

Effect of deficit drip-irrigation scheduling regimes with saline water on pepper yield, water productivity and soil salinity under arid conditions of Tunisia

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Abstract

A two-year study was carried out to assess the effect of different irrigation scheduling regimes with saline water on soil salinity, yield and water productivity of pepper under actual commercial-farming conditions in the arid region of Tunisia. Pepper was grown on a sandy soil and drip-irrigated with water having an EC_i of 3.6 dS/m. Four irrigation treatments were based on the use of soil water balance (SWB) to estimate irrigation amounts and timing while the fifth consisted of using farmers practices. SWB methods consisted in replacement of cumulated ET_c when readily available water is depleted with levels of 100% (FI), 80% (DI-80) and 60% (DI-60). FI was considered as full irrigation while DI-80 and DI-60 were considered as deficit irrigation regimes. Regulated deficit irrigation regime where 40% reduction is applied only during ripening stage (FI-MDI60) was also used. Farmer method consisted of applying the producer method corresponding to irrigation practices implemented by the local farmers. Results on pepper yield and soil salinity are consistent between the two-year experiments and showed significant difference between irrigation regimes. Higher soil salinity was maintained over the two seasons, 2008 and 2009, with DI-60 and FM treatments than FI. FI-MDI60 and DI-80 treatments also resulted in low EC_e values. Highest yields for both years were obtained under FI (22.3 and 24.4 t/ha) although we didn't find significant differences with the regulated deficit irrigation treatment (FI-DI60). However, DI-80 and DI-60 treatments caused significant reductions in pepper yields through a reduction in fruits number/m² and average fruit weight in comparison with FI treatment. The FM increased soil salinity and caused significant reductions in yield with 14 to 43%, 12 to 39% more irrigation water use than FI, FI-MDI60 and DI-80 treatments in 2008 and 2009, respectively. Yields for all irrigation treatments were higher in the second year compared to the first year. Water productivity (WP) values reflected this difference and varied between 2.31 and 5.49 kg/m³. The WP was found to vary significantly among treatments, where the highest and the lowest values were observed for DI-60 treatment and FM, respectively. FI treatment provided significant advantage on yield and water productivity, compared to FM in pepper production under experimental conditions. For water-saving purposes, the FI irrigation scheduling is recommended for drip irrigated pepper grown under field conditions and can be used by farmers to optimize the use of saline water and to control soil salinity. In case of limited water supply, adopting deficit irrigation strategies (FI-DI60 and DI-80) could be an alternative for irrigation scheduling of pepper crop under the arid Mediterranean conditions of Tunisia.

Key words: Arid, salinity, drip irrigation, irrigation scheduling, deficit irrigation, pepper, yield, water productivity

Introduction

Water is becoming increasingly scarce, creating droughts which are becoming still more serious due to changing climate conditions, especially in the southern Mediterranean region. Restricted supply of good quality water is the major limiting factor for crop production in arid regions of Tunisia. Presently, there is an increasing tendency to use saline water in this region to intensify agriculture. Irrigation of a wide range of vegetable crops such as potatoes, lettuces, carrots and peppers is expanding around shallow wells having a TDS more than 1.7 g/L. In the absence of sufficient rainfall for natural leaching, irrigated farming is exposed to accumulation of salts in the soils. Several studies have indicated that when saline water is used for irrigation, due attention should be given to minimize root zone salinity (Gideon *et al.*, 2002; Katerji *et al.*, 2004). Others have indicated the need to select appropriate irrigation systems and practices that will supply just a sufficient quantity of water to the root zone to meet the evaporative demand and minimize salt accumulation inside (Bresler *et al.*, 1982; Munns, 2002).

Efficient use of irrigation water is becoming increasingly important, and alternative water application method such as drip, may contribute to the best use of water for agriculture and improving irrigation efficiency. With the drip irrigation systems, water and nutrients can be applied directly to the crop at the root level, having positive effects on yield and water savings (Phene and Howell, 1984). Ayers *et al.* (1986) and Saggu and Kaushal (1991) showed that saline water can be efficiently used through drip irrigation even on saline soils. Moreover, it results in considerable saving in irrigation water (Yohannes and Tadesse, 1998) thus reducing the risks of salinization.

However, complementary approaches are still needed to increase WUE. In areas of recurrent water scarcity, deficit irrigation (DI) is a common practice to mitigate yield reductions (Kirda *et al.*, 1999). DI involves irrigating the entire root zone with less than full evapotranspiration (ET_c) throughout the season. Worldwide, successful attempts have been documented regarding the use of deficit irrigation method to improve irrigation WUE in various crop species (Grant *et al.*, 2004; Romero *et al.*, 2004; Cifre *et*

al., 2005; Tognetti *et al.*, 2005; Dorji *et al.*, 2005; Wakrim *et al.*, 2005). The decline in water availability for irrigation and the positive results obtained in some fruit tree crops have renewed the interest in developing information on deficit irrigation for a variety of crops (Dorji *et al.*, 2005; Fereres and Soriano, 2007).

