

Studying the effects of deficit irrigation as an on-farm strategy on carrot yield in arid environment

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Abstract: The deficit irrigation (DI) as an on-farm water management strategy was tested for 3-years to determine the water requirements and productivity, soil salinity and yield for carrot irrigated with saline water (3.6 dS/m) under actual farming conditions in southern Tunisia. The irrigation regimes were full (I100) and deficit (I80 and I60) irrigated with levels of 100, 80 and 60% of ETc when the readily available water, 35% of total available water (TAW), in the I100 treatment was depleted, and traditional farmer practice (Farmer). Regulated DI regime where 40% reduction is applied only during ripening stage (I60-ripening) was also used. Higher soil salinity is observed at harvest under I60 and Farmer treatments compared to I100. Carrot yield was highest over 3 years for the I100 scheduling technique, (29.5, 28.7 and 26.8 t/ha) although no significant differences were observed with the I60-ripening strategy. However, the I80 and I60 treatments caused significant reductions in carrot yields through a reduction in roots number and weight in comparison with I100. The farmer's method not only caused significant reductions in yield but also resulted in using 43 to 57 % more water and increased soil salinity. For all treatments, carrot yields were higher in first than the two following years. Water productivity (WP) values reflected this difference and varied between absolute extremes of 3.3 and 9.7 kg/m³. WP was the greatest in the I60 treatment and the least in the Farmer's strategy. I100 irrigation strategy provides significant advantage on yield and WP compared to farmer's method in carrot production. Therefore, for water-saving purposes, the I100 irrigation scheduling is recommended to optimize the use of saline water in carrot production and to control soil salinity. Nonetheless, under water scarcity, irrigation of carrot could be scheduled using I60-ripening and I80 deficit strategies, with some yield reductions (4-15%).

Key words: salinity, deficit irrigation, carrot, yield, water productivity

INTRODUCTION

Limited supply of good quality water is a major constraint to crop production in the Mediterranean region of Tunisia. Presently, there is an increasing pressure to use saline water to intensify agriculture in the arid part of Tunisia. Irrigation of a wide range of crops such as potatoes, lettuces, fava beans and carrots is increasing around shallow wells having a salinity more than 3 dS/m. Production systems based on crops that are not tolerant to salinity in arid regions would not be sustainable without proper management of both water and salt. Good management of irrigation water is required for farmers seeking a viable mean to maximize water use. Many studies have reported substantial increases in crop yields

as a result of suitable irrigation management, including studies in saline conditions (Jalota et al., 2006; Zhang et al., 2004; Paradiso et al., 2002; Malash et al., 2005; Nagaz et al., 2007). It has been demonstrated that optimal irrigation scheduling requires accurate estimates of crop evapotranspiration (ETc) (Doorenbos and Pruitt, 1977).

Irrigated farming in arid lands is also subject to the danger of an accumulation of salinity in the soils. Therefore, good management should take into consideration the effect of irrigation on the crop yield and at the same time on the environment, particularly the risk of soil degradation. Considerable research has been directed towards defining the effects of salts upon crop growth and development (Maas, 1990; Shannon et al., 1999). The available information is

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impressive but should be adapted to the local environment. Carrot (*Daucus carota* L.) is considered relatively susceptible to salinity (Bernstein et al., 1974) and an important short duration root vegetable grown for fresh market food. Carrot is grown in arid regions of Tunisia during autumn and winter periods which coincide with the rainy season and irrigated with well waters. Because carrot is high value crop, the best irrigation management strategy is to maximize yield by supplying the irrigation requirement of the crop. However, irrigation is applied by farmers using empirical knowledge without scheduling and application of water often exceeds crop requirements.

The impact of irrigation scheduling with saline water on carrot yield and quality has not been studied in arid regions of Tunisia. To gain information on water requirements of carrot crop, field investigations were initiated in 2007 with the objective to determine irrigation water requirements of carrot crop and to make quantitative assessments of both salt accumulation in the soil and yield response to water supply in relation to deficit irrigation strategies with saline water in order to derive an irrigation strategy that save water in irrigated carrot, reduce salt input and improve crop water productivity under the arid Mediterranean conditions of southern Tunisia.

MATERIALS AND METHODS

A Field experiment was conducted during the fall-winter carrot growing seasons over 3 years (2007-08 to 2009-10) in a private farm situated in the region of Médenine (Tunisia). The climate is typical of arid areas and the rainfall during the growing season of carrot for 3 years is reported in figure 1. Most of the rainfall occurred during September, October and January.

