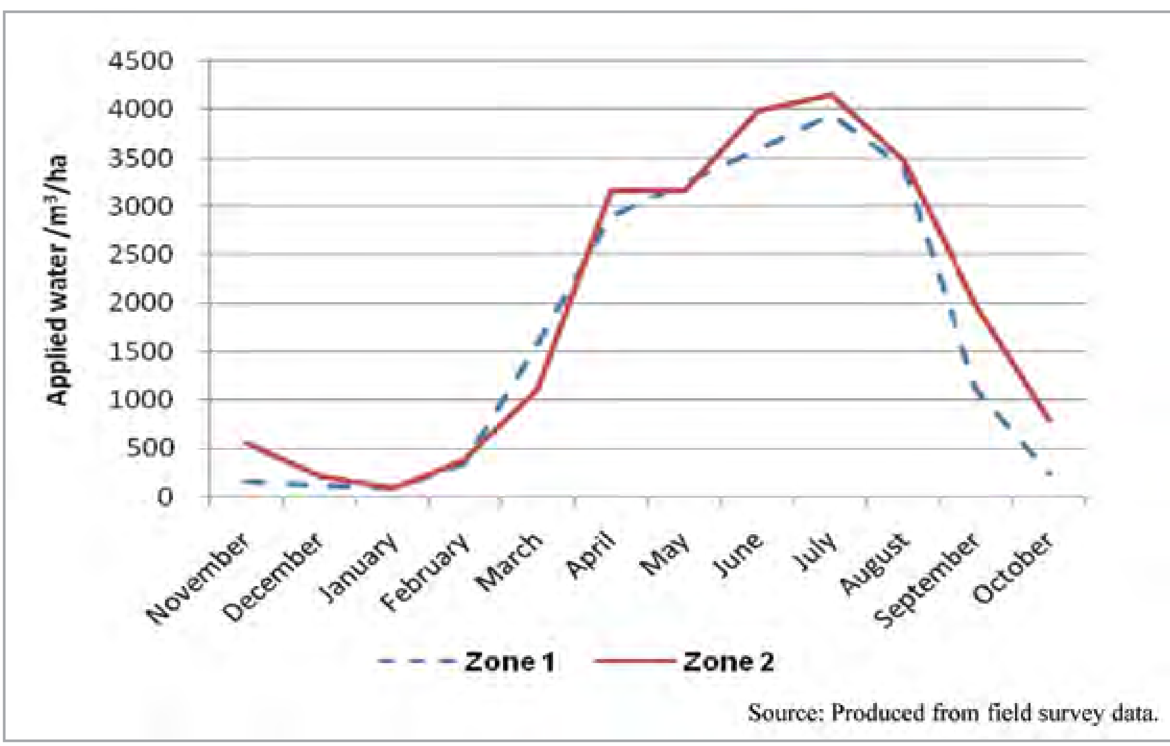


Figure 9.4: Average amount of water applied at the farm level in zones 1 and 2 by month.

This relationship between type of well and its age is highly significant. All the chuckholes are located in zone 2 in Aleppo. The wells involved in the survey are similar in some specifications but differ in others, as shown in Table 9.6.

9.3.3 Methods of irrigation and farm water use

The main irrigation methods that farmers use are surface, sprinkler and drip irrigation. These methods varied according to the type of crop. Therefore, farmers may adopt more than one method, as shown in Table 9.7, considering the most important crops.

Table 9.7 shows that the dominant method is surface irrigation and all crops are irrigated by this method. Farmers may use more than one method for the same crop, such as wheat in separate plots. On the other hand, some farmers combined surface and sprinkler irrigation or sprinkler and drip irrigation.

They used the first type (surface or sprinkler) on cotton and corn, and the second (sprinkler or drip) on cucumber. That is, from their point of view, to save water by using sprinkler irrigation at the early stages of cotton growth and to prevent local soil erosion, which protect seeds before germination. However, they prefer, after two to three sprinkler irrigations, to continue using surface irrigation, which, they believe, provides more water for better growth and production, and avoids the damage resulting from sprinkler irrigation during the later stages of cotton growth (such as fungal diseases).

Water applied to crops varied according to the crop, planting season and the farmers' perspective. The amounts of water, as illustrated in Figure 9.5, represent farm water supply without rainfall. The coefficient of variation in water supply among farmers is greater for summer crops than for winter

Table 9.6: Specification of wells.

Specifications	Province				Zone		Total	
	Aleppo		Dara'a	Hassakah	I	II		
	Artesian	Chuckhole	Artesian	Artesian	Artesian	Artesian	Artesian	Chuckhole
Depth (m)	246	58	79	188	240	154	206	58
Water level (m)	113	40	49	59	110	51	87	40
Pump diameter	3.7	3	3.8	6	4.3	5	4.6	3

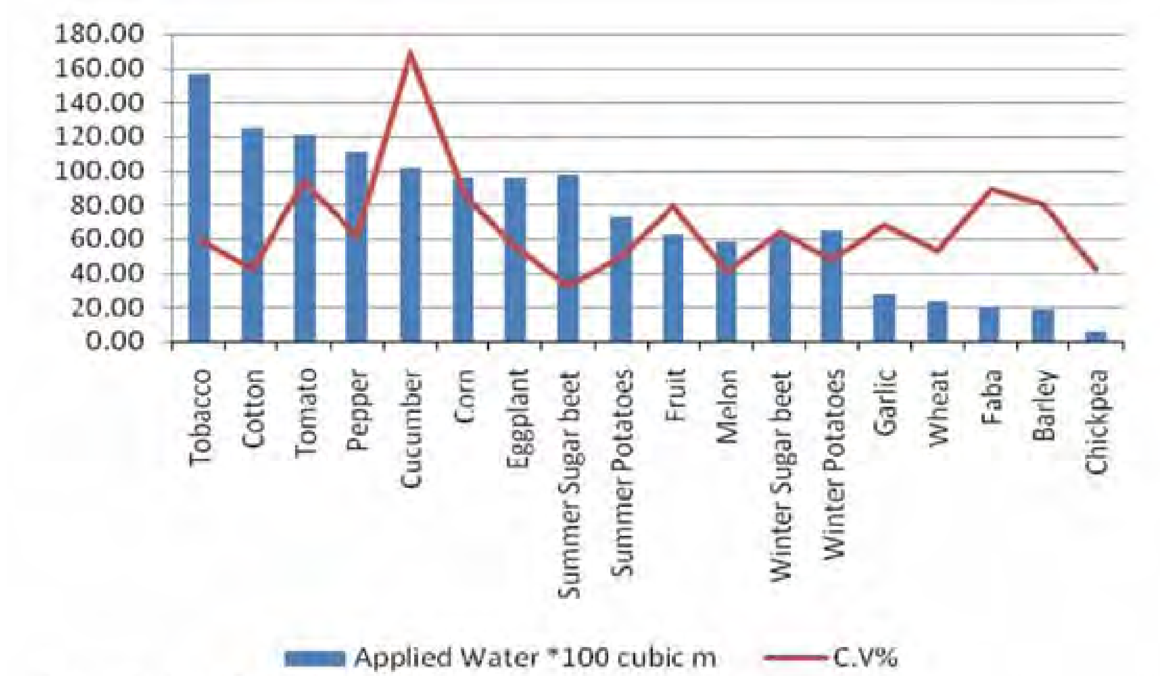
Table 9.6 shows that there are considerable differences in the depth of wells, and consequently in groundwater levels between the provinces, and also between the two types of well in Aleppo, increasing the cost of pumping as the groundwater level goes down. Also, the greater the diameter of the pump, as in the case of Hassakah, leads to more water being pumped per unit of time. All these differences are highly significant ($p<1\%$) between provinces, and between the two types of well in Aleppo.

Water quality in Aleppo and Dara'a is fresh (94% and 98% responded respectively), where 3% of farmers in Aleppo said that the water on their farms is slightly saline, 0.5% that they have saline water and 0.5% that they have sulfur in the water. While in Dara'a, 1% of farmers have saline groundwater and 1% sewage water. In Hassakah, the situation was different, since only 52% of farmers have fresh groundwater and the most important feature of water is sulfur (37% of farmers). In addition, 11% of farmers considered their water to be moderately saline, while 5% considered it saline, and 1% said that their water is calcareous. In spite of salinity, 32% of farmers intend to continue irrigation regardless of the negative effects, 13% of them in Aleppo and the others in Hassakah. However, the rest have strategies to deal with salinity by following crop rotations such as wheat–legumes, including faba beans.

Table 9.7: Distribution of farmers according to the irrigation methods used.

Crop	Surface (%)	Sprinkler (%)	Drip (%)	Combination surface and sprinkler (%)	Combination sprinkler and drip (%)	Total number of farmers
Wheat	63	37	0	0	0	430
Cotton	63	0	15	22	0	241
Potato	6	88	6	0	0	83
Tomato	13	0	88	0	0	64
Eggplant	25	0	75	0	0	53
Faba bean	64	32	4	0	0	50
Cucumber	22	2	73	0	2	45
Fruit trees	29	0	71	0	0	45
Garlic	61	32	8	0	0	38
Sugar beet	52	48	0	0	0	33
Pepper	41	0	59	0	0	31
Maize	43	29	0	28	0	14
Melon	23	0	77	0	0	13
Lentil	80	20	0	0	0	10
Barley	75	12.5	12.5	0	0	8
Tobacco	100	0	0	0	0	7
Chickpea	80	20	0	0	0	5

Source: Field survey.



Source: Produced from field survey data.

Figure 9.5: Average amount of water applied to the dominant crops at the farm level.

crops. This indicates the relative stability in applied water in the winter season, and the behavioral approach that farmers follow to estimate irrigation requirements.

The amounts of irrigation water also varied according to the agro-ecological zones. Figure 9.6 shows the differences between the zones 1 and 2 among crops. For winter crops and fruit trees, it is obvious that farmers supply more water for their crops in zone 2. The surplus sometimes reaches more than 100% as in the cases of garlic, faba bean and lentil (Table 9.8).

There is no rule that controls irrigation water quantities between the two zones for summer crops. It is based on the farmers' experience or tradition and water availability. The survey data indicated high water discharge and high duration of irrigation in zone 2 as compared to zone 1.

9.3.4 Supplemental irrigation

Shideed et al. (2003) have defined supplemental irrigation as adding a quantity of water to rainfed crops during the period in which rainfall is not adequate to keep soil moisture at a level that can enable the plant to continue growing. It aims to improve productivity and stability. This means that if the target crop is rainfed it will give a specific level of production without any irrigation, but if supplemental irrigation is not applied when rainfall stops production will be negatively affected.

Table 9.9 shows the distribution of farmers who have heard about and adopted supplemental irrigation. Generally, it is not necessary for the farmer to know what supplemental irrigation means before they adopt it. In fact, most farmers apply supplemental irrigation at a time when they do not know exactly what it means. About 83% our sample farmers, who own water sources, have heard about supplemental irrigation, and 72% of them have adopted it. However only 21% of farmers are aware of supplemental irrigation in its proper form, and received information through communication channels such as extension, public media, neighbors, and ICARDA scientists.