Pepper (*Capsicum annuum* L.) for fresh market production is rather common in the arid areas of Tunisia. This crop, classified as a sensitive crop to water stress (Doorenbos and Kassam, 1986), is grown during spring-autumn period in individual plantings usually not exceeding 1-2 ha and irrigated with water from shallow wells. Such sensitivity has been documented in several reports (Antony and Singandhupe, 2004; Sezen *et al.*, 2006). For high yields, an adequate water supply and relatively moist soils are required during the growing season. A significant yield reduction was reported by limiting the irrigation amount during different growing periods such as vegetative, flowering or fruit settings (Doorenbos and Kassam, 1986). Della Costa and Gianquinto (2002) reported that continuous deficit irrigation significantly reduced total fresh weight of fruit, and the highest marketable yield was found at irrigation of 120% ET; lowest at 40% ET, and marketable yield did not differ among 60, 80 and 100% ET. Antony and Singandhupe (2004) reported that pepper yield was less at lower levels of irrigation. Dorji *et al.* (2005) compared traditional drip system irrigation to deficit irrigation (DI) for hot pepper and found that water savings with DI were about 50% of traditional drip irrigation.

Studies on the water requirements of horticultural crops in arid regions of Tunisia are limited and irrigation is mainly scheduled according to farmers' experience, despite the water scarcity. Because pepper crop is of high economic value, the irrigation management strategy seeks maximum yield by supplying all requirement of the crop. However, irrigation is typically applied on a routine basis without scheduling and supply often exceeds crop requirements. To gain information on water requirements of pepper crop, field investigations were initiated in 2008 with the objective to determine irrigation water requirements of pepper crop and to make quantitative assessments of both soil salinity 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 pepper, reduce salt input and improve crop water productivity under the arid conditions of Tunisia. With the expectation to enable growers to incorporate more appropriate irrigation scheduling and deficit irrigation methods in their usual production practices, all field work was conducted with farmer's participation.

Materials and methods

Experimental site and climate: The field experiment was carried out during the growing season of 2008 and 2009, between May and October, in a commercial farm located in the Southern East of Tunisia (33°22' N, 9°06' E; altitude 45 m) in the region of Médenine. Climate is typically Mediterranean with dry and hot summers and precipitations irregularly distributed throughout the year. Long-term mean monthly climatic data (1979-2002) and climatic data relative to the growing seasons of the period 2008 and 2009 are presented in Fig. 1. Analysis of the climatic data indicated that in 2008 and 2009 growing season temperatures were similar to the typical of long-term means. Rainfall received

during the growing seasons (May through October) was 29.5 and 44.5 mm, respectively, which was lower than the long-term mean rainfall of 54.5 mm (Fig. 1). Most of the rainfall occurred during May, September and October. The monthly reference evapotranspiration (ET_o-PM) was similar, though with slightly higher values for the long-term ET_o-PM, with a total of 938 mm as compared to 932 and 898 mm, the ET_o-PM during the period under experiment for 2008 and 2009. Maximum ET_o-PM occurred during July-August (Fig. 1).

The soil of the experimental area was sandy with 87.9% sand, 8.9% silt and 3.9% clay. Average values in the 80 cm topsoil of field capacity (0.33 bar, pF 2.5) and permanent wilting point (15 bar, pF4.2) were, respectively, 12.0 and 3.6% and organic matter concentration was 7.6 g/kg. The soil bulk density for 0-0.8 m depth was 1.49 g/cm³. The total soil available water calculated between field capacity and wilting point for an assumed pepper root extracting depth of 0.80 m, was 100.5 mm. The electrical conductivity (EC_e) values measured before transplanting of pepper seedlings were 3.1 and 2.7 dS/m for first and second year, respectively.

Crop management and experimental design: Same amounts of fertilizers were supplied during both the cropping period. Before transplanting of pepper seedlings, soil was spread with 9.5 t/ha of organic manure. Nutrient supply followed local practices consisting of giving N in the form of ammonium nitrate, P₂O₅ and K₂O at rates of 200, 150 and 150 kg/ha, respectively. The P₂O₅ and K₂O fertilizers were applied as basal dose before transplanting. Nitrogen was divided and delivered with the irrigation water in all treatments during early vegetative growth. All treatment plots received the same amount of fertilizer.