The soil is a sandy soil with low organic matter content. The electrical conductivity (ECe) values measured before planting are, respectively, 3.74, 3.2 and 3.7 dS/m for first, second and third year of carrot crop. The total soil available water calculated between

field capacity and wilting point for an assumed carrot root extracting depth of 0.80 m, was 100.5 mm.

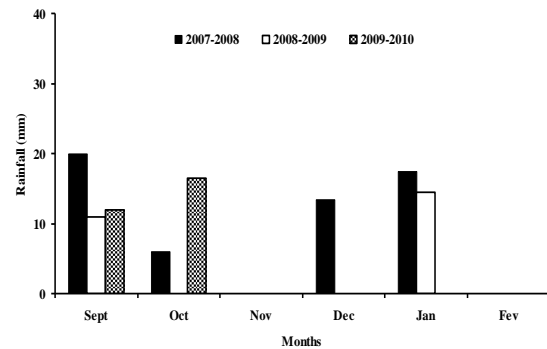


Figure 1. The rainfall received during the carrot cropping periods (2007-2010)

Carrot, native of the region, was planted every year on 15 September, in 8 x 10 m plots separated from each other in a randomized complete block design with four replicates and five irrigation treatments. The same experimental area was used for the 3 years and was divided into four blocks with five elementary plots per block. Each elementary plot consisted of fifteen rows. Carrot was surface irrigated with water from a well having an ECi of 3.6 dS/m. Measured amounts of water were delivered to the plots using a hosepipe and water meters.

Fertilizers were supplied for the cropping period in the same amounts; before planting of carrot crop, soil was spread with 16 t/ha of organic manure. Nutrient supply included N, P and K at rates of 200, 200 and 150 kg/ha, respectively, which were adopted from the local practices. The P and K fertilizers were applied as basal dose before planting. Nitrogen was divided and delivered with the irrigation water in all treatments during early vegetative growth.

Five irrigation regimes were considered: four treatments used the soil water balance (SWB) and consist in delivering total or a fraction of cumulated ETc when readily available water in the root zone is depleted and traditional farmer's method, supplying water with constant amount and frequency. For SWB methods we adopted replacement of 100% ETc (I100), considered as full

irrigation, continuous deficit irrigation regimes supplying 80% (I80) and 60% ETc (I60), and regulated DI regime where 40% reduction is applied only during ripening stage (I60-ripening). Farmer method (Farmer) consisted in giving 25 mm every 7 days from planting till harvest.

The crop evapotranspiration (ETc) was estimated for daily time step by using reference evapotranspiration (ETo) combined with carrot crop coefficient (Kc). The ETo was estimated from daily climatic data collected from the meteorological station, located at Médenine, Tunisia (data not presented) by means of the FAO-56 Penman-Monteith method (Allen et al., 1998). The carrot crop coefficient (Kc) was computed following the single crop coefficient approach.

The soil water balance (SWB) method was adopted for irrigation scheduling using the guidelines No. 56 of the FAO (Allen et al., 1998). To this end a soil water balance (SWB) model was developed to estimate the number of days to evaporate the readily available water (RAW). The model computes the soil water depletion on daily basis and projects the next irrigation event based on the target depletion (35% of total available water (TAW)). The root depth starts with a value of 0.15 m at planting and increases linearly with the increase of carrot crop coefficient up to 0.80 m.

At physiological maturity carrot yields were obtained. Forty plants per row within each plot were harvested every year by hand to determine fresh root yield, root number/m² and root weight.

Every year, soil samples were collected after harvest of carrot crop. Each elementary plot was sampled with a 4 cm auger at two points within homogeneous areas from four depths (0-0.20; 0.20-0.40; 0.40-0.60; 0.60-0.80 m in depth). Samples were air-dried and ground to pass a mesh of 2 mm size and were analyzed for ECe.

Water productivity (WP) is generally defined as marketable yield/ET, but economists and farmers are most concerned about the yield per unit of irrigation water

applied. Thus, The WP was calculated as follow: $WP \text{ (kg/m}^3\text{)} = \text{Yield (kg/ha)} / \text{irrigation water (m}^3\text{/ha)}$

Analysis of variance was performed to evaluate the statistical effect of irrigation treatments on carrot yields and components, WP and soil salinity using the STATGRAPHICS *Plus* 5.1 (www.statgraphics.com). LSD test at 5% level was used to find any significant difference between treatment means.