Table 9.9 clearly shows that the rate of adoption in Dara'a is the highest, 87%, while

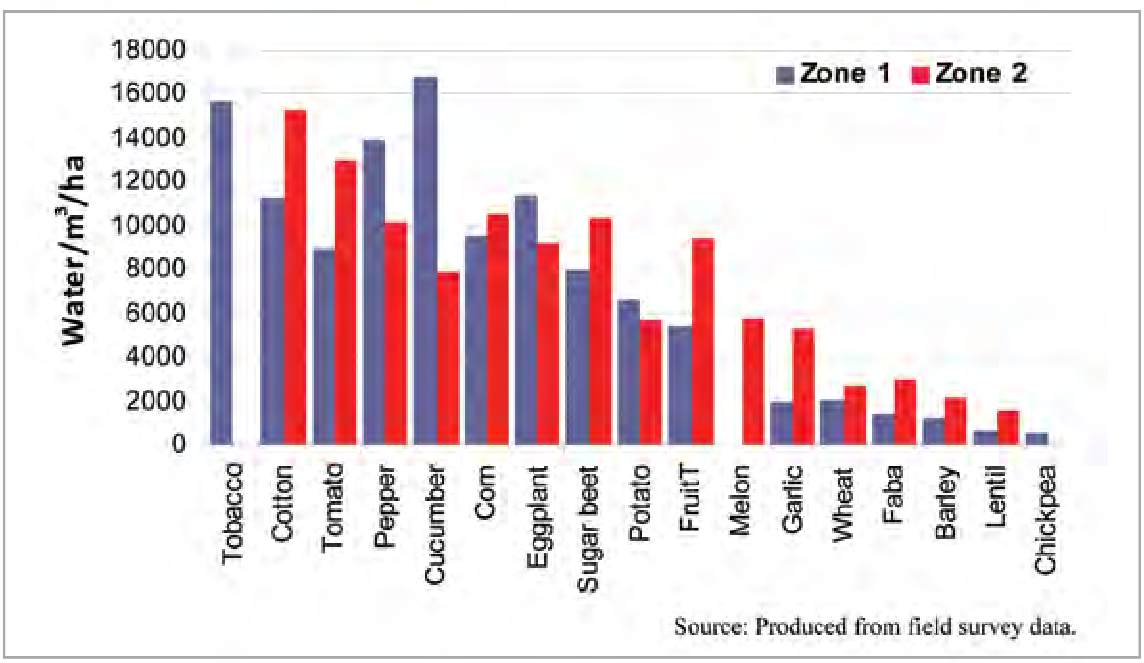


Figure 9.6: Irrigation water supply in zone 1 and zone 2 for several crops.

Table 9.8: Comparison of water applied (m^3) in the two agro-ecological zones.

Crop	Zone 1		Zone 2		Change in water supply from 1 to 2
	Mean	SD	Mean	SD	
Tobacco	15,673	9481	–	–	–
Cotton	11,304	5079	15,311	4714	35%
Tomato	8948	3548	12,998	12,596	45%
Pepper	13,881	4414	10219	7300	-26%
Cucumber	16,768	32,033	7970	8001	-52%
Maize	9529	8645	10,500	1 obs.	10%
Eggplant	11,339	3759	9262	5506	-18%
Sugar beet	8063	2642	10,333	2893	28%
Potato	6636	3111	5677	2878	-14%
Fruit trees	5434	5198	6424	5562	18%
Melon	–	–	5798	2332	–
Garlic	1988	818	5289	2159	166%
Wheat	2061	1118	2688	1287	30%
Faba	1396	1335	3003	1986	115%
Barley	1190	608	2120	1698	78%
Lentil	621	305	1611	2252	159%
Chickpea	529	225	–	–	–

Source: Field survey.

Table 9.9: The number and percentage distribution of adopters of supplemental irrigation.

	Province						Zone				Total	
	Aleppo		Dara'a		Hassakah		I		II			
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Heard about	204	88	158	99	46	46	236	89	172	76	408	83
Adopted	172	75	139	87	39	39	187	71	163	72	350	72

Source: Field survey.

in Aleppo it is 75%, and in Hassakah it is the lowest (only 39% of those who have water available on their farms).

These differences in the degree of adoption of supplemental irrigation between the three provinces are significant at the 1% level. On the other hand, the rate of adoption of supplemental irrigation in zone 1 (71%) approaches the rate in zone 2 (72%).

Those farmers, who have not adopted supplemental irrigation, form 27% of the total sample. They said that they are not satisfied with supplemental irrigation, because they believe that if they supply the crop when a lot of water it will give more yield regardless of the quantity of available rainfall.

9.3.5 Adoption of new irrigation technologies

Farmers are using surface irrigation, sprinkler, drip or a combination of irrigation systems. Surface irrigation is dominant in Hassakah (97%), sprinkler in Aleppo (79%) and drip irrigation in Dara'a (60%). However, sprinkler irrigation is dominant in zone 1 (65%), while surface irrigation is widespread in zone 2 (93%) as reported in Table 9.10.

Table 9.10: Rate of adoption of new irrigation technologies.

	Province (%)*			Zone (%)*		Total*	
	Aleppo	**Dara'a**	**Hassakah**	**I**	**II**	**No. observations**	**%**
Surface	48	92	97	55	93	320	74
Sprinkler	79	8	6	65	10	170	39
Drip	25	60	15	22	49	151	34

Source: Field survey. *Some farmers are using more than one system.

Since summer vegetables and fruit trees are relatively widespread in Dara'a, and since farmers have adopted drip irrigation for use with these crops, Dara'a has the highest rate of adoption of drip irrigation. Similarly, the spread of sprinkler irrigation in Aleppo is attributed to the diversity of winter crops, which are mainly irrigated by sprinkler (wheat, faba bean, sugar beet, garlic), in addition to summer crops such as potato. In Hassakah, wheat is more important in the cropping pattern compared with the other two provinces, but there is no diversity of crops as in Aleppo or Dara'a, and farmers prefer surface irrigation. The differences in the importance of the crops and their methods of irrigation were significant at 1% level.

The degree of adoption has been defined by Shideed et al. (2005) as a measure using the proportion of land under the new technology, which in this study means the proportion of land irrigated by new irrigation technologies – sprinkler and drip. The degree of adoption of sprinkler irrigation is 78% in Aleppo, whereas in Dara'a it is 38% and in Hassakah, 21%. However, the degree of adoption of drip irrigation is 24% in Aleppo, 45% in Dara'a and 43% in Hassakah.

It is noticeable that the highest degree of adoption for wheat and cotton crops is surface irrigation, while the degree of adoption of sprinkler is high for crops such as potato and sugar beet (Table 9.11).

The degree of adoption of sprinkler irrigation in cotton farming reflects the use of the sprinkler system during the initial stage of crop growth before converting to surface or drip irrigation when the crop reaches the stage where it becomes leafier.

9.3.6 Constraints to the adoption of new irrigation technologies

The high cost of new irrigation systems was the most important constraint to the adoption at the sample-, province-, and zone-levels, where 69% of farmers attributed non-adoption to their financial position and the high cost of such systems. However, water scarcity was an obvious constraint to adoption in Dara'a province, where some famers do not control their water, especially those who received water from governmental sources. On the other hand, water quality was a very important problem in the adoption of new irrigation technology, since 21% of farmers suffer from sulfur-laden water. Also, some farmers (2% of the sample) have some difficulties with their fields, such as field length, slope or size. Sometimes, farmers are not convinced by the new irrigation technologies and prefer surface irrigation. 6% of the sample mentioned this (Table 9.12).

9.3.7 The impact of supplemental irrigation

As this study focused on wheat-based systems, we will concentrate on wheat as the main target crop when looking at indicators of the impact of supplemental irrigation and new technologies.

Adopters of supplemental irrigation who used groundwater gained 20,823 SL/ha (SL = Syrian pound) net return, compared to non-adopters, who used more water but whose gain was only 15,386 SL/ha (Table 9.13).

Water productivity (WP), the other indicator of the benefit of supplemental irrigation,

Table 9.11: Degree of adoption of new irrigation technologies for several crops (%).

Crop	Method of irrigation	Aleppo		Dara'a		Hassakah		Zone 1	Zone 2	Total
		Z 1	Z 2	Z 1	Z 2	Z 1	Z 2			
Wheat	Surface	3	67	60	81	100	92	27	81	52
	Sprinkler	77	8	4	4	0	6	52	5	30.5
	Rainfed	20	25	36	15	0	2	21	14	17.5
Cotton	Surface	25	50	0	0	90	86	39	81	52
	Sprinkler	60	0	0	0	0	4	47	4	34
	Drip	15	50	0	0	10	10	14	15	14
Potato	Surface	14	0	50	6	0	0	15	6	14
	Sprinkler	86	100	50	31	0	0	85	39	80
	Drip	0	0	0	63	0	0	0	55	6
Sugar beet	Surface	7	75	0	0	0	0	7	75	15
	Sprinkler	93	0	0	0	0	0	93	0	82
	Drip	0	25	0	0	0	0	0	25	3

Source: Field survey.

Table 9.12: Constraints to the adoption of new irrigation technologies.

Constraint	Province (%)*			Zone (%)*		Total*	
	Aleppo	**Dara'a**	**Hassakah**	**I**	**II**	**No.**	**%**
Water scarcity	13	32	1	18	11	22	14
High cost	91	65	65	71	68	110	69
Water quality	0	0	41	3	31	33	21
Farm size	0	2	3	0	3	3	2
Not convenient	0	5	9	7	6	10	6
High depreciation	0	0	5	7	0	4	3
Policies	0	5	1	5	1	4	3

Source: Field survey. *Some farmers have more than one constraint.

Table 9.13: Impact of supplemental irrigation on net returns and water productivity in wheat farming based on groundwater.

	Net return SL/ha	WP kg/m^3
Adopters	20,823	0.94
Non-adopters	15,386	0.80

Source: Field survey. SL: Syrian pound; WP: water productivity.

is defined by Shideed et al. (2005) as the ratio of crop production (kg) to the unit of water used (m^3). Water productivity has been calculated as a ratio of production to total water applied, including rainfall. Supplemental irrigation has resulted in an increase in water productivity for adopters compared to non-adopters (0.94 kg/m^3 vs 0.8 kg/m^3), a highly significant difference ($p<1\%$) as shown in Table 9.13.

9.3.8 The impact of new irrigation technologies

The impact of the new irrigation technologies can be assessed from farm water savings when compared with traditional methods of irrigation, and with respect to the type of crop. In the case of wheat, farm water savings can be achieved by adopting new technology such as sprinklers, as shown in Table 9.14. The average quantity of water used per unit area is 1988 m^3/ha under sprinkler irrigation whereas it is 2582 m^3/ha with traditional surface irrigation

Table 9.14: Impact of adopting new technology on groundwater use in wheat farming.

Water by irrigation method (m^3/ha)	Province			Zone		Total
	Aleppo	Dara'a	Hassakah	I	II	
Quantity of water by surface irrigation	3146	1717	3458	2322	2690	2582
Quantity of water by sprinkler irrigation	1957	1736	3318	1924	2652	1988

Source: Field survey.

Table 9.14 clearly shows that adoption of sprinkler irrigation technology results in using less water overall. However, it also shows that in Dara'a province, the quantity of water per unit area is slightly higher when using this technology. That is because water flows from canals controlled by the government, and farmers have to use the entire quantity they receive. In Hassakah, the small number of sprinkler irrigation adopters versus the large number of surface irrigation users, discharging a large amount of water, reduces the difference in water quantity between surface and sprinkler irrigation. We faced a similar situation in zone 2, where the difference was too small to determine the impact of the technology. However, the weather and precipitation conditions in zone 2 pushed farmers to supply winter crops with more water regardless of other factors.

The other indicator of the impact of new irrigation technologies in wheat farming is the net return (Table 9.15). Farmers who adopted sprinkler irrigation gained greater net returns than those who continued using the traditional methods of irrigation. This difference is very marked in Dara'a and Hassakah. This result is caused by the domination of surface irrigation in wheat farming when compared with sprinkler irrigation.

Water productivity (WP) is also an indicator to demonstrate the impact of irrigation technology. Although it helps the farmer to save water, the contribution of average rainfall to crop production may confuse its impact, especially when it is high in the areas under technology adoption. WP calculated considering the total water applied, including rainfall, is shown in Table 9.16.

Table 9.16 shows that the adoption of new irrigation technologies can result in an improvement in water productivity. Sometimes, the high average rainfall in areas under new irrigation technology can be misleading and mask its real impact, especially if rainfall is not as high in areas under traditional irrigation methods.