Plants of *Capsicum annuum* (cv. Baklouti), a variety widely used in the region, were gently transplanted into the blocks on 1st May, 2008 and 2nd May, 2009, respectively on the first and second year of the study. The plants were grown 70 cm apart among the five rows in each plot with 40 cm spacing between each row, in a randomized complete block design with four replicates and five irrigation treatments. The same experimental area was used for both years and was divided into four blocks with five elementary plots per block. Each elementary plot consisted of five rows. Individual plot size was 48 m² (12 x 4 m). All plots were drip irrigated with water from a well having an EC_i of 3.6 dS/m. Chemical analysis of irrigation water is given in Table 1. Each dripper had a 4 L/h flow rate. Water for each block passed through a water meter, gate valve, before passing through laterals placed in every pepper row. A control mini-valve in the lateral permitted use or non-use of the dripper line.

The experiments consisted of five distinct irrigation treatments: The FI treatment considered as full irrigation consists of giving 100% ET_c when readily available water in the root zone is depleted. Two additional treatments were irrigated at the same frequency as treatment FI but irrigation amount covered 60 and 80% of cumulated ET_c (DI-60 and DI-80). These treatments were identified as continuous deficit irrigation treatments. In the fourth treatment (FI-MDI60), considered as regulated deficit irrigation regime, water was applied as FI treatment during the transplanting-mid-season period and restricted to 60% of ET_c afterwards, until harvest. A fifth irrigation treatment consisted of

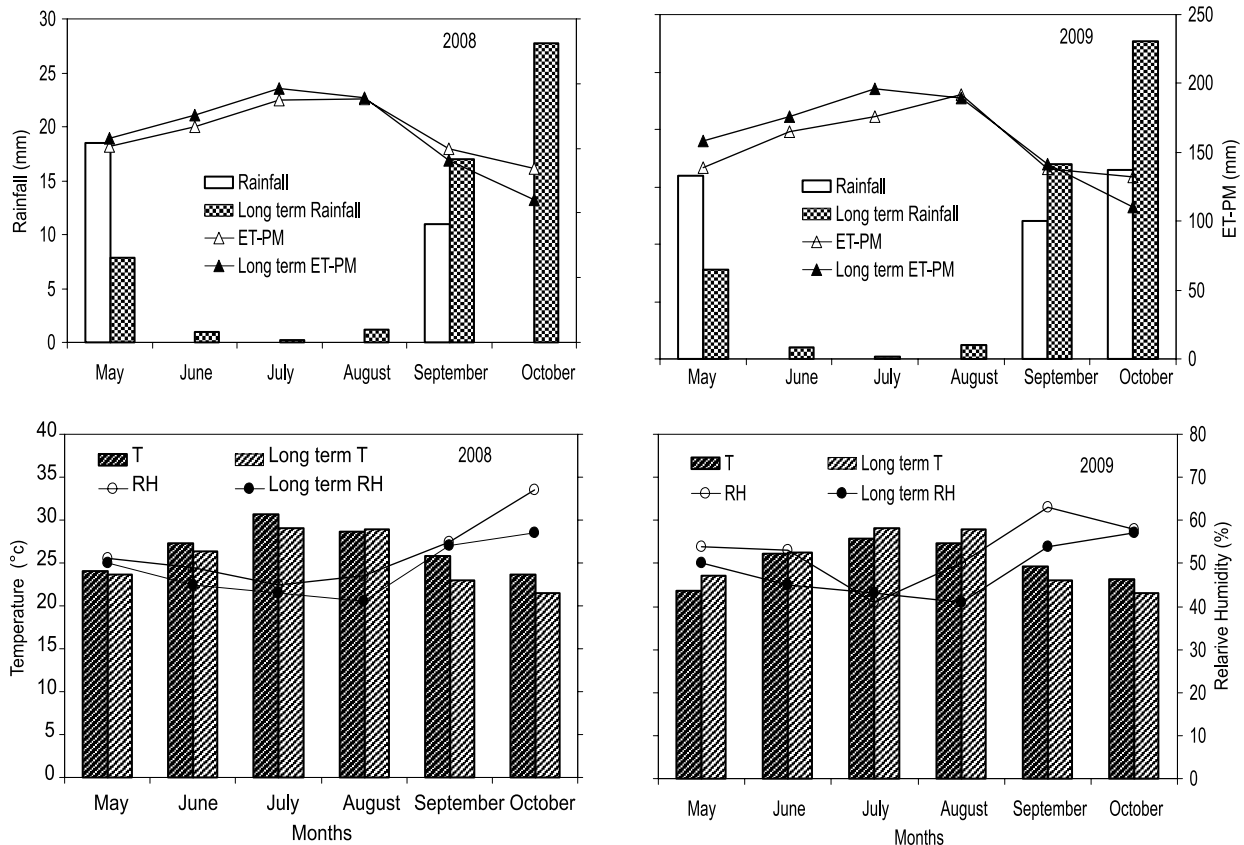


Fig. 1. Long-term mean monthly and growing season climatic data of the experimental area.

applying the farmer's method (FM) corresponding to traditional irrigation practices adopted by local farmers where fixed amount of water (30 mm) was supplied to the crop every 7 days from transplanting till harvest.

