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# Effects 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 in order to assess the effects 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 ECi of 3.6 dS/m. Irrigation treatments consisted in water replacements of accumulated ETc at levels of 100% (FI, full irrigation), 80% (DI-80), 60% (DI-60), when the readily available water in the control treatment (FI) is depleted, deficit irrigation during ripening stage (FI-MDI60) and farmer method corresponding to irrigation practices implemented by the local farmers (FM). Results on pepper yield and soil salinity are globally consistent between the two-year experiments and shows 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 resulted also in low ECe 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, the 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, respectively, in 2008 and 2009. 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/m$^3$. 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 provides 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: salinity, drip 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. Nowadays, there is an increasing tendency to use more saline irrigation water in this region, where supplemental water is needed to intensify agriculture. Irrigation of a wide range of vegetable crops such as potatoes, lettuces, onions, carrots and peppers is mainly expanding around shallow wells having a TDS ranging from 1.7 to 5 g/l and more. In the absence of sufficient rainfall events used elsewhere for natural leaching, irrigated farming in arid lands 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 (Fisher, 1980; Oster, 1994; Shalhevet, 1994; Shani and Dudley, 2001; Gideon *et al.*, 2002; Katerji *et al.*, 2003, 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 water by irrigation is becoming increasingly important, and alternative water application method such as drip, may contribute substantially to the best use of water for agriculture and improving irrigation efficiency. In areas with dry and hot climates, drip irrigation has improved WUE mainly by reducing runoff and evapotranspiration losses (Stanghellini *et al.* 2003; Jones 2004; Kirnak and Demirtas 2006). 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 and increasing the irrigation performance (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.

The trend in recent years has been towards conversion of surface to drip irrigation because cost of installation has relatively decreased with the easy access to subsidized drip irrigation equipment made possible recently. However, complementary approaches are still needed to increase WUE in irrigated agriculture. In areas of recurrent water scarcity and long drought spells, deficit irrigation (DI) is a common practice, traditional recommended, mitigating yield reductions (Kirda *et al.*, 1999). DI involves irrigating the entire root zone with less than full evapotranspiration (ETc) throughout the season. It can lead to increased net income where water supplies are limited (English and Raja, 1996). Worldwide, successful attempts have been documented regarding the use of deficit irrigation method to improve irrigation water use efficiency (IWUE) in various crop species (Arzani *et al.*, 2000; Hutton, 2000; Kang *et al.*, 2002; Grant *et al.*, 2004; Romero *et al.*, 2004; van Hooijdonk *et al.*, 2004; Cifre *et al.*, 2005; Tognetti *et al.*, 2005; Dorji *et al.*, 2005; Kirda *et al.*, 2004; 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 (FAO Report, 2002; 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, a region where water supplies for irrigation are dwindling. This crop, classified as a sensitive plant 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 that studied the yield reductions effected by water stress (Smittle *et al.*, 1994; Delfine *et al.*, 2001; Antony and Singandhupe, 2004; Sezen *et al.*, 2006). For high yields, an adequate water supply and relatively moist soils are required during the entire growing season. A significant yield reduction was reported by limiting the amount of water supplied 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) resulted that total pepper yield was less at lower levels of irrigation. Çevik *et al.* (1996) concluded that 14% of irrigation water would be saved with a 3% reduction in pepper yield under Harran Plain conditions. Dorji *et al.* (2005) compared traditional drip system irrigation to deficit irrigation (DI) for hot pepper irrigation 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 high economic value, the irrigation management strategy seeks maximum yield by supplying all requirement of the crop. However, under local practices, irrigation is typically applied on a routine basis without scheduling and supply often exceeds crop requirements, resulting in high water losses and low irrigation efficiencies, and thus creating salinity problems. Little is known about the effect of irrigation management on pepper produced for fresh market and whether it is feasible to develop deficit irrigation strategies in pepper production. Therefore, the effects of irrigation scheduling and deficit irrigation with saline water on pepper yield and water use efficiency were assessed in farmer's field. The present investigation, started in 2008 had to determine irrigation water requirements of pepper crop and to make quantitative assessments of both salt accumulation in the soil and yield response to full and deficit irrigation scheduling strategies with saline water. The objective is to identify best irrigation strategy that allow water saving in drip-irrigated pepper with reduced effect on soil salinity and crop productivity under the arid Mediterranean 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 the months of 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 Figure 1. Analysis of the climatic data indicated that the 2008 and 2009 growing season temperatures were similar to the typical of long-term means. Rainfalls received during the growing seasons (May through October) were 29.5 and 44.5 mm, respectively, which were lower than the long-term mean rainfall of 54.5 mm (Figure 1). Most of the rainfall occurred during May, September and October. The monthly reference evapotranspiration (ETo-PM) was similar, though with slightly higher values for the long-term ETo-PM, with a total of 938 mm as compared to 932 and 898 mm, the ETo-PM during the period under experiment for 2008 and 2009. Maximum ETo-PM occurred during July-August (Figure 1).