Table 9.15: Impact of adopting new technology on net returns in irrigated wheat farming based on groundwater.

Technology	Province			Zone		Total
	Aleppo	Dara'a	Hassakah	I	II	
Surface irrigation (SL/ha)	18,223	19,842	8918	11,212	14,308	13,661
Sprinkler irrigation (SL/ha)	23,488	33,600	20,054	23,190	28,899	23,702

Source: Field survey. SL: Syrian pound.

Table 9.16: Impact of adopting new technology on farm water productivity.

Technology	Zone I	Zone II	Total
Surface irrigation (WP kg/m^3)	0.77	0.92	0.86
Sprinkler irrigation (WP kg/m^3)	0.91	1.11	0.93

Source: Field survey. WP: water productivity.

9.4 Conclusions

Wheat is the most important crop cultivated in Syria, where supplemental irrigation has gained high importance as an approach to irrigation. In the target area of this study, groundwater is the main source of irrigation, which varies between traditional and modern. The study found that supplemental irrigation improves water productivity, and the adopters of this approach to irrigation achieve higher net returns when compared with non-adopters.

The adoption of new irrigation technology in wheat farming results in farm water savings and higher net returns, when compared to farmers using traditional irrigation. In spite of this, the adoption rate of new irrigation technologies is still low compared to surface irrigation. The reluctance of farmers to adopt new irrigation technologies is due to the high cost, water quality and water scarcity.

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Chapter 10: Modeling wheat yield in rainfed and irrigated systems in Tunisia

Chapter 10: Modeling wheat yield in rainfed and irrigated systems in Tunisia

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10.1 Introduction

In North Africa, many million hectares are allocated annually to the cultivation of durum wheat, bread wheat and barley. However, due to various constraints, yields are low and total production does not meet the needs of the population (Jouve et al., 1995).

Total production is also subject to large interannual variations because of high variations in both hectarage and yield. Rainfall is considered to be the main factor controlling growth and its overriding impact has been reported in many studies. The impact is complex and varies from one location to another depending on cropping patterns, the soil's ability to store water, and the severity and duration of deficits.

Droughts are feared in the region because of their devastating effects. They reduce crop production by reducing cropped areas, harvested areas and yields. Paradoxically, in some years water surplus can be the problem. For instance, it may hamper planting if it happens at the beginning of the season, or reduce yield and grain quality if it occurs during the harvest period.

Variations in hectarage can be attributed to the spatial distribution of rainfall during the autumn. On the basis of the amount of rain received, farmers decide whether to plant, to keep the land fallow or use it for grazing. In arid areas, amounts of rainfall higher than normal are incentives to grow wheat, and barley is usually cultivated under more marginal conditions.

If we assume that water is the factor most limiting cereal production, it is important to show it, for instance, through quantitative investigations into the significance of relationships between wheat yield and water.

In order to decide on what actions to take, it is necessary to obtain a complete picture of the sector, by considering its performances at different scales – farm, delegation, governorate and the entire cereal-producing area.

Quantitative modeling of yield response to rainfall at different scales has been a field of active research. However, only few applications are known, and they are mostly limited to some regressive models used for predictive purposes. Statistical techniques are more popular as an analytical tool, in spite of their inherent problem of representativeness. In contrast, the use of simulation models usually does not go beyond some application for research or training purposes due to the obvious problem of data availability.

Using Tunisia as a case study and to characterize the constraints related to the physical environment, quantitative analysis of rainfall and climatic water balance distributions have been carried out. The probability of non-exceedence is used to quantify the risks associated with water shortages during the cropping cycle for the main cereal growing environments. Non-exceedence statistics have been determined for different periods of two-months (Oct–Nov, Dec–Jan, Feb–Mar, Apr–May) and for all stations.

However, the fundamental work has been to use the basic links between yield and transpiration requirements to investigate cereal responses to water at two different scales:

- **Regional scale**, aimed at higher levels of management such as regional water allocation or manipulation of cropping systems.
- **Field scale**, to develop knowledge aimed at operational management at the farm level.

For the first objective we adopted a simple hypothesis by modeling the impact of cumulative rainfall during the growing season on wheat yield at the regional scale. If appropriate amounts of rainfall are received every ten days then limitations to regional yields would be fertilizers, cultural practices, available technologies, and other uncontrolled environmental factors. The proposed methodology is based on straightforward 'one level' modeling of the functional relationships between yield and water availability for transpiration, following the De Wit concept. Data required are production statistics, records of precipitation (P), and potential evapotranspiration (ETo).

The second objective concerns yield response to growing conditions, particularly water availability. At the farm level, it is important to develop knowledge for better managing cereal production and optimizing water allocation to the crop in times of deficit. Knowing both appropriate amounts and timing are prerequisite to successful supplemental irrigation programs. We used the simulation model AquaCrop (FAO, 2008), which is based on the same fundamental concept of De Wit, but in a more elaborate form. AquaCrop is a valuable management tool which focuses on how to assess the water productivity of cereals, in terms of kg/m^3 of water used under different environments and the many water management practices.

Finally the scale effect is discussed. Outscaling attempts have consisted in exploring the linearity of the functional relationships of wheat yields obtained at increasing scales. The underlying objective is to make an assessment of constraints to production from field to regional level and therefore explore the potential for improvement.

10.2 Environmental conditions

In Tunisia, cereals are grown every year on 1.5 million ha in the upper northern third of the country in areas with mean annual rainfall ranging from 200 to 800 mm. Durum wheat usually occupies more than 50% of the total cereal area while bread wheat and barley represent slightly less than 10% and 40%, respectively (Minagri 1994, 2006). They cover a wide range of environments.

Seasonality of precipitation changes in relation to the relief and the proximity of the Mediterranean Sea. In the lowlands, close to the sea, maxima are observed during the autumn, whereas there is a significant shift of rainfall maxima over the spring season when going towards the high plateaus located inland, where summer rains may amount to 20% of the total at high elevations. Hail and storms of 30 mm/day are more frequent in the continental parts of the country.

Average temperatures during the winter season are usually high enough to ensure vegetative growth. Inland however, slower development is seen during the cool season causing about two weeks' time lag compared to areas exposed to the warming effect of the sea. Since wheat grown in the area is of the spring type, the varieties used do not require vernalization. However, frost damage is locally feared in the high plateaus of semi-arid Tunisia.

Principally there are four major regions for cereal growing:

- **The Sub-Humid Region** represented by Beja and Bizerte. The Beja Region is wide, open country. It is characterized by white stony and rocky plateaus where limestone predominates and broad depressions on marls with fertile and medium to heavy rendzinas (limestone soils). The climate is mild to warm with annual average precipitation of 600 mm. The dominant crops are durum and soft wheat with winter and spring legumes. Usually there is no fallow. The Plains of Bizerte are principally low-lying lands with many recent rich alluvial deposits. They have good crop rotations, with wheat as the main cereal. Some areas are poorly drained.
- **The Medjerda Valley** consists of broad lowland plains. In this region alluvial soils vary from medium to very heavy. Lowlands require drainage. The bio-climate is of the semi-arid superior type

having temperate to warm variants and an annual average rainfall of 450 mm.

- **The High Tell** broken mountains interspersed with shallow basins or plains. This region is dominated by brown and red calcareous soils, alluvial and colluvial deposits in basins, and shallow soils on slopes. The bio-climate is mostly semi-arid and semi-arid superior, having cool to temperate variants. Rainfall varies typically around 350 mm (southwest of Le Kef). Two types of fallow (cultivated and non-cultivated) exist.
- **The Steppe Region** low flat plains dotted with sabkhas. There are alluvial plains around Kairouan, elsewhere soils are sandy and rich in gypsum and lime. The bio-climate belongs to the arid-superior stage having a mild winter and annual rainfall averages lower than 300 mm. Scattered wheat and barley fields can be observed in this area.

10.3 Rationale of the transpiration model

Our analysis of the regional wheat yield in relation to rainfall uses the relative yield approximation approach following the De Witt concept on the linear relationship between crop biomass production and transpiration. It considers the effective precipitation received over a growing period (Pi) divided by the maximum amount that could be lost to the atmosphere through transpiration (Ti*).

10.3.1 Transpiration

Crops need to meet the evaporative demand of the atmosphere to accomplish maximum growth and production. Using climatic data, it is possible to calculate a reference evapotranspiration (ETo) in order to assess these demands. ETc or crop evapotranspiration refers to the total amount coming from precipitation or irrigation waters that a particular crop is supposed to use during its vegetative cycle. ETc is normally determined for the crop growing under deficit free conditions. It depends upon the species, the physical environment where the crop is grown and the management practices.

Climate as expressed by ETo determines the maximum amount that the wheat crop could lose through this process (ETc).

$$ET_C = Kc\ ETo \qquad [1]$$

However the actual water utilization by the crop (ETa) could well be below ETc depending on the soil moisture status during the growing cycle.

Management practices determine the partitioning of evapotranspiration fluxes between E and T. For a given year, frequency of wetting directly affects water amounts lost to the atmosphere by evaporation. Plant cover and rooting depth have important effects on the crop's capacity for water utilization. Improvements in water use efficiencies by plants depend to a large extent on the interaction between these factors.

Potential transpiration is approximated by using the basal crop coefficient (Kcb)

$$T^* = Kcb\ ETo \qquad [2]$$

10.3.2 Effective precipitation

The soil profile can be replenished intermittently by rainfall. When the supply is too high, part of the added water might be lost through surface runoff and only a fraction will infiltrate the soil. The infiltrated water is not always totally retained in the root zone. Quite often during the wet season a considerable part percolates below the level explored by the roots and does not contribute to plant transpiration. Water can also be lost by the processes of evaporation. Effective precipitation is that part that contributes to crop growth.

10.3.3 Growing stages

The cropping cycle of wheat has been divided into 4 major periods where water is required for successful cultivation: 1)

- **Planting period**. Sowing of wheat is believed to be optimal in mid-November. However the actual sowing date varies from year to year depending upon the distribution and timing of rainfall. Delaying land preparation may reduce yield and the cropped area. Sowing may be later than optimal in dry years. Without appropriate moisture conditions, soil tillage and fertilizers are reduced. The percent reduction in yield due to late sowing depends on the type of wheat cultivars. Planting date greatly affects grain yield of wheat by influencing development and survival of tillers. Early planting causes excessive tillers, which have low survival, low harvest index, and low grain yield. Late planting causes inadequate tillering.
- **Crop establishment**. Water is the major factor leading to poor wheat establishment. With delayed planting, low soil temperature could become a limiting factor for crop establishment. Wheat stand establishment sets yield potential. Dry conditions at the planting period can slow seed germination and emergence, resulting in erratic stands with plants of variable growth and reduced yield potential. Tillering may partially compensate the differences in plant number after crop establishment.
- **Wheat stand development**. Early growth is the foundation for realizing maximum yield. Critical periods for water deficit are when plants are just completing tillering and starting elongation (15 cm tall). At this time the total number of heads and number of potential seeds per head is being determined. At the end of head development to the time flowering begins water deficit will greatly reduce the number of seeds per head.
- **Yield formation**. Grain yield and grain:straw ratio are related to the duration and intensity of water deficit during this stage. At the early yield formation period, water deficits combined with hot dry winds would result in incomplete grain filling and a reduced yield of poor quality grains.

10.3.4 Model development

As stated above, the response of crop yield (Y) to the seasonal pattern of water supply is expressed as a function of effective precipitation (P)/maximum transpiration (T*) for the different growing periods (i).

$$Y=f(\sum Pi/Ti^*) \qquad [3]$$

where:
Pi = effective precipitation calculated over the growing period (i)
*Ti** = potential transpiration as given by Equation [2] for the period (i)

This model allows for a simple representation of the functional relationships between yield and seasonal water supply under natural variability. It uses commonly available climatic data and regional yield records.