The crop evapotranspiration (ET_c) was estimated for daily time step by using reference evapotranspiration (ET_o) combined with a pepper crop coefficient (K_c) using the dual crop coefficient approach. ET_o was estimated using daily climatic data collected from the meteorological station, located at Médenine, Tunisia and the FAO-56 Penman-Monteith method (ET_o-PM) (Allen *et al.*, 1998). The Penman-Monteith method considers hypothetical grass reference crop with a crop height of 0.12 m, a fixed surface resistance of 70 s.m⁻¹ and an albedo of 0.23.

For irrigation scheduling, the method used was the water balance developed according to the methodology formulated by Allen *et al.* (1998) and implemented in an Excel spreadsheet program. The program estimates the day when the target soil water depletion (readily available water, RAW) for the treatment FI would be reached and the amount of irrigation water needed to replenish the soil profile to field capacity. The program calculates, on daily basis, the soil water depletion using the soil water balance and estimates the next irrigation date considering a depletion limit of 40% of total available water in the root zone (TAW). Soil depth of the effective root zone is automatically increased linearly with pepper crop coefficient from a minimum of 0.20 m at transplanting to a maximum of 0.80 m.

Table 1. Chemical composition of irrigation waters (meq/L)

ECi (dS/m)	Ca ²⁺ +Mg ²⁺	Na ⁺	K ⁺	Cl ⁻	SO ₄ ²⁻	CO ₃ ²⁻ +HCO ₃ ⁻	SARiw
3.6	25.60	9.45	0.95	8.50	23.00	4.50	2.64

Measurements and water-use efficiency: Sections of all plots were harvested to determine fresh fruit yield, fruit number and weight each year. In both years, the area of land harvested was 30 m² per plot depending on the physiological maturity of plants. Occurrence of the harvesting time was recorded as number of days after transplanting (DAT) accordingly. The first harvest was made on DAT 107, the second harvest was on DAT 133 and final picking was made on DAT 170 in 2008; and the corresponding harvests for the second year (2009) were on DAT 112, DAT 136 and DAT 170, respectively.

The total fruit from each treatment was weighted to determine fresh fruit yield (t/ha). Fruit number was determined by dividing total number of fruits by area of land harvested for each treatment (fruit number/ha). Fresh fruit sub-samples from each treatment were weighted to determine average fruit weight (g/fruit).

Water productivity (WP) is defined as the pepper fresh fruit yield obtained per unit of irrigation water applied. The WP was calculated as follows: WP (kg/m³) = Yield (kg/ha) / total irrigation water applied (m³/ha) from transplanting to harvest; an irrigation of 100.5 mm applied before transplanting was not included in the total.

Soil samples were collected after harvest and analyzed for EC_e. The soil was sampled at every 20 cm to a depth of 80 cm, at four sites perpendicular to the drip line at distances of 0, 10, 20 and 30 cm from the line, and at three sites between the emitters (0, 10 and 20 cm from the emitter). Conceptually, these should be areas representing the range of salt accumulations (Bresler, 1975; Singh *et al.*, 1977).

Statistical analysis: Experiments were designed as randomized complete blocks, with each replicate representing a separate block.

Treatment effects on pepper yields and components, WP and soil salinity were analyzed using analysis of variance (ANOVA) procedure of STATGRAPHICS *Plus* 5.1 (www.statgraphics.com). Least significant difference (LSD) test at $P \leq 0.05$ was used to find any significant difference between treatment means.

Results and discussion

Evapotranspiration estimates and soil water balance: Fig. 2 illustrates the course of daily E_{Tc} relative to E_{To} for both years during the growing periods of pepper crop. During the first 35 days after transplantation, high E_{To} values resulted in high E_{Tc} despite the low crop cover. Frequent wetting of the soil surface by irrigation or precipitation increased soil evaporation, controlled mainly by soil hydraulic properties and solar radiation. This period is characterized by mean values of E_{Tc} of about 1.7 and 1.2 mm/day, respectively, for the first and second year. As the crop canopy grew, E_{Tc} increased and reached its highest mean value at mid-season stage (5.4 and 5.5 mm/day). The mean E_{Tc} values at the late stage were about 5.6 and 5.8 mm/day for 2008 and 2009 respectively. The high E_{Tc} values during the late stage were mainly attributed to the soil evaporation induced by the frequency of irrigation or precipitation and to the relatively high evaporative demand.

The spreadsheet program uses water balance equation and gives estimations of the date and amounts of irrigation based on cumulative soil water depletion. Fig. 3 illustrates soil water depletion, estimated by the program, under FI treatment during the cropping period of pepper for two years. This figure also illustrates the effect of an increasing root zone on the readily available water. The rate of root zone depletion at a particular time 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 program 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.