The soil of the experimental area is sandy soil 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) are, respectively, 12.0 and 3.6% and organic matter concentration is 7.6 g/kg. The soil bulk density for 0-0.8 m depth is 1.49 g/cm$^3$. 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 (ECe) values measured before transplanting of pepper seedlings are, respectively, 3.1 and 2.7 dS/m for first and second year.

### *Crop management and experimental design*

Fertilizers were supplied for the cropping period in the same amounts; 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, $P_2O_5$ and $K_2O$ at rates of 200, 150 and 150 kg/ha respectively. The $P_2O_5$ and $K_2O$ 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 treatments plots received the same amount of fertilizer.

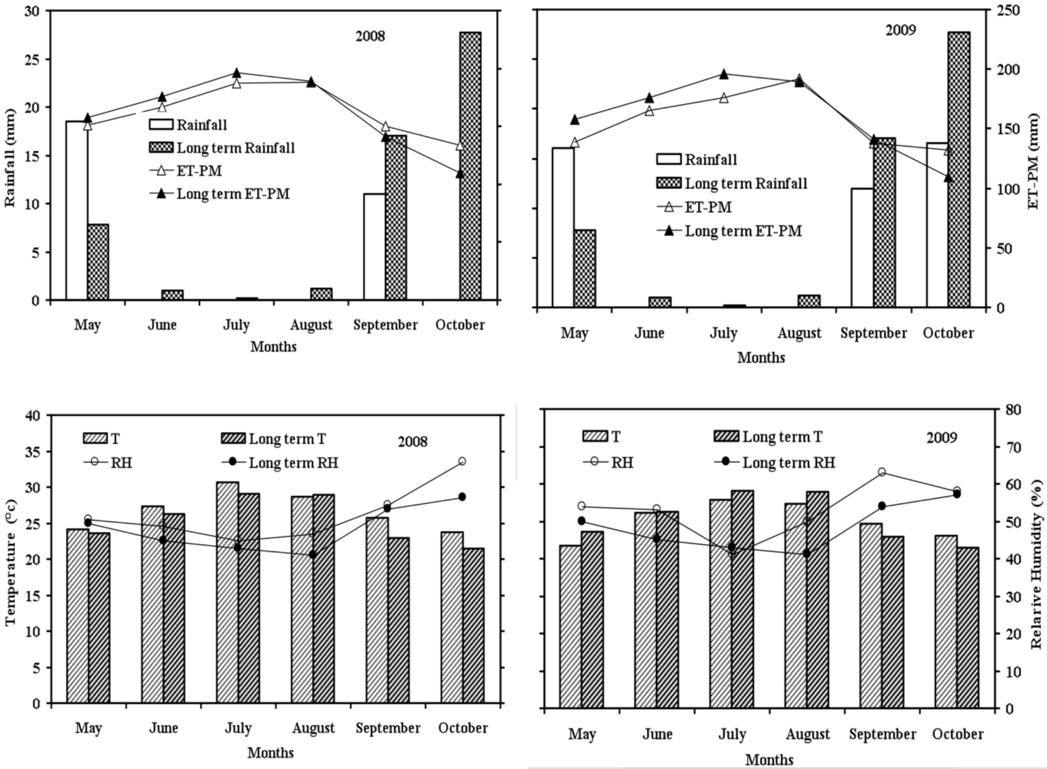


*Figure 1 - Monthly climatic data of the growing season for the period (1979-2002) and for the two years of field experiment.*

Plants of Capsicum annuum (cv. Baklouti), a variety widely used in the region, were gently transplanted into the blocks on 1 May 2008 and 2 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 in 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 $m^2$ (12 m x 4 m). All plots were drip irrigated with water from a well having an ECi of 3.6 dS/m and chemical analysis 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 permits use or non-use of the dripper line.

*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 |

The experiments consisted of five distinct irrigation treatments: the FI treatment considered as full irrigation was irrigated when readily available water in the root zone has been depleted and plants in that treatment received 100% of accumulated crop evapotranspiration. Two additional treatments were irrigated at the same frequency as treatment FI but irrigation amount covered 60% and 80% of cumulated ETc (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 ETc afterwards, until harvest. A fifth irrigation treatment consisted of applying the farmer's method (FM) corresponding to traditional irrigation practices adopted by local farmers where fixed amount of water (30 mm) are supplied to the crop every 7 days from transplanting till harvest.

