Deficit irrigation of orchards

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DEFICIT IRRIGATION OF ORCHARDS

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ABSTRACT

Water scarcity has become a major constraint for economic development in many countries. To face the increasing demand, agriculture is required to increase its performance and probably to reduce its share for this resource. The pressure is particularly affecting fruit trees since they represent a sector of high irrigation water consumption particularly during the summer season. In many Mediterranean countries, waters of increasing salinity have been used to reduce the gap between the supply and demand. During droughts drastic cuts in supply have been observed. Because of chronic shortages, traditional management based on full irrigation and maximum yields is no longer appropriate. The concept of agricultural intensification needs probably to be reviewed. Adoption of Deficit Irrigation (DI) as a strategy in irrigation seems to be a relevant choice. This document explores the potential of this strategy to save water in orchards. Application to the peach species shows that irrigation water could be reduced by one third without affecting significantly yield (10 % reduction). Results obtained on apple show a similar potential. In both cases, appropriate scheduling seems to be a key element in water saving and in reducing risks of soil salinization.

INTRODUCTION

Many Countries have devised development plans on the basis of water mobilization. Important investments have been made for the construction of hydraulic infrastructure during the second half of the last century. Consequently, there has been an impressive expansion of the irrigated lands. But, because of the limitation in water supply, the need for management practices to save water became rapidely vital in many areas. Observed degradations of soils and contamination of aquifers stressed this need.

In the irrigated sector, this concern was expressed by a strong will to adopt practices that reduce water losses and protect the soil from degradation. During the 1990s, research showed a sharp shift from focussing on intensification towards integration and preservation of natural resources.

On the regional scale, many collaborative projects have been implemented in order to address the issue of water saving in agriculture. It is possible to list here, projects that have known a direct impact on the decision-making process and contributed to the increase of awareness at various levels in the Arab region.

For Tunisia, the supplemental irrigation national program is probably a land mark to a series of measures aimed at improving water productivity in the irrigated sector. It was launched in the 1980s following an active research on the irrigation of wheat that started fifteen years earlier. The objective was to adopt supplemental irrigation in a sector that was totally rainfed. Backstopping of this ambitious work was provided by "Projet d'appui au programme national d'irrigation d'appoint des céréales, UNDP/FAO/TUN 86/014".

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

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

The IAM-Bari irrigation network established in 1993 was intended to develop synergies among teams working on water use efficiency, management of irrigation systems and the use of saline waters in agriculture.

The ICARDA initiative (1995) concerning the "On farm water husbandry" addressed the issue of water harvesting techniques and showed its potential for improving agricultural production in the dry areas of West Asia and North Africa.

The WASIA project came at an essential moment to consolidate the available knowledge and to promote capacity building in the subject matter of water management. Within this context the Tunisian team had the opportunity to strengthen its ongoing research program concerning water saving through the adoption of deficit irrigation (D.I.).

Presently there is clearer ideas about the adoption of Deficit Irrigation instead of full irrigation as a strategic choice to handle severe problems of water shortages. This is essential in countries where the gap between supply and demand keeps growing.

At our level, research inline with WASIA was carried out within the framework of the national federative project "Besoin en eau et systèmes de culture" with funding from the Government of Tunisia, the World Bank and the Belgian Cooperation Agency. The productivity of water in agriculture and possibilities of its improvement has been investigated under this program. Moreover, an important effort has been deployed in terms of capacity building at the national level.

The rationale of the research program, the objectives and the selection of the fruit species were based on the actual priorities. Peach and apple were selected because of their rapid expansion in the irrigated sector. By targeting these species we wanted to complement research findings about fruit trees.

RESEARCH ON IRRIGATION OF FRUIT TREES

Crop water requirement studies have been strongly implemented in Tunisia. Early investigations on annual crops started with the use of Lysimeters during the 1930s and then evolved to cover olive and citrus trees during the 1960s. A large body of information is available on water consumptive use of many crops. Knowledge is particularly important in the domain of using saline water for irrigation, due to the low quality of the water available in the country. A rapid review of relevant research about trees is presented in Table 1.

Table 1. Major experiments carried out in Tunisia on water consumptive use of trees

Species	Location	Period	Objective/exp. design
Olive	Tunis	1960-78	Yield response to three irrigation amounts with fresh (0.8 ds/m) and saline water (4.7 dS/m).
	Ksar Ghriss	1965-80	yield response to irrigation with saline waters (4.5 dS/m).
	Mornag	1998-pres.	Consumptive use of individual trees (sap flow).
Citrus	Tunis	1960-78	Yield response to three irrigation amounts with fresh (0.8 dS/m) and saline water (4.7 dS/m).
	Mornag	1974-76	Use of drip irrigation vs. surface irrigation
	Cap bon area	1974-76	Yield variability under drip irrigation .
Peach	Mornag	1996-2002	Deficit irrigation, its impact on vegetation, yield and fruit quality.
Apple	Mornag	1996 2000	Deficit irrigation applicability.

Major results have showed the quantitative relationships between production and water supply. Thus on olives the work carried out in Tunis was intended to evaluate the potential of using different irrigation doses to complement rainfall. Results showed that olive production was almost unchanged when water supply increased from 300 to 650 mm/year in addition to the 450 mm of rainfall. The use of saline water (4.7 dS/m) in this experiment gave similar conclusions.

In the central zone of the country (Ksar Ghriss), results showed that with an annual rainfall of 200 mm, irrigation amounts ranging from 450 to 950 mm/ year produced the same yield on young olive trees (Bouaziz, 1983). Furrow irrigation gave satisfactory results in terms of productivity and salinity control . Adoption of drip systems to deliver 400 mm/ year resulted in small increase of yield (15%) although two surface applications were provided : one at the beginning of the irrigation season for good moisture setting under the drippers and a second at the end to wash salts downward.