Soil salinity: The initial and final average E_{Ce} values in the 0-80 cm soil layer under different irrigation treatments are presented in Fig. 4. Initial soil salinity values determined at transplanting were, respectively, 3.1 and 2.7 dS/m in the first and second year. The results show that during the two years, an increase in E_{Ce} values measured in the root zone (0-80 cm) at harvest was observed

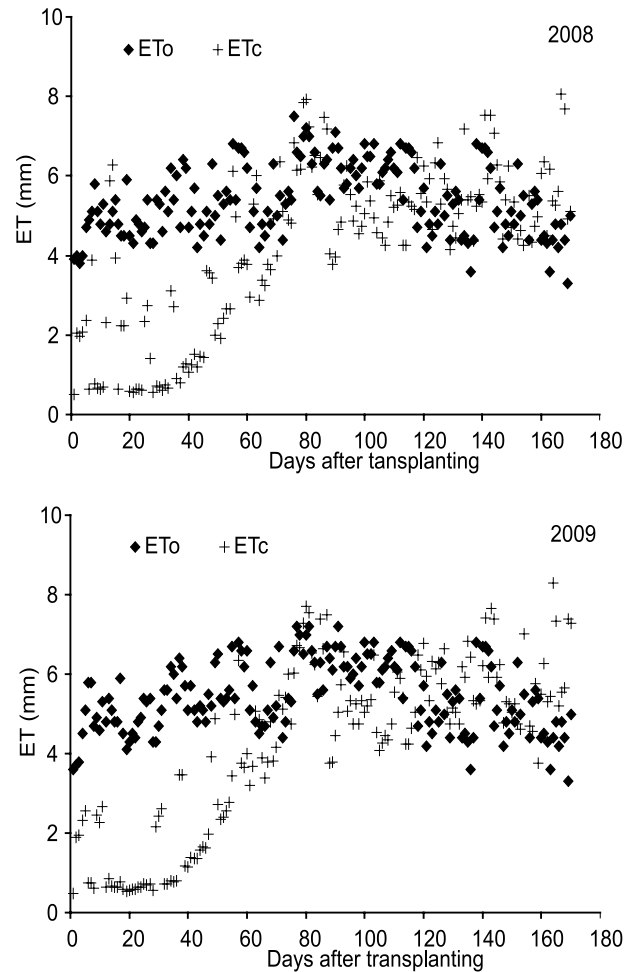


Fig. 2. Estimated daily E_{Tc} for pepper crop during the cropping seasons.

under all irrigation treatments compared to initial soil salinity. The E_{Ce} for the treatments FI and FI-MDI60 increased from 3.1 and 2.7 at transplanting in May to approximately 4.1 and 3.7 dS/m at harvest, respectively, for 2008 and 2009. However, the E_{Ce} was higher at harvest than the initial E_{Ce} for DI-80, DI-60 and FM treatments as compared to FI and FI-MDI60 treatments. The higher soil salinity obtained for all irrigation treatments at harvest during the two years may be attributed to the high evaporative demand during the cropping period and since rainfall received during that period was 29.5 and 44.5 mm, respectively and water supply was provided mostly through irrigation, little leaching of the soil was expected. The highest E_{Ce} values occurred during

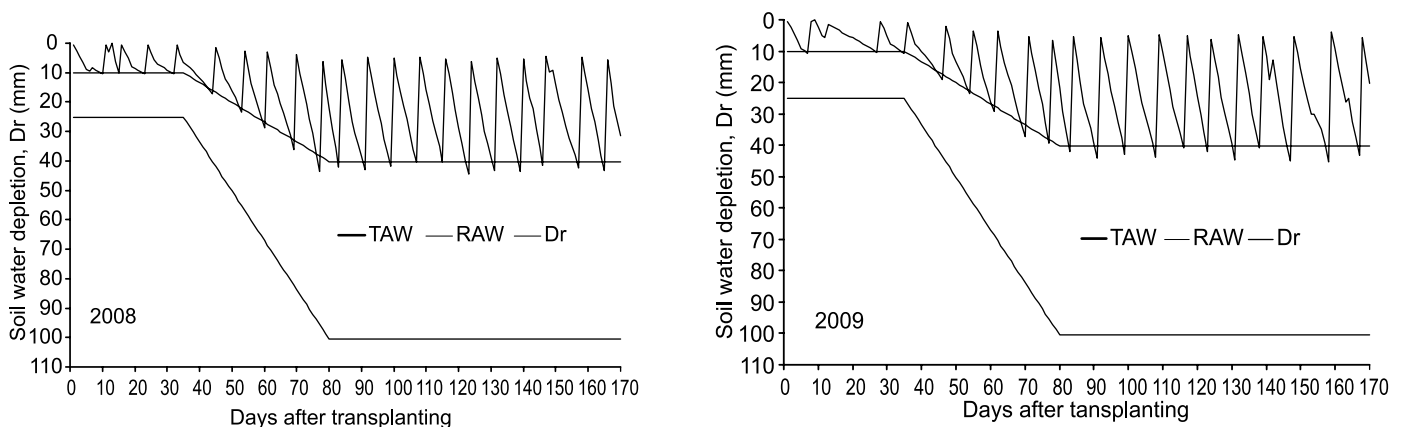


Fig. 3. Estimated daily soil water depletion under FI irrigation treatment during the cropping seasons of pepper (2008-2009)