RESULTS AND DISCUSSION

Figure 2 illustrates the course of mean daily ETc relative to ETo for three years during the periods of carrot crop. During the first 30 days after plantation of carrot, high ETc values were observed when the wetting of the soil surface by irrigation or precipitation coincides with high evaporative demand. Most of the daily crop ET consisted of soil evaporation, controlled mainly by soil hydraulic properties and solar radiation. This period is characterized by mean values of ETc of about 3.6 mm/day. The ETc values for the carrot crop were, respectively, 3.1 and 2.2 mm/day at development and mid-season stages. The ETc value at the late stage was about 2.5 mm/day. At the late stage, where the canopy senescence began, the relatively high ETc value of carrot crop was principally attributed to the important soil evaporation induced by the frequency of irrigation or precipitation and to the relatively high evaporative demand.

Figure 3 illustrates soil water depletion, estimated by the spreadsheet program, under I100 treatment the cropping period of carrot for 3 years. The program develops a water balance and supplies information on the timing and amounts of irrigation events. This figure illustrates also the effect of an increasing root zone on the readily available water. The rate of root zone depletion at a particular moment in the season is given by the net irrigation requirement for that period. Each time the irrigation water is applied, the root zone is replenished to field capacity. Because irrigation is not applied in the

spreadsheet until the soil water depletion at the end of the previous day is greater than or equal to the readily available water, occasionally plants could be subject to a slight stress on the day prior to irrigation.

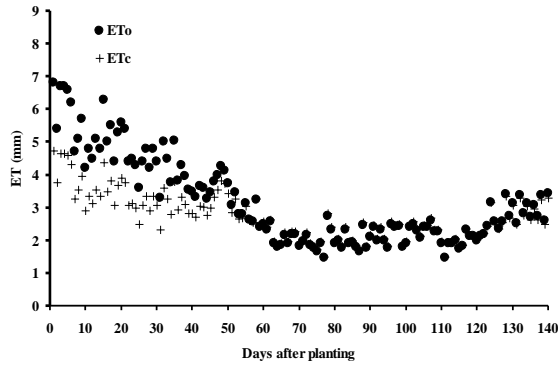


Figure 2. Mean values of daily ET₀ and ET_c during the cropping period of carrot (2007-2010).

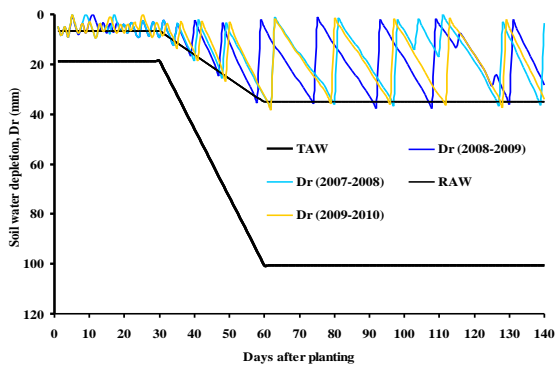


Figure 3. Daily soil water depletion under I100 treatment during the cropping season of carrot (2007-2010).

The initial and final average EC_e values (0-80 cm soil depth) under different irrigation treatments are presented in Figure 4. Initial soil salinity values determined at the time of planting were, respectively, 3.74, 3.2 and 3.7 dS/m in the first, second and third year. The results show a decrease in EC_e values measured at harvest under all irrigation treatments relative to initial soil salinity during the first year. The decrease of EC_e values were due to the leaching of soluble salts by fall and winter rains (57 mm) (Figure 1). At harvest in 2009 and 2010, the EC_e in treatments I100, I80 and I60-ripening decreased as compared to initial soil salinity. However, the EC_e values were relatively

higher than the initial EC_e for I60 and farmer's method despite leaching during the period of fall and winter rains.

The lowest EC_e values occurred during the first year, and the highest was attained during the third year. The small EC_e in first year was attributable to the leaching that had occurred during both fall and winter periods. The total rainfall during carrot growing season that year was the highest of the three years (Figure 1).