The experiment concerning citrus growing showed that the crop coefficient for this species when conducted under intensive systems was about 0.75. With saline waters (ECw = 4.7 dS/m), good yields were obtained over many years. The most serious problem observed in this orchard was chlorosis. Corrective soil measures for iron deficiencies were relatively costly and the profitability of the whole operation was a serious question. Nevertheless, trees that received saline water amounts equivalent to rainfall (450 mm) suffered less from iron chlorosis.

Concerning leaching, precipitation of about 500 mm helped remove salts from the 0-125 cm soil profile whereas amounts higher than 600 mm were needed for the leaching processes to reach the 125-200 cm stratum.

From these results it seemed that adding waters having total dissolved solids of about 3 g/l to tree crops can improve agricultural productivity without being detrimental to the environment provided that the rainfall regime and the soil structure allow for natural leaching of salts.

The recent research work is addressing the issue of purposly reducing the supply below the crop requirements. It is different from studies concerned by physiological response of plant to water stress. It considers D.I. as a strategy that could be used to save water with the cost of reducing yield.

RATIONALE OF DEFICIT IRRIGATION

D.I. strategy is based on the concept that water supply can be reduced to control vegetation growth during specific times of the growing season, while fruit growth remains unaffected. The idea is very attractive because of its simplicity and because of its large implication on water saving opportunities. Furthermore, DI may help reduce the cost of pruning by controlling the whole vigor of trees.

As a choice, deficit irrigation is particularly important for orchards which are frequently subject to chronic water shortages during the dry season. For the Maghreb countries, orchards represent an important part of the irrigated sector and are using the highest share of irrigation water (Table 2). For instance, in Tunisia fruit trees cover more than 40% of irrigated lands and represent an important component of the productive farming system in the country. However productivity is usually low and irrigation with waters having more than 1.5 g/l of TDS is commonly practiced without provision of drainage. Moreover during years of drought water supply could be seriously reduced.

Table 2. Share of orchards in the irrigated sector for the Maghreb countries (Source : Medagri-FAO).

	Irrigated area (1000 ha)	Irr. Fruit trees (1000 ha)	Ratio (%)
Algeria	560	293	52
Morocco	1291	301	23
Tunisia	380	182	48
Maghreb	2231	776	35

In Tunisia, various water management strategies based on reduced water supply have been the subject of active investigation during the last ten years. More recently, and within the framework of the national federative project on water requirements and cropping systems a particular effort has been devoted to means to increase water marginal productivity. WASIA Project helped probe deeper into the long-term impact of DI. The potential of using saline waters under restrictive conditions has been also tackled.

Unlike research carried out during the 1960s and 1970s on citrus and olives, the work conducted on peach and apple trees was intended to explore the potential of DI for water saving.

Experiments on these species started in 1996. The objective was to reduce the amount of water supply during the less sensitive periods without substantially affecting yields. Thus, various deficit irrigation strategies have been tested.

In relation to our work, many interesting results have been obtained under Mediterranean type climate around the world with application of a wide variety of methodologies. In Australia, Mitchell et al. (1984) applied, on pears, water amounts to replace 92%, 47% and 23% of the evaporation rate during times of rapid vegetative growth; whereas, during the period of rapid fruit growth all trees were irrigated at the rate of 150%.

Girona et al. (1993) used Pennman equation and estimated crop coefficients to apply full crop water requirements (ETc) to the control. Trees under DI received 25% of the control during fruit growth stages I and II and post harvest and 100% to 130% of ETc during stage III. In their study on prune trees, McCutchan and Shackel (1992) irrigated daily their wet plots and used soil moisture contents as a reference for irrigation scheduling. In another work, a lysimeter was used to measure hourly ET from two peach trees and soil surface in order to investigate the irrigation treatments that are normally used by the industry (Crisosto et al., 1994).

CLIMATE, SOIL AND WATER OF THE EXPERIMENTAL SITE

The experimental work has been conducted in a commercial orchard located in the plain of Mornag, at 15 km South-East of Tunis (Latitude 32,7° N, longitude 10°14 E).

Climatic data of Tunis, supposed to represent the region, have been analyzed. Time series for 20 years of climatic data for each 10 days have been used to characterize evapotranspiration (Fig. 1) and rainfall (Fig. 2).

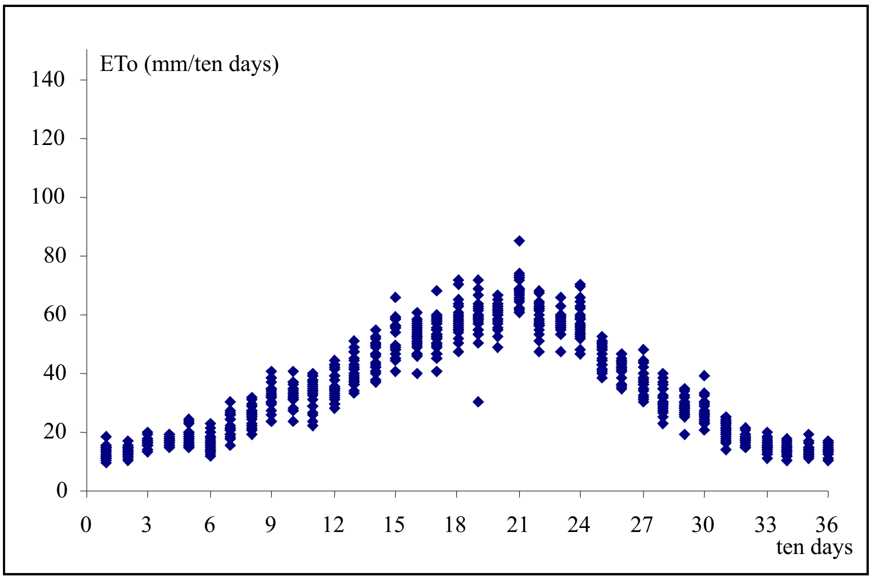

Fig. 1. Ten days Reference evapotranspiration of Tunis station over 20 years.