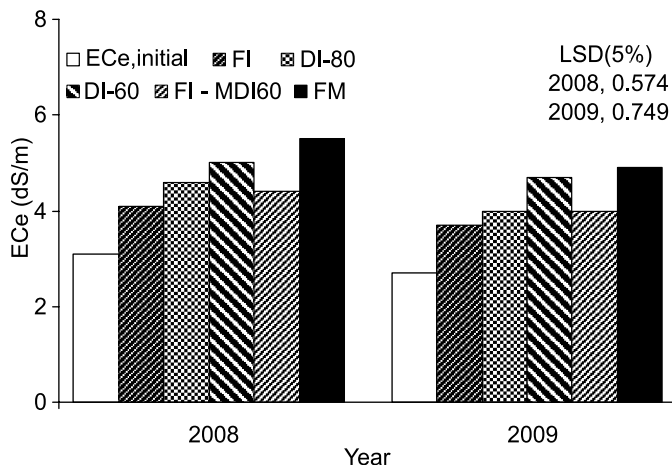


Fig. 4. Soil salinity (ECe, dS/m) under different irrigation treatments.

the first year, and the lowest was attained during the second year. The low values of ECe in second year were due to the relatively low initial soil salinity and the leaching of soluble salts with the relatively higher amount of rainfall received (Fig. 1). The total rainfall during pepper growing season of second year was higher than the first year (Fig. 1).

Data shows that ECe decreased in full irrigation treatment (FI). FI-MDI60 and DI-80 irrigation treatments resulted in low ECe values. The ECe values were not significantly different between FI, DI-80 and FI-MDI60 treatments. However, higher soil salinity was observed in case of DI-60 deficit irrigation treatment and FM than FI treatment. The reason for the higher soil salinity obtained for deficit irrigation treatment (DI-60) is attributed to absence of substantial leaching under deficit irrigation conditions. Geerts *et al.* (2008), Kaman *et al.* (2006) and Schoups *et al.* (2005) reported that one consequence of reducing irrigation water by deficit irrigation is the greater risk of increased soil salinity due to reduced leaching. With the FM treatment, irrigation is typically applied without scheduling and application of irrigation water frequently exceeds crop requirements. Over irrigation helps to leach salt below the root zone during the first few periods of cultivation, but it carries the danger of a rapid soil salinization because of increased salt input. Thus, the higher ECe values obtained under FM treatment may be attributed to the fact that more irrigation water under conditions of high evaporative demand would result in higher direct evaporation rates leading to an increase in salt accumulation in the soil.

Crop yield: Pepper yields data are presented in Fig. 5. The data shows that pepper yield over the two years of the study were affected by irrigation treatments. Fresh fruit yields ranged from 17.97 to 24.40 t/ha in both years. Yields were highest in the second year because of the low soil salinity and the relatively higher amount of rainfall received (44.5 mm). The highest pepper fresh fruit yield was obtained under the FI irrigation treatment. FI-MDI60 where water restriction is applied only during the ripening stage also provided higher fruit yield and was not significantly different with FI, similar to what was found by González-Dugo *et al.* (2007). Yield obtained under FM treatment was 21 and 19% lower, respectively, in 2008 and 2009 and significantly different ($P < 0.05$) than that obtained with FI treatment. Although 6.2 and 7.1% yield reduction was evident under DI-80 in 2008 and 2009, it was not statistically different than yield of the FI treatment,

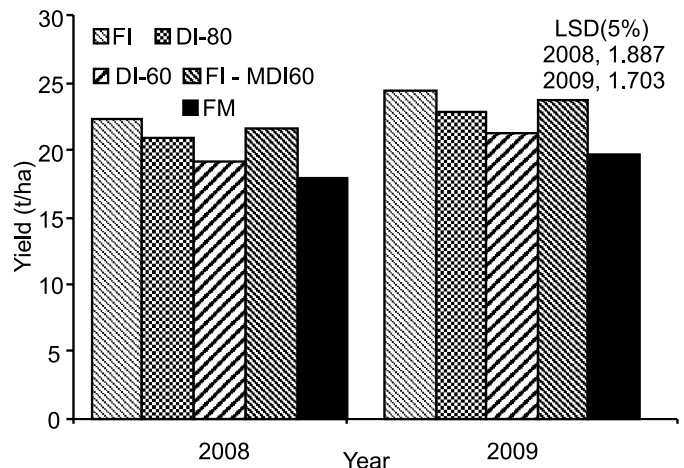


Fig. 5. Fresh fruit yield under different irrigation treatments.

