Chapter 1: Irrigation water management in Morocco: a review

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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

Note: *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

Note: [(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	–*

Note: *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 irrigation

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
	Water use	mm/ha	1607	1398	1286	1077	964
1998/99	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
	Water use	mm/ha	1795	1562	1436	1203	1077
1999/00	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
	Water use	mm/ha	1833	1595	1466	1228	1100
2000/01	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
	Water use	mm/ha	2130	1853	1704	1427	1278
2001/02	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
	Water use	mm/ha	1841	1602	1473	1234	1105
Average	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.

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