EC_e data (Figure 4) shows that there were decreases in the EC_e in full irrigation treatment (I100). I60-ripening treatment resulted also in low EC_e values. During this 3-year study, the EC_e values were not consistently different for I100 and I60-ripening treatments. However, higher soil salinity was observed in case of deficit irrigation treatments than full irrigation (I100). EC_e values were, in a decreasing order, I60 > I80 > I100. The reason for the higher soil salinity obtained for deficit irrigation treatments may be attributed to little leaching of the soil expected under deficit irrigation conditions. One consequence of reducing irrigation water use by deficit irrigation is the greater risk of increased soil salinity due to reduced leaching (Kaman et al., 2006; Geerts et al., 2008b; Schoups et al., 2005). The highest EC_e values were observed for farmer's irrigation method despite the fact that more water was applied in this treatment. Adopting fixed amounts and frequency during the whole growing season may result in applying excess water during the first growing stage and insufficient water during mid and late seasons. Under such situation, leaching of salts could not take place and salts accumulate in the root zone.

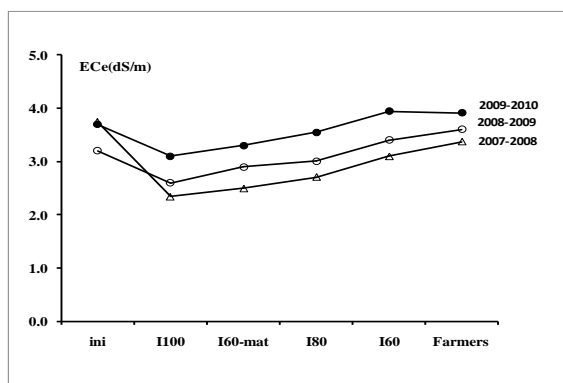


Figure 4. Soil salinity (EC_e , dS/m) under different irrigation treatments of carrot.

Low values of EC_e under the prevailing climatic conditions were due to the leaching of soluble salts with the received rainfall (Figure 1). The leaching by rain water occurred during fall and/or winter periods. Thus, under actual farming conditions, the adoption of a short productive cycle during the rainy season facilitates the use of saline waters for irrigation and reduces of soil salinization by natural leaching.

Carrot yields data are presented in figure 5 and table 1. Carrot yields over the three years of this study were significantly different between the I80 and I60 treatments (Figure 5). Lower yields were observed for the farmer's method and I60. These two last treatments did not show a statistical difference between them and were considerably lower than that obtained under I100 treatment. In 2007-2008, even though numerically higher yield was observed with the I100 than with the I60-ripening treatments, they were not statistically different. Similar results were observed for these treatments in 2008-2009 and 2009-2010. However, yields dropped significantly with the I80 and I60 treatments during the three years of the study.

The I60 and farmer's irrigation treatments produced a similar root yield, but the first saved 40% irrigation water. Also, I80 strategy produces 22 and 29% more yield than farmer's method. Roots number/m² and weight (Table 1) were influenced by the irrigation treatments. The root weight and number for producer's method was lowest

while I100 and I60-ripening treatments did not differ significantly from each other. The decreased root yields in the I60 and farmer's strategies compared to that in the I100 were associated with lower root number/m² and root weight (Table 1) as a result of water shortage during the period between fruit-set and harvest. Thus, the increase in yield under I100, I60-ripening and I80 treatments was attributed to improved growth and yield components due to water supply. These results are in agreement with those reported by Paradiso et al. (2002), Imtiyaz et al. (2000) and Hartmann et al. (1986), who obtained higher total marketable, root size and number with 100% ET_c , full irrigation. therefore, water stress should be avoided between fruit-set and harvest, the most critical period of carrot for irrigation.

Higher yields were observed in the first year because of the low soil salinity and the higher amount of rainfall (57 mm). The differences in yield under I100 and I60-ripening treatments were not significant. Due to its effect of reducing the build-up of salinity the I60-ripening treatment resulted in carrot yields comparable with those obtained in I100 strategy.

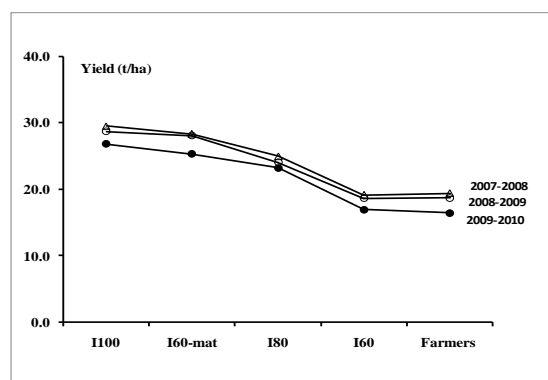


Figure 5. Yields of carrot in relation to the irrigation treatment and the year of production. LSD (5%): 2007-2008, 2.45; 2008-2009, 2.50 and 2009-2010, 2.62)

The irrigation scheduling based on SWB as in I100 treatment resulted in greater yields as compared to that with fixed frequency and amounts practiced by local farmers. I60 and farmer's strategies resulted in greater salinity

in the rooting zone than that in I100 (Figure 4). The higher soil salinity levels associated with the I60 and farmer's strategies induced substantial yield reduction of carrot. These results support the use of SWB strategy for irrigation with saline water. Numerous reports recommend the use of SWB strategy for conditions similar to those of the present study (Raes et al., 2002; Nagaz, 2007).