respectively. However, a significant reduction in yields occurred with the DI-60 as compared to FI treatment (Fig. 5). Della Costa and Gianquinto (2002) and Katerji *et al.* (1993) reported that continuous water stress significantly reduced fresh fruit yield. Statistically significant differences ($P < 0.05$) were found between the DI-80 and DI-60 treatments for both years. Among the DI-60 and FM, fresh fruit yield of FM was the lowest but the difference was not significant ($P < 0.05$). The difference between the FM and other treatments (DI-80 and FI-MDI60) were significant ($P < 0.05$).

The influence of irrigation treatment on the fruit number and weight was highest for treatment FI and was followed by FI-MDI60 and DI-80 treatments in both years (Table 2). Differences between FI, FI-MDI60 and DI-80 treatments were not significantly different ($P < 0.05$). Statistically significant differences ($P < 0.05$) were found between FI treatment and DI-60 and FM treatments for each year. There was no significant difference between DI-60 and FM treatment and DI-80 and DI-60 treatment in fruit weight and number during both years. Fernandez *et al.* (2005) and Dorji *et al.* (2005) reported that water deficit affect fruit number and weight.

Pepper is among the most susceptible horticultural plants to drought stress (Alvino *et al.*, 1994; Dimitrov and Ovtcharow, 1995). The water deficit during the period between flowering and fruit development reduced final fruit production (Jaimez *et al.*, 2000; Fernandez *et al.*, 2005 and Dorji *et al.*, 2005). Note that the deficit irrigation treatment (DI-60) and producer method (FM) resulted in higher salinity in the rooting zone than the DI-80, FI and FI-MDI60 treatments (Fig. 4). The higher salinity associated with deficit irrigation DI-60 and FM treatments were sufficient to cause reduction in pepper yield through a reduction in fruits number and weight (Table 2).

The yield is greatly dependant on timing, amount and frequency of irrigation applied. Lower yields obtained under FM treatment may be attributed to the fact that the farmer applies water to the crop regardless of the effective plant needs. This seems to relate irrigation occurrences to days after transplanting rather than to progress of crop growth stages. The corresponding irrigation applications are often characterized by periods of over- and under-irrigation. Raes *et al.* (2002) reported that excess watering in saline conditions may cause loss of valuable nutrients out of the root zone and soil salinization, especially during crop

sensitive periods, which results in limited growth and reduction in crop yield.

Irrigation scheduling based on crop water requirements and soil characteristics allows for applying irrigation water when needed during the growing season. However, its application is only possible when water supply and irrigation amounts can be managed independently by farmers (Smith, 1985). In areas where pepper is irrigated with well waters, accurate scheduling is manageable. This is precisely the case of our area; therefore there is a high chance to optimize water supply to crops.

Water supply and productivity: Amounts of irrigation water and total water supply for each irrigation treatment during the two years are presented in Table 3. Irrigation water applied before transplanting of pepper (100.5 mm) each year is not included in the total. For all treatments, total water supply ranged from about 420 to 780 mm. With the producer method (FM) more irrigation water was used than the FI and deficit irrigation treatments. Surplus was 94 to 356 mm in 2008 and 77 to 339 mm, in 2009. Rainfall was 29.5 mm in the first year and 44.5 mm in the second year.

For FI treatment, irrigation amounts of the both years were quite similar with 656 mm in 2008 and 654 mm in 2009. Using the FI-MDI60 strategy, 77 and 53 mm of water was saved in the first and second year, respectively. Similarly, the water savings achieved with DI-80 and DI-60 treatments were 131 and 262 mm compared to the FI treatment.

TWP and IWP values reported in this study were similar to those reported for pepper by Gençoğlan *et al.* (2006) and Dağdelen *et al.* (2004) and were significantly influenced by the irrigation treatments (Table 3). There is also a variation in WP values between years. For all irrigation treatments, yield was higher in the second year compared to the first year. Values of water productivity of irrigation (IWP) reflect this difference; they varied typically around 2.4-4.84 and 2.7-5.49 kg/m³ in the first and second year, respectively. TWP values ranged from 2.31 kg/m³ in FM to 4.93 kg/m³ in the DI-60. IWP values varied from a minimum of 2.4 kg/m³ in FM to a maximum of 5.49 in kg/m³ in the DI-60 treatment in the experimental years.