10.4 Material and methods

10.4.1 Wheat data

Datasets on climate, cropped area, yield and related information have been made available for the main cereal growing areas. The conditions of the study area represent a large spectrum of environments which are typical of North Africa: sub-humid, semi-arid (higher, medium and lower), and higher arid, i.e. a range of rainfall regimes between 800 and 200 mm. First year tasks were concerned with data quality checking, before investigating yield–water functional relationships.

A total of seven governorates covering this large spectrum of bio-climatic environments were used for model calibration and validation. Annual precipitation means range from 645 mm at Bizerte to 270 mm in Sidi Bouzid (Table 10.1).

Data on production and yield covered the period 1982–1998 except for Tunis for which the data series starts in 1984. Climatic data, in terms of 10-days values of reference evapotranspiration and rainfall were obtained from records published by the

Table 10.1: Cropped areas for cereals and durum wheat in the selected CRDAs and corresponding rainfall and ETo averages.

CRDA	Cereal area (1000 ha)	Durum wheat (1000 ha)	Rainfall (mm/ year)	ETo (mm/year)
Period	1980–94	1980–94	1980–99	1980–99
Tunis (Grd)	52	32	460	1250
Bizerte	86	62	645	1230
Beja	134	80	625	1300
Jendouba	82	54	455	1300
Siliana	160	92	410	1280
Kairouan	157	72	298	1440
Sidi Bouzid	95	51	270	1440
Total	628	349	-	-
Tunisia	1556	814	-	-

CRDA: Commissariat régional de développement agricole; ETo: potential evapotranspiration

national weather service for the relevant governorates.

For the statistical work, data corresponding to the period 1982–1992 were used for model calibration and the remaining six years (1993–1998) were used to validate the method.

The cropping season was divided into four major periods where rainfall is required in various amounts for successful cultivation: 1) planting period, 2) crop establishment, 3) active growth, and 4) yield formation.

- **October–November**: although sowing of wheat usually takes place by mid-November, early rains are important for seedbed preparation and for the replenishment of the upper soil profile, therefore it is reasonable to consider these two months as representing the planting period.
- **December–January**: is supposed to correspond to crop establishment and to the full replenishment of the expected root zone of wheat.
- **February–March**: corresponds to wheat stand development.
- **April–May**: is the period of yield formation. Harvest index (HI) is related to the transpiration intensity during this stage.

10.4.2 Climatic data

Time series of annual precipitation (60 to 100 years) were used for the physical characterization of the cereal growing areas. Two statistical methods were selected: Deviation from the Mean (DM), and the Standardized Precipitation Index (SPI).

For regional modeling, 10-day values for precipitation (P) and reference evapotranspiration (ETo) over the period 1980–2000 were made available. The districts considered to be cereal producing area (Table 10.1) are represented by their climatological stations: Tunis, Bizerte, Beja, Jendouba, Siliana, Kairouan, and Sidi Bouzid.

Using the crop coefficient approach, an assessment of crop ETc and T was made from the basic data. A fixed calendar for growing stages has been adopted for all locations.

Growing stages:

Planting	=	21 November
Emergence	=	1 December
Early tillering	=	1 January
Booting	=	21 March
Anthesis	=	1 April
Harvesting	=	10 June

Crop coefficients:

Kcb-ini	=	0.15, 1Dec–1Jan
Kcb-mid	=	1.10, 21Mar–1Apr
Kcb-end	=	0.15, 10Jun
Pe	=	P, (5–60mm)

10.4.3 Field experiments

Field work was carried out at the INAT (Institut National Agronomique de Tunisie) experimental station located in the plain of Mornag, 20 km south-east of Tunis (Latitude 36°5 N, longitude 10°14 E). The region of Mornag is characterized by a Mediterranean semi-arid climate with an average rainfall of 450 mm/year and average evapotranspiration of 1200 mm/year. The objective was to assess the response of wheat to limited supplemental irrigation and estimate water-use efficiency.

Climatic conditions precipitation, maximum and minimum temperatures were recorded daily during the experimental year. Three watering regimes were considered – rainfed, and irrigated treatments with one (I-1) or two applications (I-2) during the growing cycle. Field observations concerned crop phenology, crop cover, biomass production and soil water content of the upper 100 cm.

10.4.4 Fertilization

Phosphorus: 150 kg/ha of P_2O_5 was applied before sowing.
Nitrogen: 110 kg N/ha was applied in three fractions: 30 kg N/ha after emergence, 50 kg N/ha at tillering and 30 kg N/ha at the stem elongation stage.

Changes in water contents of the soil (volumetric water content x depth z; DW, mm) over the cropping cycle were calculated using the water budget equation of the root layer (equation 4):

$$DW = I + P + G - D - E - T \qquad [4]$$

where:
DW = water content changes in the root zone (mm)
I = infiltrated irrigation water (mm)
P = effective precipitation, infiltrated (mm)
G = capillary rise from the water table (mm)
D = deep percolation, below the rooting depth (mm)
E = evaporation from the soil surface (mm)
T = transpiration (mm)

Water amounts that are readily available to the wheat crop are thus used to investigate basic relationships between crop yield and water deficits at different periods of the growing cycle.

10.4.5 AquaCrop

FAO AquaCrop allows simulation of annual crop growth under variable water supply conditions. It is arranged in four modules – climate, crop, soil and management – and has a relatively small number of parameters.

Considering water as the main production factor, AquaCrop was used to estimate attainable yields in relation to local environmental and climatic conditions. Default parameters were modified to suit local growing conditions.

10.4.6 Outscaling

Steps in outscaling from field to the entire wheat growing areas were investigated by considering the relationships between wheat yield records obtained at increasing scales: farm, 'delegation' or county, governorate and region.

For the farm and 'delegation' levels we used data on wheat yield observed under rainfed and supplemental irrigation separately. At the larger scale, production values reported normally for rainfed areas were used to correlate wheat yields for the delegation/governorate and governorate/country sets. Data records over the period 1988–1998, from the Delegation of Medjez, the Governorate of Beja and six other governorates were in this regression analysis.

Medjez city is located 60 km south-west of Tunis, 36.3°N, 9.36°E. The climate of the region is typically Mediterranean of the semi-arid type with an annual rainfall of 425 mm and an ETo of 1350 mm. The county has a total arable area of 42,000 ha of which 55% are cropped with cereals. 7000 ha are irrigated, with cereals representing 43% of this area.

Data on wheat yields under rainfed and supplemental irrigation (SI) conditions for Medjez were obtained through surveys by the extension services over a 10-year time span, during the implementation of the National Program on Supplemental Irrigation (1988–1998). The surveys also reported on irrigation amounts and timings over the same period. Similarly data on yield, rainfall and irrigation were recorded at the field level at a state-owned demonstration farm. Reliable rainfall data were obtained from the weather station of the extension service.

10.5 Results

From existing records it can be seen that substantial improvements in cereal production have been achieved over the past three decades.

Maximum yields are associated with rainfall levels higher than 400 mm for the Oct–May period. However, while production during rainy years was generally satisfactory, minimum values observed during dry years were still very low (0.3 t/ha). Rainfall distribution remains the most important factor governing crop performance, showing the high vulnerability of cereal-based cropping systems to climatic variations.

It is our hypothesis that further improvements in wheat yields could be obtained with the available rainfall levels. Observed yields seem to be much below levels that potentially could be obtained with rainfall amounts between 800 and 200 mm. Vague socioeconomic factors, such as market pressure and low investment capability of farmers are frequently put forward to explain low performance in the region. Such explanations often seem to be a surrogate of our failure to identify appropriate technologies or to develop effective management options to improve farm production.

10.5.1 Agro-climatic characterization

Regions where cereals are normally grown under rainfed conditions cover a wide range of environments. If the objective is to achieve a good understanding of the impact of rainfall variations on the entire sector, it is important to quantitatively characterize these variations.

Annual rainfall distribution

Rainfall distribution patterns are sought in order to identify opportunities to grow crops with a given probability of success. Because of the large variation in environmental conditions, a variety of cereal production systems and practices need to be developed with integration of varieties, cropping periods, planting densities, etc.

With the objective of describing rainfall conditions in the major wheat growing areas non-exceedence values of annual precipitation were computed (Figure 10.1). The gamma function was used to characterize annual precipitation, since preliminary analyses of annual rainfall records show that precipitation is not normally distributed, especially in relatively arid environments.

The calculated distribution shows that rainfall in four out of five years is lower than 300 mm for the driest area (Sidi Bouzid) and higher than 500 mm in the sub-humid region of the country. Water requirements for supplemental irrigation calculated on the basis of these distributions vary from 300 to 100 mm.

The standardized precipitation index (SPI) and deviation from the mean (DM)

Using precipitation time series, the standardized precipitation index (SPI) and deviation from the mean (DM) were determined for the major wheat-growing areas. Results obtained for Tunis and Kairouan, given here as an example, show that SPI is more appropriate than DM for characterizing annual variations. As a measure of drought intensity, SPI is also a better indicator (Figure 10.2.).

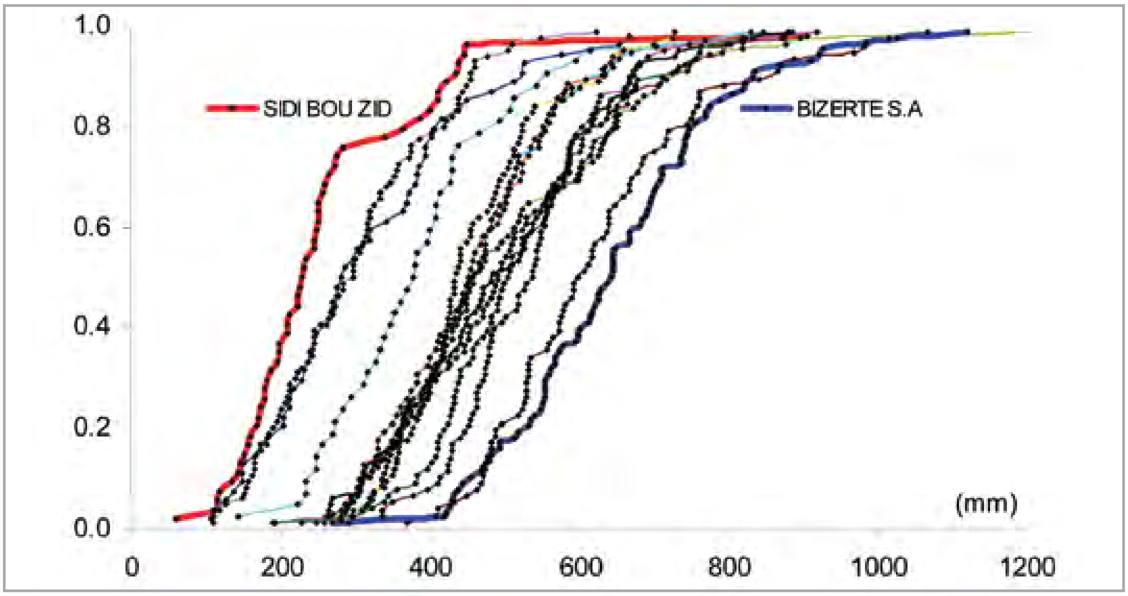

Figure 10.1: Probability of non-exceedence of annual precipitation calculated for 14 major climatic stations showing the range of environments where supplemental irrigation is practiced.