The crop evapotranspiration (ETc) was estimated for daily time step by using reference evapotranspiration (ETo) combined with a pepper crop coefficient (Kc) using the dual crop coefficient approach. ETo is estimated using daily climatic data collected from the meteorological station, located at Médenine, Tunisia and the FAO-56 Penman-Monteith method (ETo-PM) given in Allen *et al.* (1998).

The Penman-Monteith method considers hypothetic 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. Once the maximum root depth is reached, it is held constant.

### *Measurements and Water-use efficiency*

Sections of all plots were harvested to determine fresh fruit yields, fruit pepper number and weight each year. In both years, the area of land harvested was 30 $m^2$ 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 figures for the second year (2009) were DAT 112, DAT 136 and DAT 170, respectively.

The total mass from each treatment was weighted to determine fresh fruit yield (t/ha) and individual fruits were counted. Fruits numbers were determined from the counted fruits divided 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 follow: WP (kg/$m^3$) = Yield (kg/ha) / total irrigation water applied ($m^3$/ha) from transplanting to harvest; an irrigation of 100.5 mm applied before transplanting is not included in the total.

Soil samples were collected after harvest and analyzed for ECe. The soil was sampled 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 £ 0.05 was used to find any significant difference between treatment means.

## Results and discussion

### *Evapotranspiration estimates and soil water balance*

Figure 2 illustrates the course of daily ETc relative to ETo for both years during the growing periods of pepper crop. During the first 35 days after transplantation, high ETo values resulted in high ETc 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 ETc of about 1.7 and 1.2 mm/day, respectively, for the first and second year. As the crop canopy grew, ETc increased and reached its highest mean value at mid-season stage (5.4 and 5.5 mm/ day). The mean ETc values at the late stage were about 5.6 and 5.8 mm/day, respectively, for 2008 and 2009. The high ETc values during the late stage were mainly attributed to the important 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. Figure 3 illustrates soil water depletion, estimated by the program, under FI treatment during the cropping period of pepper for two years. 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 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 ECe values in the 0-80 cm soil layer under different irrigation treatments are presented in Figure 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 ECe values measured in the root zone (0-80 cm) at harvest is observed under all irrigation treatments compared to initial soil salinity. The ECe for the treatments FI and FI-MDI60 increases from 3.1 and 2.7 at transplantation in May to approximately 4.1 and 3.7 dS/m at harvest, respectively, for 2008 and 2009. However, the ECe was higher at harvest than the initial ECe 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