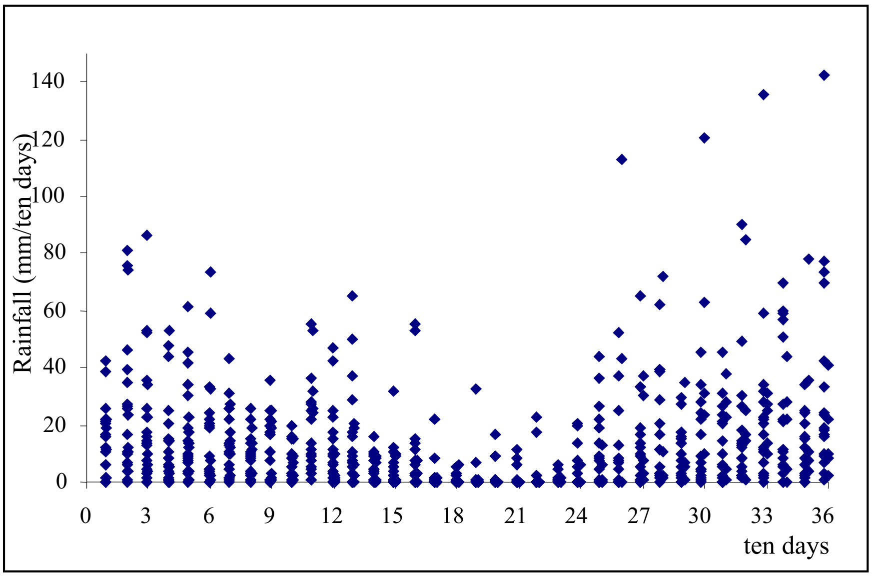

Fig. 2. Ten days rainfall amounts recorded at Tunis weather station over 20 years.

The Mornag plain is characterized by an alluvial soil, its physical properties at the experimental site are shown in Figure 3.

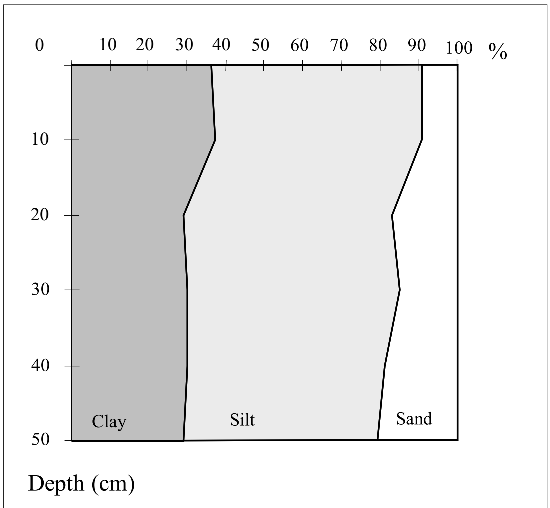

Fig. 3. Properties of Mornag experimental station soil.

The water related properties of the soil are presented in table 3. The important storage capacity of the root zone is a determinant factor in the valorization of water coming from natural precipitation.

Table 3. Water related soil properties of the experimental station.

Soil layer (cm)	0-20	20-40	40-60	60-80
Bulk density (g/cm^3)	1.41	1.62	1.42	1.31
Moisture at field capacity (cm^3/cm^3)	0.39	0.46	0.39	0.37
Moisture at wilting point (cm^3/cm^3)	0.24	0.29	0.25	0.22

Irrigation water is supplied from deep acquifers with ECi=1.88 dS/m or 1.31g/l TDS.

DEFICIT IRRIGATION OF PEACHES

Experimental setting

Experiments have been conducted in a drip irrigated commercial orchard of Carnival, a late peach cultivar (Prunus persica (L.) Batsch). The trees were planted in 1992 with a density of 555 trees/ha (3m x 6m), using GF677 rootstock. For the experiment, four irrigation treatments were applied at different fruit growth stages:

T0: is the grower's conventional irrigation program, taken as a control
Res. I-II: irrigation restriction during stages I and II
Res. III: irrigation restriction during stage III
Res. I-II-III: irrigation restriction during all phases I-II-III.

Irrigation reduction, when applied, consisted in 33% less water than the control. From 1999 and on, only the two extreme treatments have been maintained i.e. the control (T0) and the treatment with restriction during all stages (Res. I-II-III). Daily meteorological data have been used to estimate the Penman-Monteith reference evapotranspiration (ETo). These data were used to scale watering conditions by a coefficient K_s defined as (Irrigation+precipitation)/ETo.