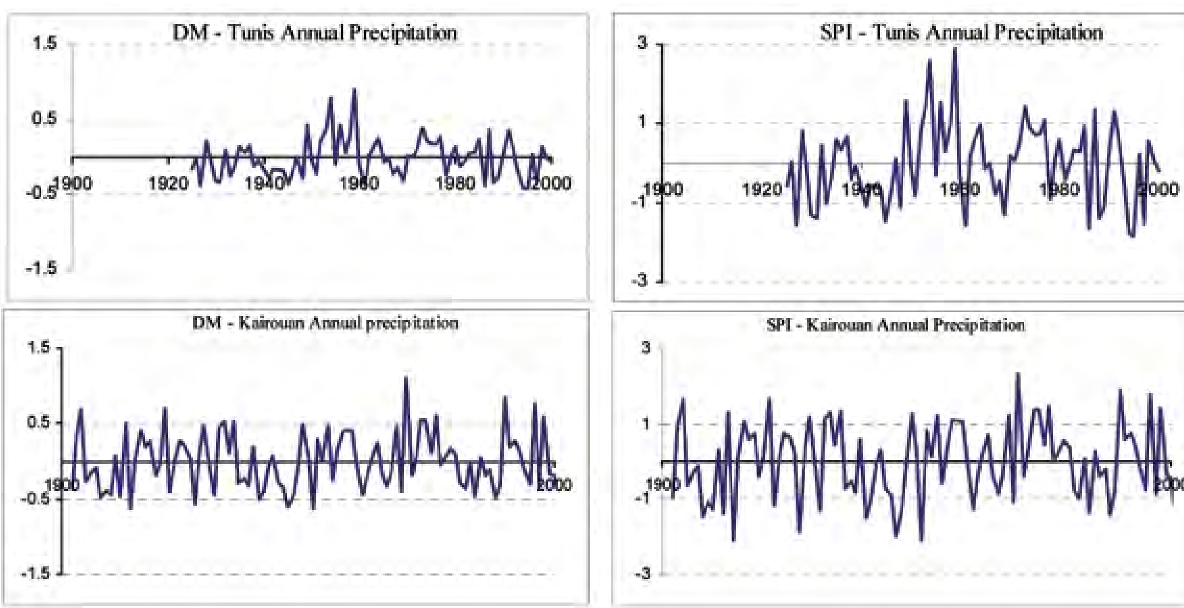

Figure 10.2: Deviation from the mean (DM) and standardized precipitation index (SPI) for annual precipitation in Tunis and Kairouan.

There is a wide agreement that climatic conditions play a major role in the conception and launching of agricultural development strategies. Exceptional events always trigger significant actions at the national scale. This is the case for the droughts observed during the years 1985/86 and 1987/88 in Tunisia.

The climatic conditions of the cropping year 1985/86 were the triggering factor for the widespread acceptance of SI and the launching of the National Program for Supplemental Irrigation. Autumn 1985 was exceptionally dry in the north where 80% of cereals are normally produced. December was dry everywhere. Cumulative amounts over September–January generally recorded a considerable deficit in the sub-humid region – 200 mm (only 1/3 of the annual total)

– and the NW and NE semi-arid regions – 80–120 mm (1/4 of the annual total). The central or lower semi-arid area had a total of only 50 mm. Consequently cereal production was much below average.

After the launch of the National Supplemental Irrigation Program for cereals, the year 1987/88 was dry in all regions. Climatically, this year was disastrous, since only 36,000 ha of cereals out of 50,700 ha planned for irrigation benefited from supplemental irrigation. Shortages of irrigation water and shortages of animal feed and forage led some farmers to put their cereals to grazing. Consequently only 28,500 ha of irrigated cereals reached harvest, giving a total production of 54,500 t (less than 2 t/ha).

Seasonal water balance

Practices to buffer the effect of rainfall variations are those that will increase the amount of precipitation water used by the crop. Seasonal water balance distribution studies are supposed to help identify appropriate cropping strategies to mitigate the impact of inter-monthly deficits (Figure 10.3).

While rainfall is usually sufficient to cover wheat requirements during the cold months of the year, risks of severe shortages are always high particularly during the yield formation period. Imbalances in water availability over successive months show the importance of selecting the growing period for buffering variations. For the entire cereal-growing area, the water balance is on the average almost negative during the grain filling period.

Seasonal deficits

The availability of water to cereals during critical periods depends very much on soil characteristics and land morphology. The buffering role of soils becomes increasingly determinant with increasing climatic limitations (Figure 10.4).

Globally, the cereal-growing area receives significant amounts of precipitation and farmers attempt to make the best use of the water received, but with more or less success. Obviously, there is a great potential for further improvement by adapting cropping practices to the available climate and soil resources.

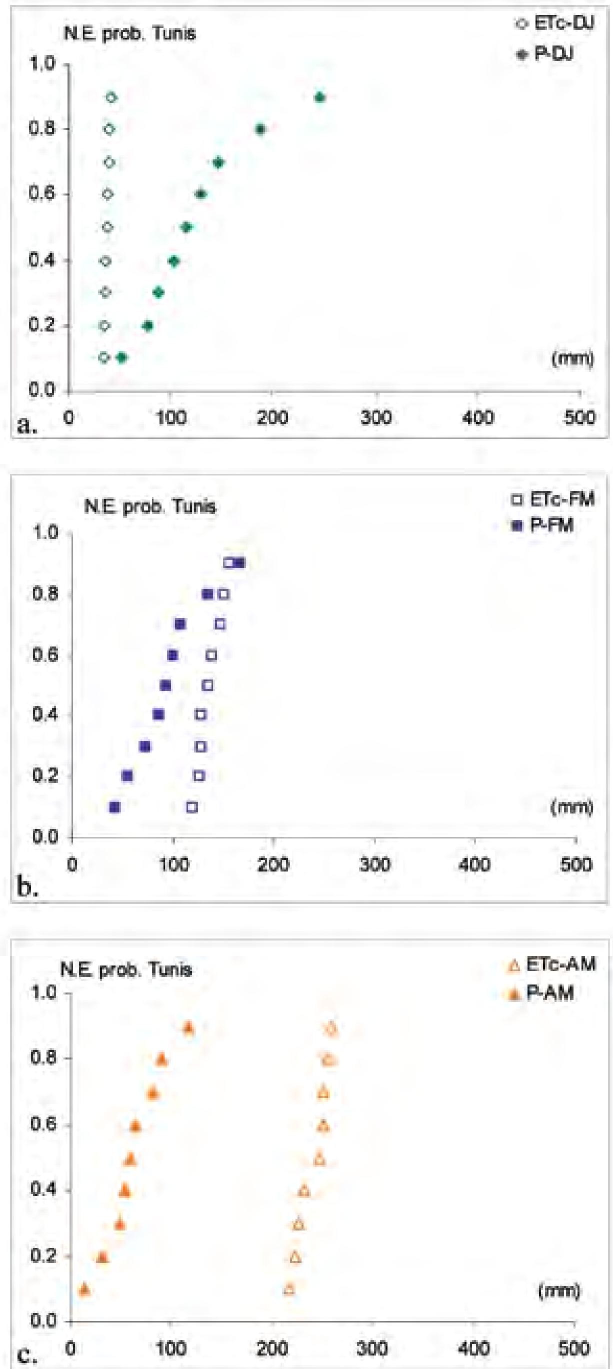

Figure 10.3: Non-exceedence probabilities of precipitation and ETc calculated for Tunis station. D, J, F, M, A and M are the corresponding months of the year.

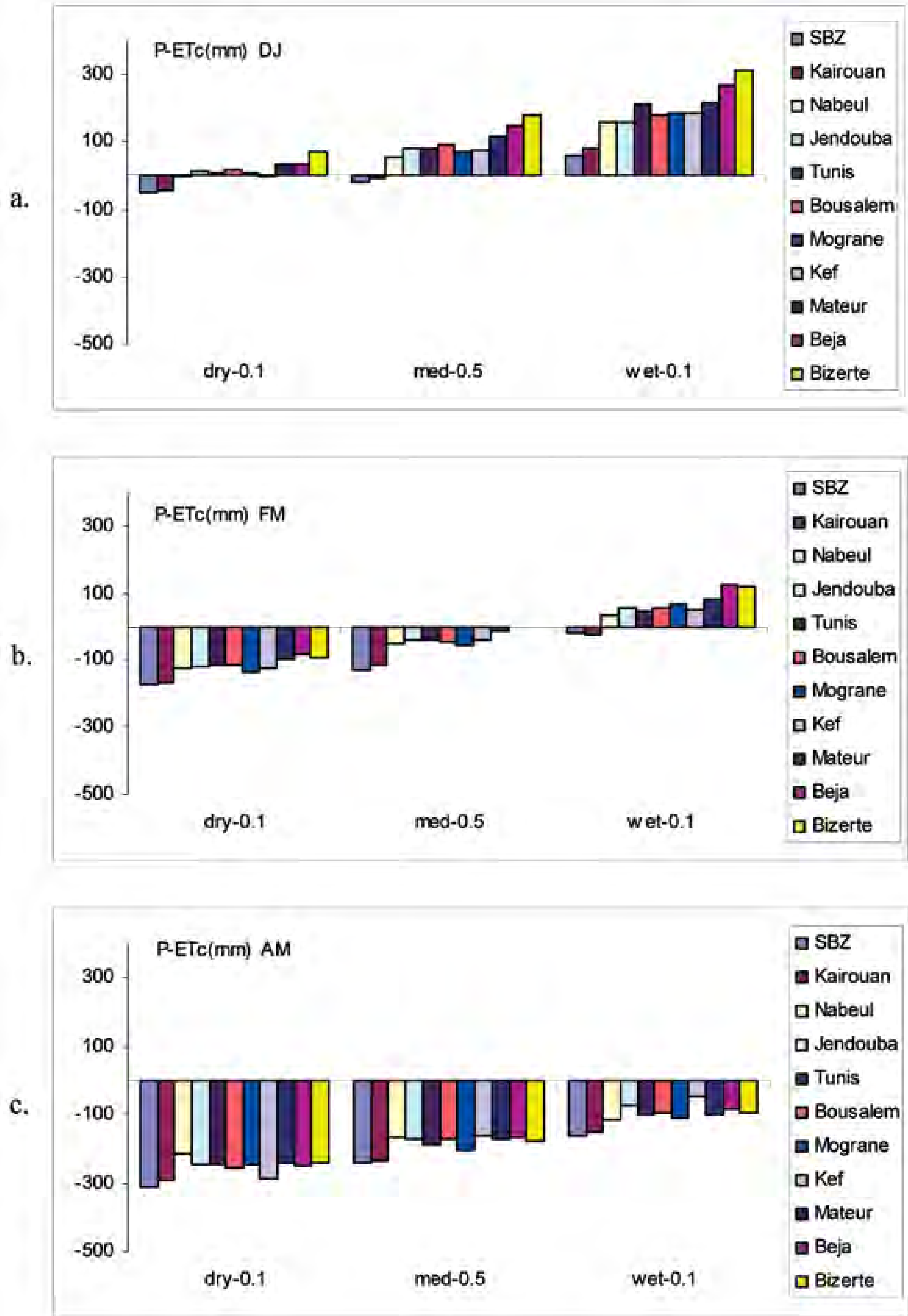

Figure 10.4: Calculated water deficits for the various cereal growing areas in Tunisia, on a bi-monthly basis corresponding to the defined growing calendar. Dry, wet and medium conditions are indicated on the figures.

Since the cropped areas cannot expand, increasing water productivity is considered to be the most direct way of improving cereal production. Under strictly rainfed systems, this objective could be achieved through an optimal match between rainfall distribution and the cropping season. Another way is through the adoption of supplemental irrigation to compensate for seasonal rainfall deficits.

Agronomic practices need to be improved and adjusted for regional conditions and within the same region for the annual rainfall variability to optimize the exploitation of available resources. To do so, the mechanisms by which inadequate water supply affect production must be understood to allow the highest crop yields and most efficient use of resources. A better understanding of the crop's response to environmental factors and production inputs such as fertilizers and pesticide is also required.