Table 1. Yield components of carrot under different irrigation treatments for the three years of the study (2007-10).

Regime	2007- 2008	2008- 2009	2009- 2010
Root number/m ²			
I100	71	70	67
I80	64	59	59
I60	60	55	52
I60-ripening	70	68	63
Farmer's	62	57	52
LSD (5%)	4.37	5.23	5.04
Root weight (g/root)			
I100	41.4	41.0	40.1
I80	35.4	40.7	39.3
I60	24.2	33.9	32.6
I60-ripening	36.2	41.3	40.2
Farmer's	23.7	32.8	31.6
LSD (5%)	3.63	2.77	3.11

The lower yields obtained under farmer's method can be attributed to the fact that water was applied in excess of crop needs. Farmer method of application of fixed amount of irrigation water with fixed interval from planting till harvest is often characterized by periods of over- and under-irrigation. This may result in nutrients leaching out of the root zone during early stages of growth and low water availability during periods with high water needs, therefore limiting crop growth and yield. The irrigation scheduling based on crop water requirements and soil characteristics resulted in water amounts and intervals adapted to the crop requirement change during the growing season and then allows

for applying irrigation water when needed during the growing season. According to Smith (1985), optimal scheduling is only possible when water supply and irrigation amounts can be managed by farmer. For small farmers with their own water source, as in arid regions of Tunisia where irrigation uses shallow well waters, the capacity to decide moment and water amounts of irrigation can facilitate the adoption of the suitable scheduling.

The amounts of water applied for the carrot from planting to harvest over the three-year period are given in Table 2. The irrigation water amount applied (100.5 mm) before planting of carrot each year is not included in the total. Total rainfall amounts for the three growing seasons were 57, 25.5 and 28.5 mm in 2007/2008, 2008/2009 and 2009/2010, respectively. Cumulative reference evapotranspiration over the three year study were 438, 443 and 440 mm, respectively. Less rainfall received and relatively higher evaporative demand resulted in more irrigation amounts applied (Table 2).

When the crop was irrigated at 100% ET_c (I100), irrigation amounts averaged 328 mm in 2007/2008, 330 mm in 2008/2009, and 328.5 mm in 2009/2010. Compared to the 100% ET_c treatment, 31, 15 and 29.5 mm of water were saved by irrigation treatment I60-ripening, respectively, in first, second and third year. Similarly, the water savings from the 60 and 40% of ET_c approach (I80 and I60) were 66 and 131 mm compared to the 100% ET_c treatment. The amount of irrigation water for I100 irrigation treatment was comparable to that reported by (Paradiso et al., 2002).

Water productivity based on fresh root production was expressed as the ratio of root yield at final harvest to the water supply (Figure 6). The WP values reported in this study were similar to those reported for carrot by Imtiyaz et al. (2000) and were affected by irrigation treatments. There is also a variation in WP values between years. For all irrigation treatments, yield was higher in first than the two following years.

WP values reflect this difference, it varied typically around 3.8-9.7, 3.6-9.4 and 3.4-8.8 kg/m³, respectively, in first, second and third year.

Table 2. Irrigation water supply under different irrigation treatments during the growing period of carrot for 3 years

Regime	Irrigation (mm)		
	2007-2008	2008-2009	2009-2010
I100	328	330	328.5
I80	262	264	263
I60	197	198	197
I60-ripening	297	315	299
Farmer's	509	518	471