The four irrigation strategies have been evaluated according to their impact on the amount of irrigation water saving, yield, fruit size, dry matter, total soluble solids (°Brix) and soil salinity.

yield response to water reduction at different stages

The average value of annual Penman-Monteith reference evapotranspiration (ETo) for the five years (1996-2000) was 1233 mm. The climatic demand of water was compensated by rainfall and irrigation. The average value of annual rainfall for this period was 471 mm, with no substantial precipitation during the third phase of fruit growth. Almost the all precipitation was concentrated during the autumn to early spring season. During the period 1996-2000, the average annual amount of irrigation water was 690 mm and 460 mm respectively for the Control (T0) and treatment (Res. I-II-III). The restriction of 1/3 of irrigation during the entire season (Res. I-II-III) saved 33% of total irrigation water, while treatment (Res. I-II) and (Res.III) saved respectively only 10% and 22% of water (table 4).

Table 4. Irrigation, total water supply (I+P) and irrigation water saving (IWS) for different water restriction treatments applied at different fruit growth stages of the peach variety '*Carnival*'. Mornag, 1996-1998. (source : Ben Mechlia et al 2002).

1996-1998	Irrigation (mm)	I+P (mm)	IWS (mm)	IWS (%)
Control (T0)	740	1268	-	-
Res. I-II	661	1189	79	10
Res. III	573	1101	167	22
Res. I-II-III	494	1022	246	33

Precipitation: 528 mm/year
Eto: 1295 mm/year

Variable fruit yields were obtained under the different irrigation treatments (table 5). The relationship between yield (Kg/tree) and the average K_s corresponding to the fruit-set-harvest period was not linear.

Table 5. Irrigation water saving (IWS), yield and yield loss for different water restriction treatments applied at different fruit growth stages to the peach variety '*Carnival*'. Mornag-Tunis, 1996-1998. (source: Ben Mechlia et al 2002).

1996-1998	IWS (%)	Yield (Kg/tree)	Yield loss (%)
Control (0)	-	85.0	-
Res. I-II (1)	10	71.8	15
Res. III (2)	22	66.1	22
Res. I-II-III (3)	33	76.1	10

Precipitation: 528 mm/year
Eto: 1295 mm/year

The highest yield was obtained for the unrestricted treatment control (T0). However, while receiving less water, trees under the most severe treatment (Res. I-II-III) gave better yields than those of treatment (Res. I-II) and (Res. III) (table 2). Under our experimental conditions, a continuous water restriction seemed to give a better yield than restrictions during just the vegetative growth phase or during the final fruit growth stage.

Long term impact on yield

Year to year variation of yield was quite large (Fig. 4) and seemed to be linked more to climatic conditions and to a changing tree load rather than watering conditions. The difference between the two extreme treatments i.e. the most watered (T0) and the least watered regime (Res. I-II-III) was quite stable for the entire period 1996-2000.

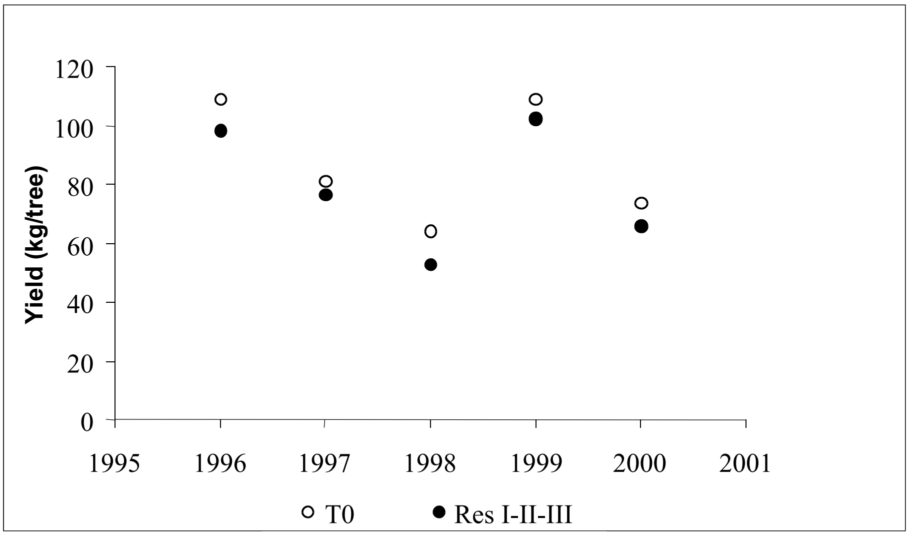

Fig. 4. Peach yield (kg/tree) of the Control (T0) and the D.I. treatment Res. I-II-III over the 1996-2000 period. (Ben Mechlia et al 2002).

Impact on fruit quality

Fruits picked at commercial maturity were weighted and sized separately. The classification according to the fruit size resulted in a high percentage of large fruits (diameter >67 mm) for both extreme treatments (T0) and (Res. I-II-III) (Table 6). Water restriction during the whole growing season seemed to improve the dry weight of fruits for the five years of experimentation (Table 6).

Table 6. Dry weight (g/fruit) variation and percentage of fruits having a diameter larger than 67 mm for the control (T0) and the least irrigated treatment (Res. I-II-III).

	Dry weight (g/fruit)		% fruits having a diameter > 67 mm	
Year	Control	Res. I-II-III	Control	Res. I-II-III
1996	13.0	14.0	95	95
1997	15.3	16.1	91	75
1998	-	-	99	97
1999	15.6	15.0	99	97
2000	16.7	17.7	98	98
2001	14.28	14.68	-	-
Average	**14.97**	**15.50**	**96**	**92**

Fruit sugar content seemed to be well related to watering regimes (Figure 5). The total soluble solids in °Brix was higher for low water supply treatments. In fact, its value increased linearly from 10.7 to 13.5 as the water supply coefficient, K_s decreased from 0.99 to 0.54 (Ben Mechlia et al 2002).