10.5.2 Modeling

Yield–rainfall relationships

Statistical regression was used to derive linear relationships between precipitation and yield data obtained for the selected governorates. Using a simple presentation, it could be seen that wheat yield starts increasing rapidly with increasing amounts of rainfall. The observed scatter of points in Figure 10.5 could be related to various causes including: i) the representativeness of the reference station, ii) excessively high rainfall amounts during winter, and iii) rainfall deficit periods long enough to cause irremediable damage to the crop pushing farmers to graze it (Figure 10.5).

The transpiration model

The $Y = f(\sum Pi / Ti^*)$ model follows the relative yield approximation approach, which considers that relative yield is directly related to the relative transpiration of the crop. Initially, the relationship between wheat yield and the ratio P/T* was investigated. Then the robustness of the model was studied using official wheat production statistics and good quality weather data for seven governorates as input data (Figure 10.6).

Our results show that a better fit is obtained when using P/T* instead of P with more explanatory capacity. The model shows that wheat responds favorably to water supply. However, yield seems to increase up to a limit much lower than the potential, with an average maximum yield of a little less than 3 t/ha when rainfall amounts and distribution are approaching their optimum.

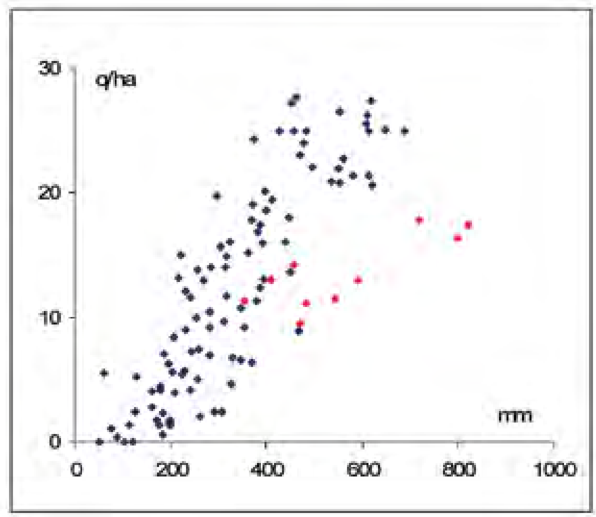

Figure 10.5: Variations in wheat yields (q/ha) in relation to total rainfall of the October–May period (mm).

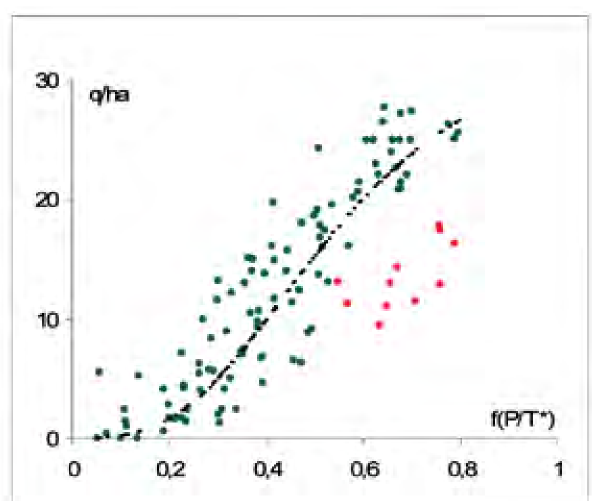

Figure 10.6: Variation in wheat yields (q/ha) in relation to the ratio between rainfall and maximum evapotranspiration (P/T*).

The challenge is to explore in depth the underlying causes of this limitation.

Performance of the transpiration model

With different regression models, relatively high correlation coefficients are obtained, indicating the overriding effect of rainfall on yield throughout the wheat producing areas (Table 10.2). However substantial improvements in R^2 are obtained by using the effective rainfall instead of total rainfall.

In the transpiration model, the effect of rainfall is recognized through the cumulative effect of relative supply during the different stages of growth. This approach gives a better representation of the reality and resulted in producing the highest values of R^2. Another improvement was obtained by using the model with specific weighting factors for each development stage (Table 10.2). The values for R^2 were 0.73 and 0.83 respectively under calibration and validation work.

recorded during the stem-elongation and booting stages with only 36 mm in March. During the period from anthesis to maturity the total rainfall was approximately 30 mm.

Development stages
Table 10.3 shows the phenological observations. Full ground cover was reached at the end of February, and a maximum leaf area index (LAI) of 6 was reached at the end of March.

Table 10.3: Phenological observations for the cropping season 2005/2006.

Stage	Date
Sowing	22 Nov (2005)
Emergence	4–6 Dec
Tillering	2 Jan–3 Feb
Anthesis	1–7 Apr
Milky stage	8 Apr–18 May
Maturity	29 May

Table 10.2: Performance of models considered for the estimation of wheat yield.

Data used	Period	R^2 calibration 1982–1992	R^2 validation 1993–1998	MAE validation 1993–1998
P	Oct–May	0.55	0.77	4.1
Pe	Oct–May	0.61	0.81	4.5
P/T*	Oct–May	0.55	0.73	4.4
Pe/T*	Oct–May	0.61	0.78	4.0
Pei/T*i	O-N, D-J, F-M, A-M	0.67	0.83	3.5
ai.Pei/T*i	O-N, D-J, F-M, A-M	0.73	0.83	3.1

10.5.3 Yield response to water at the field level

Results for 2005/2006

Experimental conditions
After sowing on 22 November, a long period without rainfall occurred and it was necessary to apply 30 mm to all treatments on 6 December in order to ensure the good establishment of the crop. Heavy rainfall occurred during the period from the end of December to January with a total amount of 236 mm. However, only small amounts were

Water use
Irrigation scheduling was based on the estimation of soil water depletion by a simplified water balance model. The model uses rainfall and crop evapotranspiration as calculated by the FAO 56 method (Allen et al., 1998).

The first irrigation was applied after emergence. Other irrigations were applied during the flowering and milky stages for the I-2 treatment and only at flowering for the I-1 treatment. Table 10.4 gives the dates and amounts of irrigation water.

Table 10.4: Irrigation dates and amounts (mm) and total water supply during the period October–May, for the three watering regimes in 2005/2006.

Date	Rainfed*	I-1	I-2
I, 6 Dec	30	30	30
I, 4 Apr	0	45	45
I, 1 May	0	0	70
P (Oct–May, mm)	412	412	412
Total I (mm)	30	75	145
Total P + I (mm)	442	487	557

*N.B. Because of autumnal drought, the rainfed treatment received 30 mm on 6 Dec.
I: irrigation; P: precipitation.

Yield

LAI values were measured periodically during the growth cycle of wheat. The maximum LAI values of 6 occurred during the booting stage (21 March). Grain yield was determined at harvest for all watering regimes. Table 10.5 shows the average yield and harvest index obtained from plots of 150 m^2.

Table 10.5: Above ground biomass (B) grain yield (Y) and harvest index (HI) for rainfed and irrigated durum wheat (2005/2006), Mornag, Tunisia.

Water regime	B (g/m^2)	Y (g/m^2)	HI
Rainfed	1138	368	0.32
I-1	1304	582	0.45
I-2	1503	680	0.45

Results for 2006/2007

During the second year, field work on wheat was again carried out at the INAT Mornag experimental station. Field observations included climatic data, crop phenology and crop cover, biomass production and soil water content of the upper 100 cm. Irrigation was applied during the milky stage. The information collected was used in AquaCrop.

Experimental conditions

The year was characterized by a relatively good temporal distribution of rainfall with a total amount of 513 mm during the October–May period. Irrigation was applied during the milky stage (20–26 April) with 50 mm for irrigation treatment I-1 and 140 mm treatments I-2. Table 10.6 summarizes the timing and amounts of water supplied.

Table 10.6: Irrigation dates and amounts and total water supply during the period October–May for the three watering regimes in Mornag, 2006/2007.

Treatment	Rainfed	I-1	I-2
I. (20–26 Apr, mm)	0	50	140
P (Oct–May, mm)	513	513	513
Total P + I (mm)	513	563	653

Development stages

Results of the phenological observations are reported in Table 10.7. It should be noted that the crop reached full ground cover by the end of February, while maximum LAI was achieved at the end of March.

Water use

Soil water content of the upper 100 cm was measured regularly in the rainfed and irrigated plots. Its value remained within the readily available water (RAW) limits until the grain filling stage although a long period with rainfall deficit was observed from January to March. Rainfall of 100 mm occurred by mid-March compensating soil water depletion. As a result, soil water content fell below RAW only during the second half of April, i.e. at the late milk stage. Irrigation was therefore applied to the SI treatments at the level of 50 mm (I-1) and 140 mm (I-2).

Soil water content in the upper 100 cm of soil is shown in Figure 10.7. Observed and simulated values, in spite of some differences are coherent with rainfall and irrigation patterns.

Table 10.7: Phenological stages of wheat observed in Mornag 2006/2007.

Stage	Date
Sowing	18 Nov (2006)
Emergence	6–8 Dec
Tillering	2–23 Jan
Anthesis	17–30 Mar
Milky stage	2 Apr–8 May
Maturity	15 May

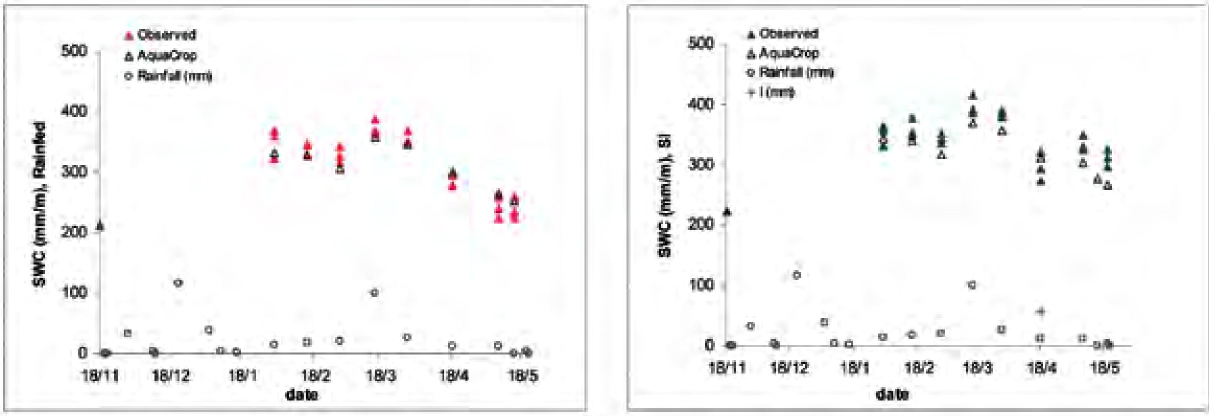

Figure 10.7: Observed and simulated soil water content (SWC) in the upper 100 cm of soil for rainfed and irrigated (I1) treatments, Mornag, 2006/2007.

Yield

Total biomass (B), grain yield (Y) and harvest index (HI) obtained under rainfed and irrigated treatments during the experimental year 2006/2007 seem to be typical for the cultivar used, Karim (Table 10.8).

Table 10.8: Above ground biomass (B), grain yield (Y), and harvest index (HI) for rainfed and irrigated durum wheat, Mornag, 2006/2007.

Water regime	B (g/m²)	Y(g/m²)	HI
Rainfed	1545	615	0.40
I-1	1585	655	0.41
I-2	1460	567	0.39

Simulation results

AquaCrop was used to simulate crop growth in rainfed and SI plots. Graphical outputs of simulated and actual transpiration, canopy cover and soil water depletion for the rainfed plot showed that rainfall distribution allowed good watering conditions, simulated transpiration was always at its maximum value and soil moisture remained within RAW limits until 130 days after sowing (DAS 130). Thereafter, soil water depletion fell below RAW and a substantial reduction in transpiration occurred.