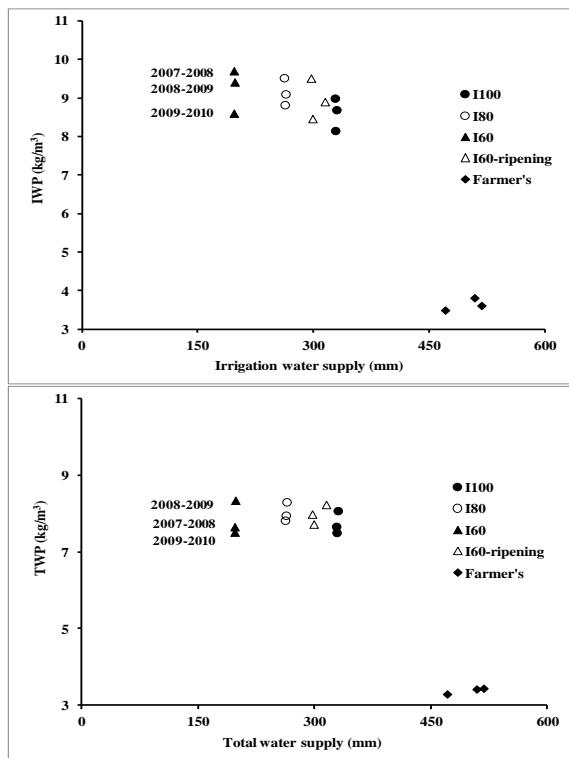


Figure 5. Irrigation and total water productivity (IWP, TWP) under different irrigation treatments during the growing period of carrot for 3 years

For all experiments, the WP with I100 regime was not significantly different from those obtained with I80 and I60-ripening treatments but statistically different from that obtained with I60 and farmer regimes. WP with farmer's method was statistically different from those obtained with I80 and

I60 regimes. These two last regimes did not show a statistical difference between them. Highest IWP averaging 9.70 kg/m³ was obtained in I60 regime, followed by I80, I60-ripening and I100 regimes with 9.52, 9.51 and 8.99 kg/m³ in 2007-2008.

Minimum IWP was obtained from the farmer's treatment as 3.81 kg/m³ for the first experimental year. In 2008-2009 and 2009-2010, similar to the previous year, maximum IWP was obtained from the I60 treatment as 9.41 and 8.60 kg/m³ and followed by I80, I60-ripening and I100 treatments with IWP of 9.10, 8.90 and 8.69 kg/m³ versus 8.82, 8.46 and 8.15 kg/m³, respectively. Minimum IWP as in the first year were obtained from the farmer's treatment with 3.61 kg/m³ for the second experimental year and 3.49 kg/m³ for the third year. The low WUE for the farmer method during the two experiments can be attributed to reduced yields but also to higher irrigation water use.

CONCLUSION

This study showed that full-irrigated carrot grown over fall-winter period used on average 328-330 mm of irrigation water for production. The need for irrigation can be reduced by adopting regulated and moderate deficit irrigation (I60-ripening and I80). Full irrigation (I100) and deficit treatments (I60-ripening and I80) decreased the soil salinity. Higher soil salinity was maintained with I60 regime and farmer's method. Carrot yields were influenced by irrigation treatments and yields of deficit irrigated treatments (I60 and I80) were significantly lower than those in I100 treatment. Treatment I60-ripening gave also good yields. Deficit irrigation treatments gave lower yields and resulted in higher soil salinity than the full irrigation (I100). The farmer's method was the least efficient and caused higher salinity in the rooting zone and gave the lowest root yields. The water productivity was significantly affected by irrigation treatments. The lowest WP values were observed for the farmer's method, while the highest values were obtained under I60 deficit irrigation

treatment. I80 seems to represent the best tradeoff between yield and water productivity.

Full irrigation (I100) and deficit irrigation (I60-ripening and I80) strategies offer significant advantage for both carrot yields and WUE and reduce the soil salinity compared to the I60 and farmer's strategies in carrot production. Results of field experiments were demonstrated to the local farmers where the yield increase and savings in irrigation water was fully understood. Thus, full irrigation I100 is suggested for irrigation of carrot crop under the arid conditions of Tunisia. However, under water scarcity, irrigation of carrot could be scheduled using I80 and I60-ripening strategies (DI).

Finally, DI can only be successful if measures are taken to avoid salinization. By using DI strategies, over-irrigation only rarely occurs. Therefore, leaching of salts from the root zone is lower under DI than under full irrigation (Ragab, 1996; Hsiao et al., 2007; Geerts et al., 2008b). The solutions can be found in practice of periodic leaching. The deficit irrigation presents also a great potential to improve water productivity and to control soil salinization by exploiting the natural leaching of salts by the rain. Under such choices natural leaching of salts could help reduce tremendously the cost of drainage.

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