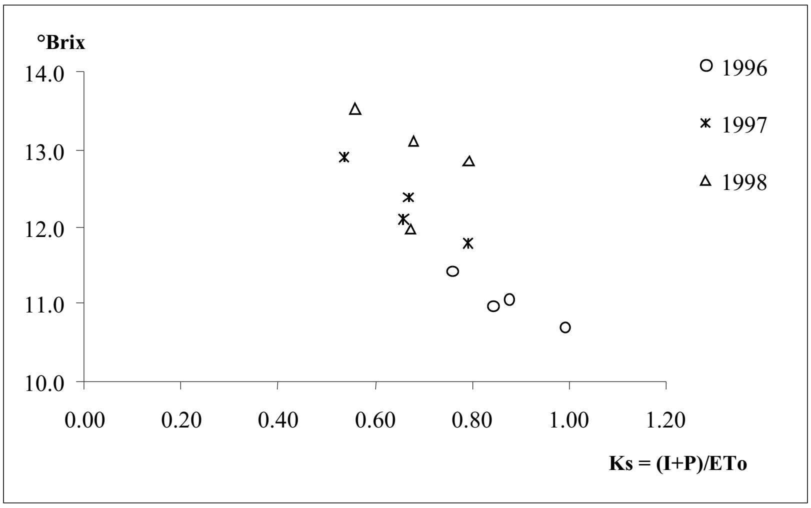

Fig. 5. Total soluble solids (°Brix) of peach fruits at mid - harvest stage in relation to K_s of the fruit set-harvest period. (source Ben Mechlia et al 2002).

Impact on Vegetative Growth

Measurements of the shoot length have been performed during two successive years. An active vegetative growth was observed during phases I an II of fruit growth for both years (Fig. 6 and 7). However no substantial difference was observed between the two extreme treatments T0 and Res. I-II-III during the second year of experiment (Ghrab et al, 1998).

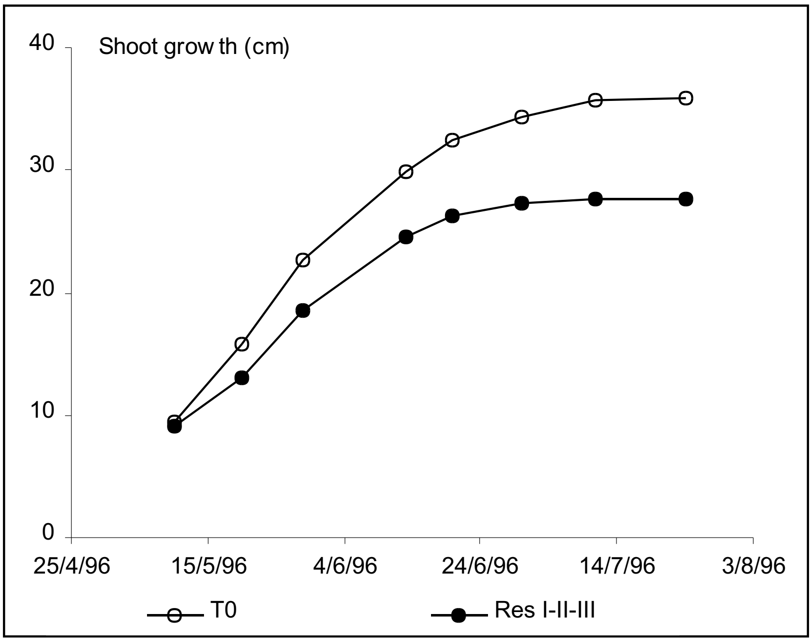

Fig. 6. Shoot growth during the first year of DI application.

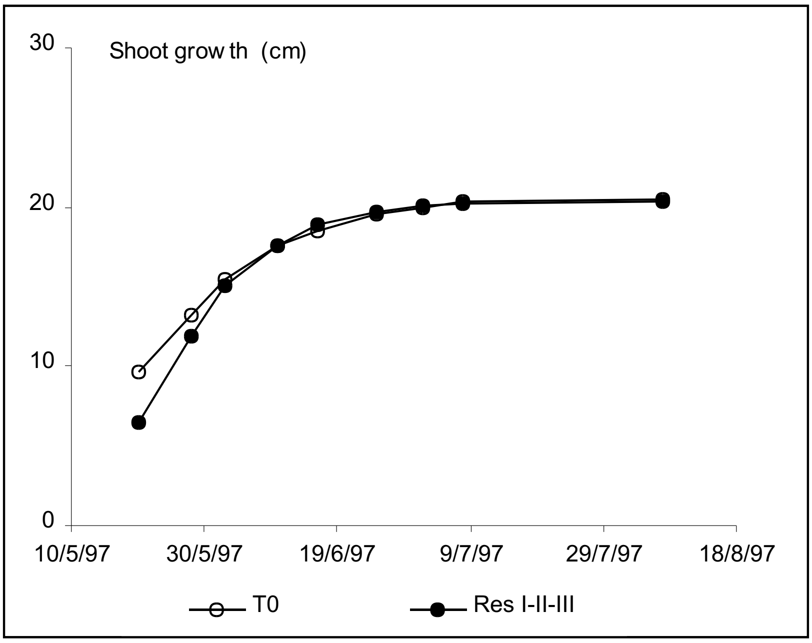

Fig. 7. Shoot growth during the first year of applying DI..

DEFICIT IRRIGATION OF APPLE TREES

Experimental set up

The experimental works on deficit irrigation of apple tree was carried out on ten-year-old Golden Delicious cultivar planted at the density of 1250 trees/ha. With reference to the control (T0), water reductions of 50% were applied at phase I (Res. I, flowering to end of cell division), phase II (Res. II, fruit growth) and at both stages (Res. I-II). Monitoring concerned fruit and shoot growth, climatic factors and water supplies. Final yields and fruits total sugar contents expressed in °Brix were measured at harvest.