Simulated and observed above-ground biomasses are shown in Figure 10.8 for rainfed and SI regimes. Both curves are

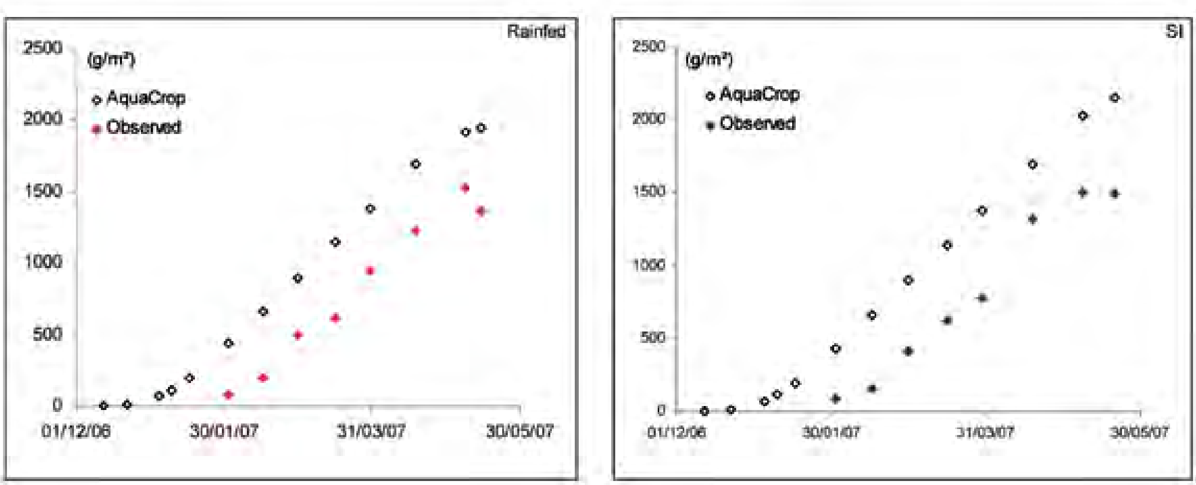

Figure 10.8: Measured and simulated above-ground biomass under rainfed and SI conditions, Mornag, 2006/2007.

the same shape but the one produced by AquaCrop has systematically higher values. The difference between the observed and simulated biomass seems to result from an over-estimation of biomass production during the emergence-tillering stage.

Although there is globally good agreement between AquaCrop outputs and field observations under rainfed and supplemental irrigation, fine tuning of the AquaCrop parameters is needed to enhance its predictive capacity under local conditions.

Results for 2007/2008

Again during the third year, field work on wheat was carried out at the INAT Mornag experimental station. Field observations included climatic data, crop phenology crop cover, biomass production and soil water content of the upper 100 cm. The AquaCrop model was used to simulate water balance and for irrigation scheduling. Irrigation was applied during the booting stage.

Experimental conditions
The year was characterized by low rainfall with 373 mm during the period October–May and only 85 mm over the months January–April. Irrigation was applied during the booting stage on 6–10 March. Irrigations levels of 60 mm (I-1) and 120 mm (I-2) were applied (Table 10.9).

Development stages
Results of the phenological observations are reported in Table 10.10. It should be noted that the crop reached full ground cover by the end of February, while maximum leaf area index (LAI) was achieved by mid-March.

Yield
Total above ground biomass (B), grain yield (Y) and harvest index (HI) obtained under rainfed and irrigated treatments during the experimental year 2007/2008 were relatively low compared to the previous year (Table 10.11).

Results show that when low rainfall is recorded during January and February, application of relatively small amounts of irrigation (60–120 mm) before anthesis substantially improve yield and harvest index.

Table 10.9: Irrigation dates and amounts (mm) and total water supply during the period October–May, for the three watering regimes in Mornag, 2007/2008.

Date	Rainfed	I-1	I-2
I, (6–10 Mar, mm)	0	60	120
P (Oct–May, mm)	373	373	373
Total P + I (mm)	373	433	493

Table 10.10: Phenological stages of wheat observed in Mornag, 2007/2008.

Stage	Date
Sowing	20 Nov (2007)
Emergence	4–6 Dec
Tillering	13 Dec–21 Jan
Anthesis	17–23 Mar
Milky stage	24 Mar–24 Apr
Maturity	5 May

Table 10.11: Total above ground biomass (B), grain yield (Y), and harvest index (HI) obtained under rainfed, and irrigation regimes, Mornag, 2007/2008.

Water regime	B (g/m²)	Y (g/m²)	HI
Rainfed	1292	330	0.26
I-1	1345	414	0.31
I-2	1560	501	0.32

10.5.4 Outscaling

Data needed to out-scale the models were collected and checked for quality. Ten years' data on wheat yield at the field and delegation levels under rainfed and SI regimes are readily available. Data for governorates cover longer time periods but are presented in a global manner without distinction between the two systems.

Yield vs seasonal rainfall: the scale effect

Using the available data, regression analysis between yield and rainfall totals (summed over different time spans) were carried out at the county and the demonstration farm level (Table 10.12).

Table 10.12: Determination coefficients (R^2) obtained for regressions between wheat yield and precipitation totals calculated over different periods.

Period	Farm	County
Sep–Aug	0.78	0.51
Sep–May	0.77	0.53
Oct–May	0.81	0.59
Nov–May	0.75	0.53
Autumn	0.21	0.07
Winter	0.69	0.33
Spring	0.66	0.42
Sowing	0.21	0.07
Tillering	0.69	0.33
Elongation	0.64	0.42
Grain filling	0.26	0.25

This analysis seems to confirm our hypothesis about the relevance of the October–May period for using the ($Y= f(\sum Pi / Ti^*)$) modeling approach. As demonstrated earlier, the cropping cycle can be divided into four major periods when water is required for successful cultivation: 1) planting period (Oct–Nov), 2) crop establishment (Dec–Jan), 3) active growth (Feb–Mar), and 4) yield formation (Apr–May). The relationship between yield and precipitation during the active growth period is highest because this corresponds to the phase when the most important component of yield (seed number) is being determined.

Farm to county

Figure 10.9 shows that a strong correlation between the farm and county (delegation) level is observed for rainfed conditions in Medjez, contrasting with the low relationship seen under supplemental irrigation. This difference probably reflects the high heterogeneity in irrigation practices among farmers and the interference of the different management factors.

County to governorate

A relatively weak relationship was also found between the yield observed at the delegation and governorate levels (Figure 10.10). However correlation improved when considering the larger scale Northern Tunisia region and the Governorate of Beja.

Outscaling should probably focus on intermediate spatial scales for which a greater sensitivity to local variations was seen.

10.6 Conclusion

There are different methods by which wheat yield can be related to total water supply from rainfall, irrigation or both. When searching for management methodologies, at least two scales have to be considered: i) the field scale with the objective of adapting tools aimed at operational management and ii) the regional scale, for devising strategies concerned with water allocation and manipulation of the cropping systems.

This work has shown that methodologies based on straightforward functional relationships between crop yield and transpiration water are most suitable for conducting quantitative analyses on the role of water as a primary limiting factor for cereal production. A model using precipitation and potential evapotranspiration data is proposed as a tool for exploring options for improving rainfall-use efficiency for cereals on a regional scale.

On the basis of yield data obtained in Tunisia at field, county, governorate, and country levels, our analysis shows that further improvements in total cereal production could be obtained under present rainfall regimes. Outscaling, based on the available research findings and the proposed modeling approach could be carried out for the benefit of the cereal sector.

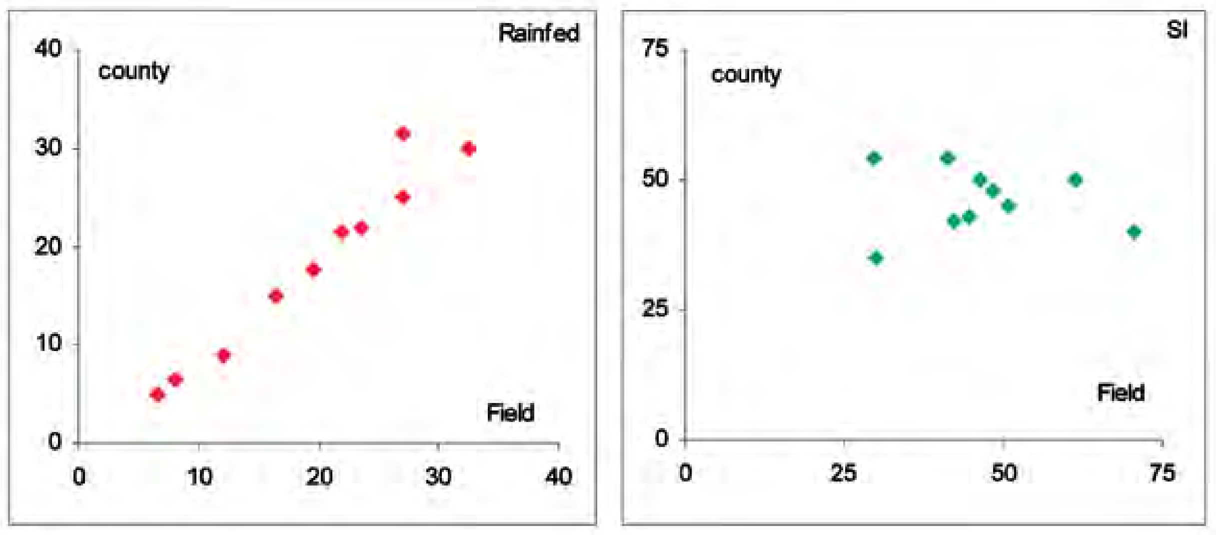

Figure 10.9: Relationship between wheat yield (q/ha) observed at farm and county (delegation) level under rainfed and SI conditions in Medjez, 1988–1998.

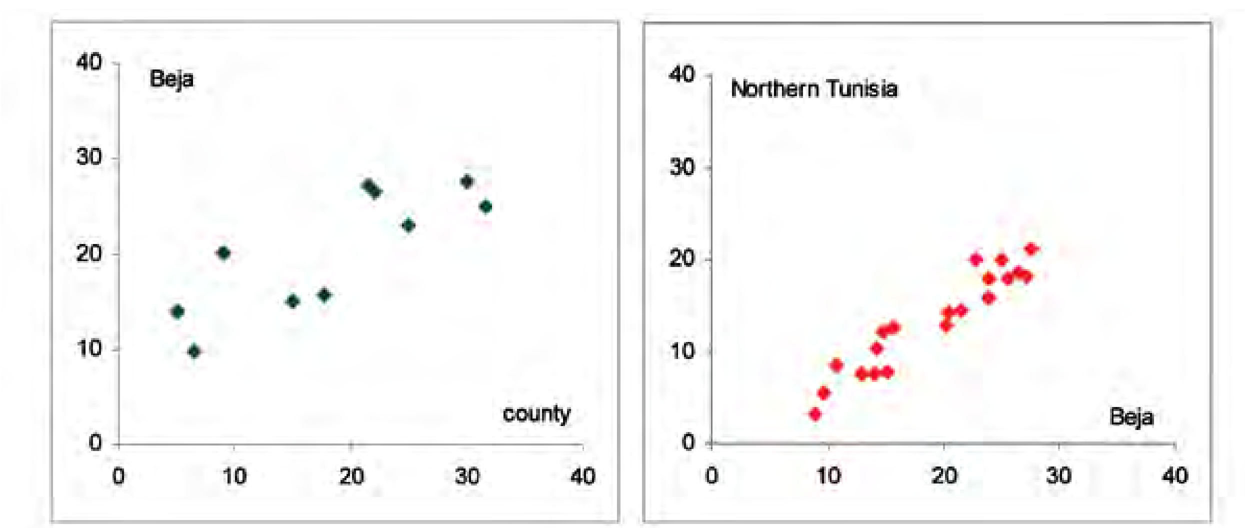

Figure 10.10: Relationship between average wheat yield (q/ha) for the Governorate of Beja/ County of Medjez (1988–1998) and Northern Tunisia/Governorate of Beja (1980–1998).