For both the years, WP values of FM and full irrigation (FI) treatments were considerably lower than those of the deficit treatments. The WP with FI treatment was not significantly different from those obtained with FI-MDI60 treatment but statistically different from those obtained with DI-80, DI-60 and FM treatments. These three last treatments show a statistical difference between them. The low irrigation water productivity for the producer method (FM) during the two experiments can

Table 2. Yield components under different irrigation treatments

Treatment	2008		2009	
	Fruits number (1000/ha)	Average fruit weight (g/fruit)	Fruits number (1000/ha)	Average fruit weight (g/fruit)
FI	1046	21.297	1061	23.011
DI-80	1006	20.278	1012	22.201
DI-60	991	19.219	1004	21.102
FI-MDI60	1022	21.039	1026	23.005
FM	983	18.290	998	19.997
LSD (5%)	54	1.114	50	1.107

be attributed to reduced yields and also to higher irrigation water use.

In this study, our results demonstrate that the effects of irrigation treatments are significantly important in order to obtain higher yields of field grown pepper under the Mediterranean climatic conditions in Tunisia. Irrigation treatments had significant effect on soil salinity, pepper yield and its components parameters. Full irrigation (FI) and deficit irrigation treatments (FI-MDI60 and DI-80) decreased the soil salinity. Higher soil salinity developed in the root zone with DI-60 deficit irrigation and farmer method (FM). Fresh fruit yields of deficit irrigated treatments (DI-60 and DI-80) were significantly lower than those in full irrigation treatment (FI) which had the lowest soil salinity. Treatment FI-MDI60 also gave good yields. Moreover, FI and FI-MDI60 treatments resulted in better yield components parameters such as the number of fruits and fruit weight as compared to other treatments. Note that the deficit irrigation treatments gave lower yields and resulted in higher salinity in the rooting zone than the full irrigation (FI). The “fixed amount approach” used by the farmer was the least efficient and caused higher salinity in the rooting zone. This method gave the lowest fresh fruit yields with 14 to 43%, 12 to 39% more irrigation water applied than FI, FI-MDI60 and DI-80 treatments, respectively, in 2008 and 2009. The data show that factors such as fruit number and weight are significant components of pepper yield. The higher salinity associated with the farmer’s method and deficit irrigation treatments caused reduction in fresh fruit yield and yield components.

The water productivity for fresh fruit yield was significantly affected by irrigation treatments. The lowest values occurred under the FM treatment, while the highest values were obtained under deficit irrigation treatment DI-60. High efficiencies observed for the most severe restricted regime (DI-60) is therefore counterbalanced by reduced yield and quality. The relatively high yields and water productivity values obtained under DI-80 and FI-MDI60 treatments indicate the high potential of the pepper crop to valorize irrigation waters of poor quality under mild water deficit conditions. FI-MDI60 and DI-80 saved water by 8-20%, reduced soil salinization and improved irrigation water

Table 3. Water supply (mm) and productivity (WP, kg/m³) for different irrigation treatments in both years

Treatment	Irrigation* (mm)	Rainfall (mm)	I+R (mm)	IWP (kg/m ³)	TWP (kg/m ³)
2008					
FI	656	29.5	685.5	3.40	3.25
DI-80	525	29.5	554.5	3.89	3.68
DI-60	394	29.5	423.5	4.84	4.50
FI-MDI60	579	29.5	608.5	3.71	3.53
FM	750	29.5	779.5	2.40	2.31
LSD (5%)	-	-	-	0.36	0.34
2009					
FI	654	44.5	698.5	3.73	3.49
DI-80	523	44.5	567.5	4.31	3.97
DI-60	392	44.5	436.5	5.49	4.93
FI-MDI60	601	44.5	645.5	3.93	3.66
FM	731	44.5	775.5	2.70	2.55
LSD (5%)	-	-	-	0.34	0.28

* an irrigation of 100.5 mm supplied just before transplanting is not included in these totals

productivity. Although DI-80 and FI-MDI60 treatments reduced fruit number and weight, fresh fruit yield was maintained, when compared to well-irrigated treatment FI and had higher fresh fruit yield than the farmer treatment (FM).

In conclusion, FI treatment is recommended for drip irrigated pepper grown under field conditions and can be used by farmers to schedule irrigation of pepper in order to obtain higher yield in the Mediterranean region of Tunisia. The results of this study suggest that the DI-80 and FI-MDI60 practices can be viable and advantageous option next to FI to reduce soil salinization and prevent crop yield reduction when and if there is water shortage. Deficit irrigation (DI) can only be successful if measures are taken to avoid salinization since leaching of salts from the root zone is lower under DI than under full irrigation (FI). The deficit irrigation presents a potential to improve the water productivity and the control of soil salinization when it can benefit from the leaching capacity of rains. Future investigations should focus on this issue and evaluate the efficiency of the small amounts of rain that occur in spring-fall for natural leaching.

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