Impact on fruit quality

For all DI treatments, apple diameter ranked between 60 to 66 mm, whereas for T0 it varied between 62-69 mm. Reduction of irrigation during the entire growing season resulted in better total sugar contents (Table 7).

Table 7. Total soluble solids (°Brix) of apple fruit for full and deficit irrigation regimes. (source : Nasr and Ben Mechlia, 2002)

	Full Irrigation	Deficit Irrigation		
		Res. I	Res. II	Res. I-II
1996	13.0	13.4	13.6	13.2
1997	11.8	12.5	11.9	12.8
1998	14.6	15.2	14.7	15.8
average	**13.1**	**13.7**	**13.4**	**13.9**

Impact on yield

The limited number of trees used during the 1996-99 period didn't allow for clean cut conclusions although there is an indication that water supply reduction during phase II (Res. I-II and Res. II) could decrease yield in a significant way (Nasr and Ben Mechlia, 2002). During the year 2000, the number of trees was increased to 10 for each irrigation regime (To, Res. 1, Res. 2, and Res. 3). A modified strategy with adjustments concerning the period of D.I. application was used. Results are summarized in table 8.

Table 8. Effect of D.I. applied at different developmental stages on growth and yield of apple trees (cv Golden Delicious), Mornag-Tunis (year 2000).

	Full Irrigation	Deficit Irrigation		
		Res. 1	Res. 2	Res. 3
Period of DI applicat°.	None	20/03-20/06	21/06-15/07	20/03-15/07
Rainfall (mm)	446			
ETo (mm)	1300			
Irrigation (mm)	541	401	482	342
Shoot length (cm)	20	24	21	26
Fruit diameter (cm)	73.2	72.4	70.6	69.5
Fruit weight(g/fruit)	179.9	164.9	177.8	144.3
Fruit number (frt./tree)	372.9	274.1	273.4	268.1
Yield (Kg/tree)	67.1	45.2	48.6	38.7

Source: Master Thesis of Ben Mrad M.R. (INAT 2002)

PHYSIOLOGICAL INDICATORS FOR THE ADOPTION OF D.I.

Extrapolation of results obtained at Mornag to other Mediterranean regions is possible on the basis of measurement of tree water status. To this end, predawn and midday leaf and xylem water potential were measured on peach for the two extreme treatments at different stages.

Predawn water potential showed an increasing difference between the control and Res. I-II-III treatments. During the period June-July its value varied from 0.21 to 0.27 MPa for the control while it dropped from 0.25 to 0.53 MPa for the less watered regime (Fig. 8). Midday xylem water potential, minimums were around 1.0 and 1.5 MPa respectively for the control and Res. I-II-III treatments.

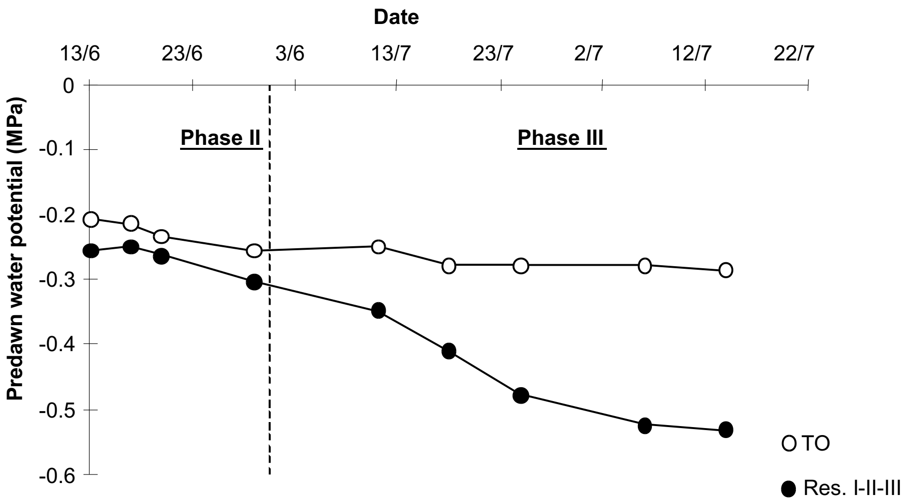

Fig. 8. Predawn water potential of peach during phase I and II for full (T0) and deficit (Res. I-II-III) irrigation regimes. (Source : Ghrab et al, 1998)