10.7 References

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Annex: Project dissemination and potential uptake

1 Communications and training

1.1 The community approach

Irrigation water in Morocco is generally considered as a common resource, especially in the mountain zones. In these zones, irrigation water is managed and controlled by local communities to ensure its sustainability. Similarly, in the project zone, many actors are involved in the water allocation process: the Water Basin Agency (WBA), ORMVAT (Agricultural Development Institute) and the Water Users' Associations (WUA). All these actors were involved in the first phase of the project to make sure that all components were considered in the design of our interventions. In addition, and to respond to the project's main objective, the Moroccan team of scientists decided to work with farmers as a community and not as individuals. We believe that this approach makes it more likely that efficient water-use technologies will be disseminated as widely as possible. Furthermore, decision-makers would be more likely to use research results, if researchers identified the intended users and involved them in formulating questions, problems and adapted solutions.

1.2 The participatory approach

Two participatory workshops were conducted with all the representatives of national and local actors involved in water management issues to select relevant communities representative of the project study area,. The main objectives were: 1) to ensure a minimum level of participation by the community by raising awareness of the project and its major objective which is the efficient use of water in supplemental irrigation; and 2) to improve the interaction of researchers with community members and partners such as the Chamber of Agriculture, local authorities, Water Users' Associations, cooperatives, etc.

The workshops used a participatory, iterative and flexible approach in which priority was given to visualization as a stimulus to communication and capitalization of the information. Different tools were used to reach the assigned objectives – Venn and flux diagrams in plenary sessions and agricultural activities, and constraints and potentials during group work.

Each workshop had two sessions – one plenary meeting with all participants and the second small thematic group meetings. The first session focused on presentation by farmers giving a general description of the community and its linkages and fluxes with its environment. This first meeting also facilitated establishment of communication among participants. The second session aimed to exchange information and promote discussion of problems by small groups concerned with specific subjects related to water-use efficiency.

1.3 Communication and linkages with policy makers

An important aspect of linking research to policy is effective communication. This requires an effective communicator and means of communication. Various communication channels have already been identified. A common communication channel is during field days, where researchers present their technologies to the community and at the same time collect the community's feedback about the technologies being tested. Key stakeholders previously identified with the community are usually invited to participate to these field days. Because decision-makers tend to deal with demands from pressure groups and to respond more to ideas and suggestions from these groups, the team identified some key people in the region (politicians and deputies) who can help in transferring our messages to decision-makers more easily.

Other communication channels include the press. The team invited the press on many occasions (field days and workshops) and articles about project activities and their impact have been published. The project coordinator, the project team and representatives of participating farmers have been interviewed on radio and national TV during field days. It is also important to mention that the project's national steering committee has members from different water authorities involved in making water policies.

1.4 Workshops and meetings

In addition to the workshops organized during the early stages to help design the project with the participation of farmers, we have also presented our achievements to the community of scientists and other actors at the ICARDA/INRA annual meeting. Our interventions are also reported to local Government representatives, water associations and the Chamber of Agriculture. Frequent and informal technical meetings are held with the main actors – WBA, ORMVAT technicians and representatives of the farmers involved in the project. But the most important workshop was organized on 25 November 2008 at ORMVAT. This workshop was co-chaired by the INRA and ORMVAT DGs and presented the achievements of Phase 1 of the project. About one hundred people attended the workshop, which included representatives of farmers, Water Users' Associations and agricultural extension services.

In addition the Rainfed Benchmark site of Morocco organized a traveling workshop from 5 to 9 March 2007 in the Souss-Massa hydraulic basin situated in the southern part of Morocco. The trip was organized with the collaboration of ORMVAT. The participants, mainly farmers and extension technicians, visited the region which is experiencing many problems and difficulties resulting from the over-use of underground water in irrigation. They had meetings with WUAs and the president of the WUAs federation in the Souss river basin.

1.5 Public awareness

Project activities were communicated to the public via a number of articles published in local and national newspapers. The local press was invited to field days and workshops. Interviews with farmers and the project team were reported on the radio and TV on many occasions.

1.6 Capacity building

A training course for technical staff from research centers and extension services working in the project area was organized. Participants were trained in the follow-up of on-farm trials and in the use of improved technical packages under supplemental irrigation. This training was aimed at preparing teams for technology dissemination over a larger area and to widen the project's impact over the coming years.

2 Uptake of the project early output

2.1 Uptake of the project approach

On principle, the project encouraged collaboration and linkages at the local and national level. To achieve the project's expected outputs different institutions involved in water management – the WBA, ORMVAT, the WUAs and the AGR (Rural Development Administration) – worked together to set the broad outlines of the project, to follow-up different activities undertaken and to contribute to the existing database at different levels. They all supported the community-based approach and they are all jointly responsible for the success of the dissemination of project interventions.

2.2 Adoption of technologies

The technical options for crop and water management that have been developed by research studies have been introduced and used with the participation of farmers on their fields. Significant improvements in yield and water productivity were achieved and witnessed by neighboring farmers. The participatory approach involved research, extension and farmers and through a number of field visits and discussions, farmers became aware of the alarming situation regarding water scarcity in their region. Another notable parameter is the growing numbers of farmers who have asked for the same trials to be carried out on their fields.

Results of socioeconomic studies have shown that the adoption rate was up to 98% for the use of suitable varieties and 52% for the use of early sowing date by farmers participating in the trials. In contrast, these figures were only 36% and 5%, respectively, for farmers participating in field days. The degree of adoption ranged from 25% to 67% for farmers participating in the trials and from 0 to 50% for farmers participating in field days. In addition, farmers ranked the introduced technologies from easy to very difficult as follow: varieties, sowing date, nitrogen rate and deficit irrigation. The time lag between knowing about the technologies and their full adoption was one year for varieties, two years for sowing date and nitrogen rate, and more than two years for deficit irrigation. Economic water productivity improved after adopting project technologies. Before the introduction of project technologies, it was about 2.25 MDh/m^3 and after adopting the technologies, it ranged from 2.55 (sowing date) to 3.75 MDh/m^3 (deficit irrigation).

2.3 Field days

Since we were using a community-based approach, field days were arranged each year from the beginning of the project. More than 40 farmers were taken to the trial plots to share experiences with researchers, extension agents and the farmers who hosted the trials. These field days encouraged interactions between farmers and technicians and among farmers themselves, which is a positive point in terms of back-up for research and in terms of technology transfer. We also had the chance during the first year to welcome to the field day colleagues from the satellite sites in Algeria and Tunisia and representatives from IDRC-Egypt. On the same occasion, Algeria received support from IDRC to set up a small project.

2.4 Effect of government investment in the new initiatives

Morocco is well aware of the problems associated with water scarcity since it has experienced them at different levels of severity. The degree of severity increases from north to south and from west to east. It was for this reason that the state created the 1995 Water Law that governs water use all over the country. It reiterates that all water in Morocco is in the public domain and establishes organizational structures responsible for the concerted management of water. The most important feature of the law, however, is the establishment of the Water Basin Agencies, at the regional level. The essential task of a WBA is to attend to the equitable and efficient distribution of water for different uses – irrigation, energy production and drinking water. To this end, they hold regular consultations with users and their representatives. The law has provided for this continuing consultation process by instituting Provincial (or Préfectoral) Committees for the Integrated Management of Water Resources. Moreover, two-thirds of the WBA administrative boards are composed of representatives of users – governmental and non-governmental.

To encourage farmers, the state grants subsidies for the implementation of irrigation projects that include the use of water-saving technologies. These subsidies cover about 60% of the total project cost. The new technologies include drip irrigation equipment, water reservoirs to store water from the irrigation network to be used at critical plant growth stages and others accessories. The rate of subsidies granted can increase to 80% in some cases.

3 Potential uptake to be realized after completion of the project and beyond

Because of the nature of our interventions – technical and institutional – time is needed to assess their impact. The project area has experienced many development project related to the efficient use of agricultural water. We intend to complement their achievements by acting, especially at the farm level, to optimize field inputs and increase water productivity. We have already started to sense the positive impact of some interventions that are easily mastered by farmers. The economic assessment of the impact of new irrigation practices identified technologies to be recommended to the communities. For the Bradia community, net benefits associated with the introduced techniques were estimated at US$1130/ha by using Marjana wheat variety, US$1175/ha by using 60U of nitrogen, US$1514/ha by planting early, US$892/ha, and US$1634/ha with irrigation at 70% of field capacity. For Ouled Zmam community, the use of Achtar wheat variety resulted in a net benefit of US$611/ha and US$684/ha when planted early.

The use of drip irrigation in citrus orchards is becoming common in Morocco. We introduced a program for scheduling irrigation that allows water savings of around 300 mm with a significant increase in water productivity, about 25%. We also intend to investigate water use in alfalfa, the principal forage crop in the area (about 20,000 ha).

A modeling activity was initiated with the objective of evaluating, together with the stakeholders, the potential strategies that match water requirements with water supply and optimize the use of water within the biophysical and socioeconomic environment of the target areas. We intend to further investigate this subject to come up with a model of irrigation water management and suggested cropping patterns that allow the best use of the available water.

Planting date trials 2006-2007

		Yield t.ha-1		ET (mm)				Scenario Planting date 15 Oct			
Farmer	*Treatment*	Obs	Sim	Obs	Sim	Irrig	Rain	Yield	ET	Irrig	Rain
Erraji	Early 2 Nov 06	7,00	5,58	779	401,0	617	221				
	Late 1 Déc 06	4,00	4,96	622	335,0	458	188	6,46	416	458	243
Hattat	Early 2 Nov 06	4,00	5,40	521	381,0	329	221				
	Late 1 Déc 06	2,00	4,94	462	334,0	254	188	6,25	408	254	243
Ferrari	Early 2 Nov 06	6,00	5,18	688	376,0	513	221				
	Late 1 Déc 06	4,00	4,76	583	326,0	407	188	5,54	384,0	407	243
Bennaceur	Early 2 Nov 06	6,00	5,33	641	382,0	439	221				
	Late 1 Déc 06	5,00	4,96	556	330,0	359	188	6,42	410,0	359	243

Variaty trials 2006-2007

		Yield t.ha-1		ET (mm)				Scenario Planting date 15 Oct			
Farmer	*Treatment*	Obs	Sim	Obs	Sim	Irrig	Rain	Yield	ET	Irrig	Rain
REKIOUI	Achtar	8,00	4,93	608	344	433	207	5,89	395	433	243,0
FERRARI	Achtar	8,00	4,92	666	341	477	207	5,64	386	477	243,0
HETTAT	Achtar	2,00	4,99	569	353	389	207	5,92	397	389	243,0
BENNACEUR	Achtar	3,00	5,19	502	355	316	207	6,45	417	316	243,0

Deficit Irrigation trials 2006-2007

		Yield t.ha-1		ET (mm)				Scenario Planting date 15 Oct			
Farmer	*Treatment*	Obs	Sim	Obs	Sim	Irrig	Rain	Yield	ET	Irrig	Rain
REKIOUI	Farmer	8,00	4,91	426	343,0	244	207	5,85	393	244	243,0
	70%	8,00	4,88	372	341,0	190	207	5,79	390	190	243,0
	100%	7,00	4,93	556	344,0	381	207	5,89	395	381	243,0
DEHBI	Farmer	7,00	4,91	508	342,0	317	207	5,7	389	317	243,0
	70%	4,00	4,90	411	341,0	221	207	5,65	385	221	243,0
	100%	5,00	4,91	533	342,0	357	207	5,7	389	357	243,0
HATTAT	Farmer	3,00	4,98	527	352,0	346	207	5,92	397	346	243,0
	70%	3,00	4,91	338	349,0	158	207	5,83	391	158	243,0
	100%	2,00	4,98	512	353,0	326	207	5,89	396	326	243,0

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