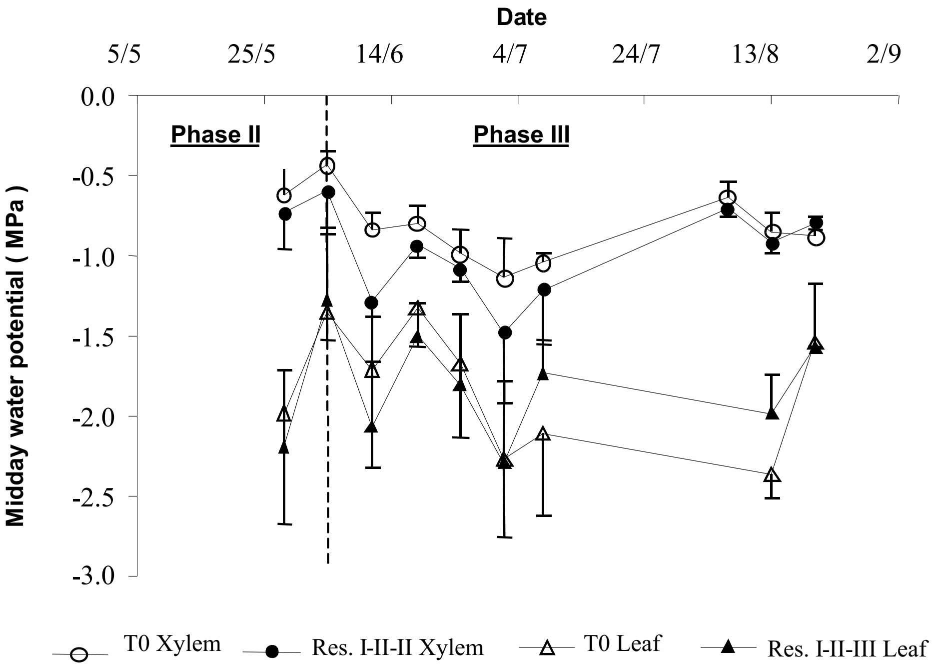

Fig. 9. Midday leaf and xylem water potential of peach tree during phase II and III for full and restricted irrigation regimes.

SALT ACCUMULATION IN THE SOIL

Measurements of soil salinity under full irrigation and deficit irrigation treatments in the apple orchard didn't show significant differences (Nasr et Ben Mechlia, 2002). Values of 3.0 and 2.9 dS/m were obtained for 12 samples taken under the drippers respectively for the control and the restricted treatment. For peaches more precise measurements with intensive sampling were carried out.

Electrical conductivity of saturated paste (ECe) measurements in the peach orchard started in august 2001 in order to evaluate the effect of the highest and lowest irrigation regimes (control T0 and Res. I-II-III) on soil salinity in the first 80 cm layer. Soil samples were taken for every 20 cm layer in 14 sampling points situated at different distances from the drippers.

Conductivity of the extract of saturated paste was determined at four dates during the growing season (09/08/2001, 23/10/2001, 12/02/2002 and 13/05/2002). A weighted average of soil salinity have been performed using the kriging interpolation method (Fig. 10 and 11).

Results show that salts were mainly concentrated near the trunk and that soil salinity distribution pattern varies in the same manner for both treatments. Under the control T0 and Res. I-II-III, the largest values of soil salinity were observed during periods of high evaporative demand in the absence of rainfall.

Soil salinity decreased during wet periods as a result of natural leaching. The experimental results obtained for 2000-2001 indicated that natural leaching is possible even during years with below normal precipitation. During the winter season, the contribution of rainfall to salt removal from the root zone could be enhanced by adding small amounts of irrigation waters.

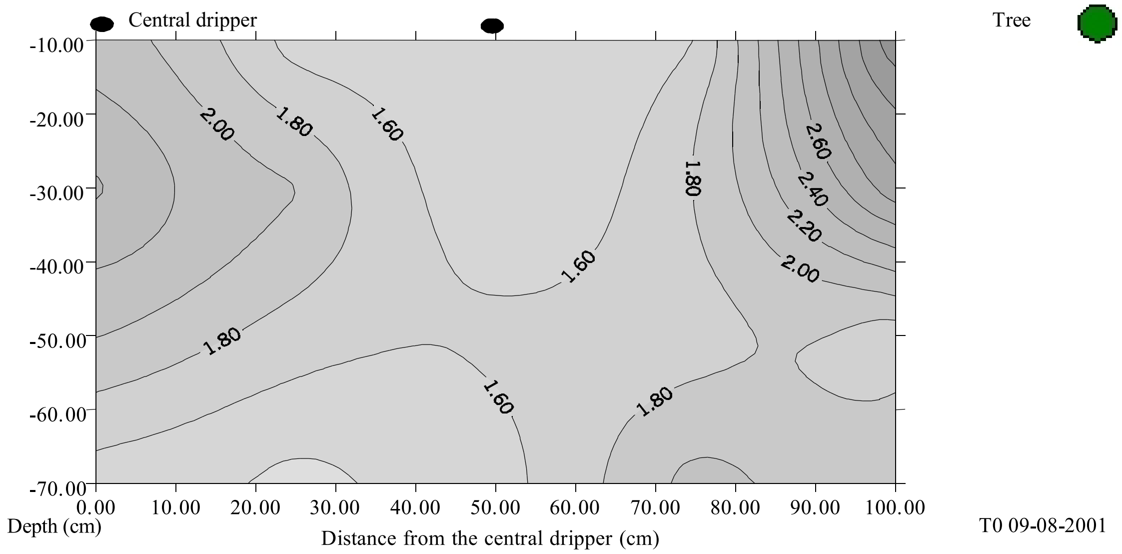

Fig. 10. Salt distribution (g/l) along the line of drippers for trees under full irrigation.

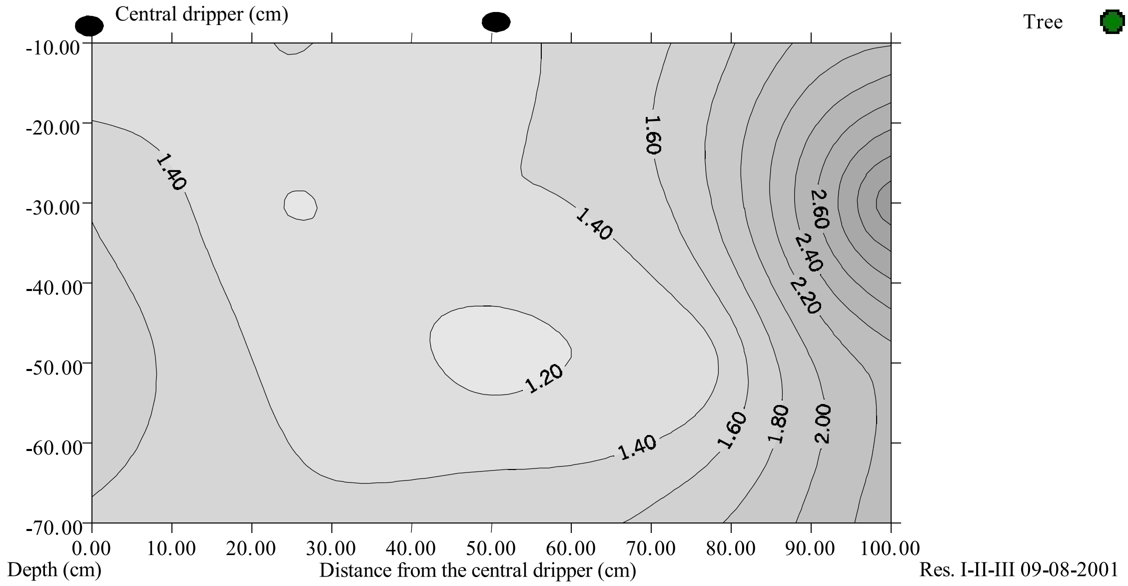

Fig. 11. Salt distribution (g/l) along the line of drippers for trees under D.I.

Apparently D.I. strategy can be applied in a way that allows substantial irrigation water savings without contributing to additional salt accumulation in the root zone.

PERSPECTIVES

Reducing the amount of total salts in addition to saving water with little impact on the yield makes D.I. a very valuable technique when no drainage systems are used, as it is the case of many arid regions.

However it is important to investigate the quantitative relationships between irrigation restrictions, trees growth, yield and quality of fruit production under conditions of relatively severe water shortages, high ETo and saline waters. The objective should be the development of guidelines for D.I. practices suitable for conditions of chronic water shortages and salt control with natural leaching.

In this line, the project team initiated a research work in Mornag which aims at the integration of deficit irrigation management, the variety and cultivation techniques.

An orchard of peach trees of 1.4 ha has been planted in march 2001 at the INAT station. Two rootstocks (GF 677 and Cadaman) and two planting densities have been used. The trees were grafted in September 2001 with two varieties having different growing cycle and thus water requirement.

The station has been equipped with an automatic weather station and a drip irrigation system using water with two qualities. This infrastructure allows fundamental research work on the relationships between main production factors in relation to the environment. The adopted experimental design and irrigation system allow the use of different irrigation amounts and/or water qualities.

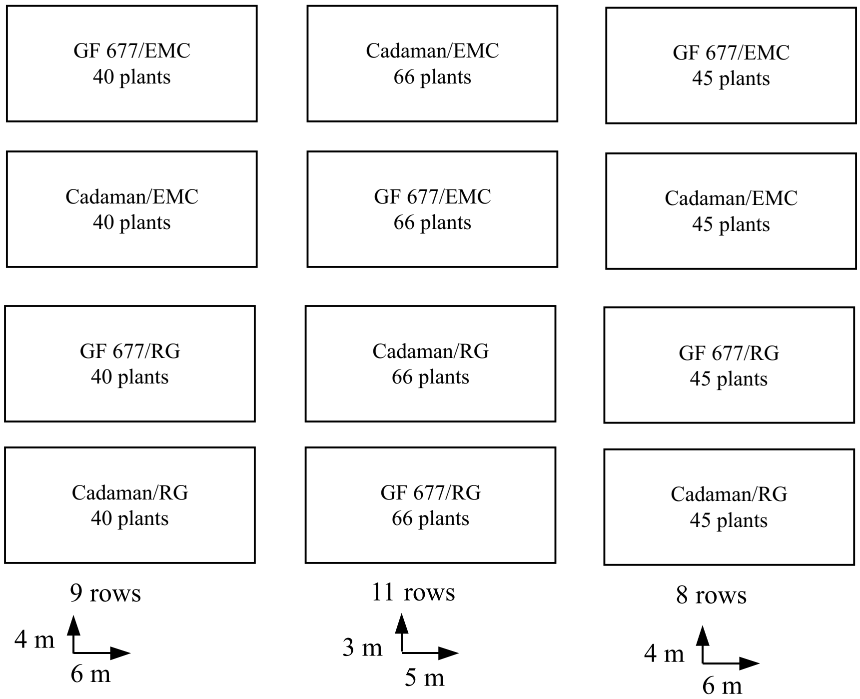

Fig. 12. Experimental layout adopted at the INAT-Mornag station to investigate D.I. in relation to the variety, the rootstock and the planting density.

CONCLUSIONS

Innovative methods and techniques that ensure the best use of water coming from natural precipitation need to be developed for semi-arid environments. Traditional options based on full irrigation with intensive cropping systems are not probably relevant choices anymore, when considering chronic water shortages. Whereas practices such as supplemental irrigation, deficit irrigation, conjunctive use of rainfall and saline ground-waters have the potential to save water and to increase choices for non-conventional water utilization in the dry areas.

Under environments characterized by alternating wet and dry seasons, addition of small amounts of water during the growing season can increase water productivity many times. This potential must be explored for a better use of saline waters for deficit irrigation particularly in the semi arid Mediterranean where natural leaching of salts out of the root zone is possible.

Application of D.I., however, requires scaling of the restriction to be applied. It needs precise knowledge on the grown species, the local environment and soil conditions. A wide range of scaling techniques of D.I. is needed to suit the many Mediterranean microclimates.

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