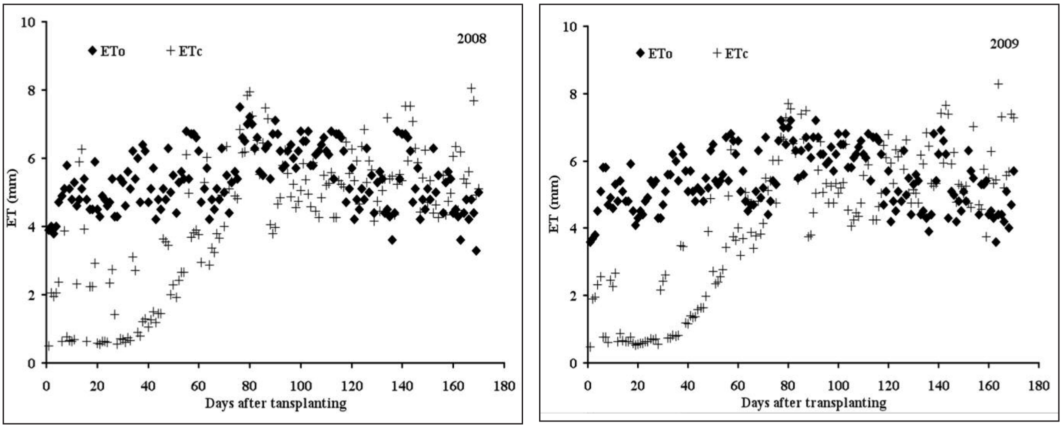


*Figure 2 - Estimated daily ETc for pepper crop during the cropping season.*

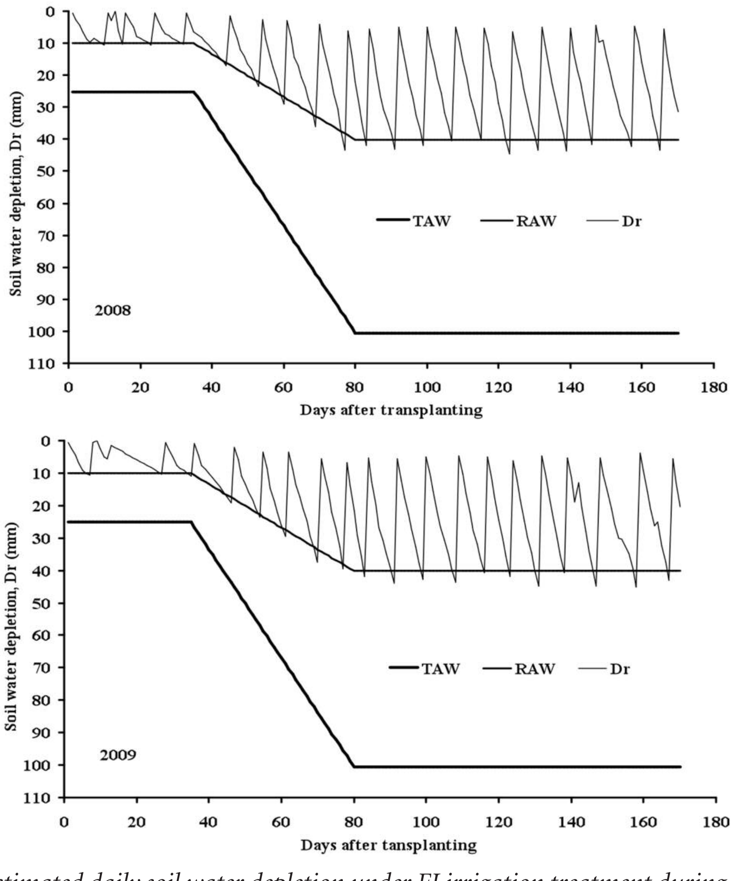


*Figure 3 - Estimated daily soil water depletion under FI irrigation treatment during the cropping season of pepper (2008-2009).*

and since rainfall received during that period was 29.5 and 44.5 mm, respectively, during the two years and water supply was provided mostly through irrigation, little leaching of the soil is expected. The highest ECe values occurred during 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 (Figure 1). The total rainfall during pepper growing season that year (2009) was the highest of the two years (Figure 1).

ECe data shows that there were decreases in the ECe with full irrigation treatment (FI). FI-MDI60 and DI-80 irrigation treatments resulted also 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.* (2008b), Kaman *et al.* (2006) and Schoups *et al.* (2005) reported that one consequence of reducing irrigation water use 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

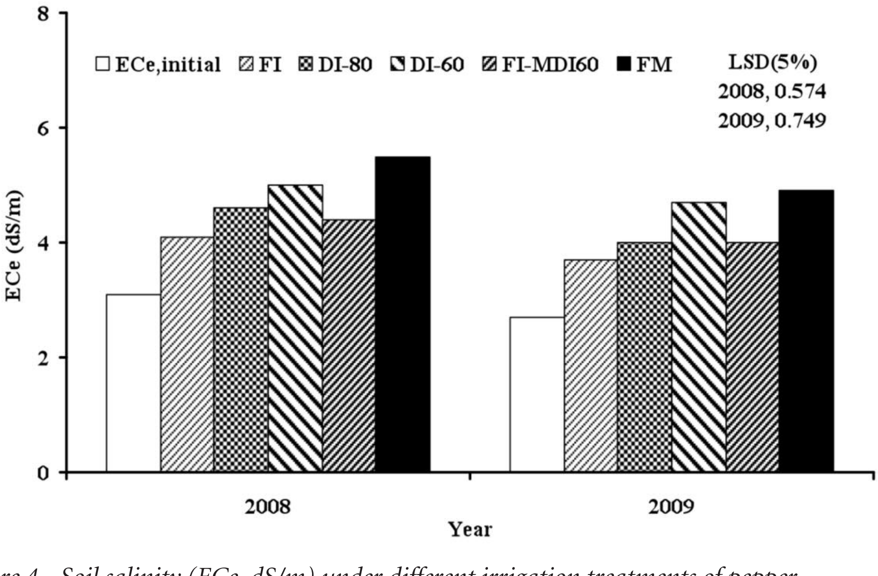


*Figure 4 - Soil salinity (ECe, dS/m) under different irrigation treatments of pepper.*

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 Figure 5. The data shows that pepper yields over the two years of this 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 provided also highest fruit yield and was not significantly different with FI, similarly 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 the DI-80, respectively, in 2008 and 2009, it was not statistically different than yield of the FI treatment. However, a significant reduction in yields occurred with the DI-60 as compared to FI treatment (Figure 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

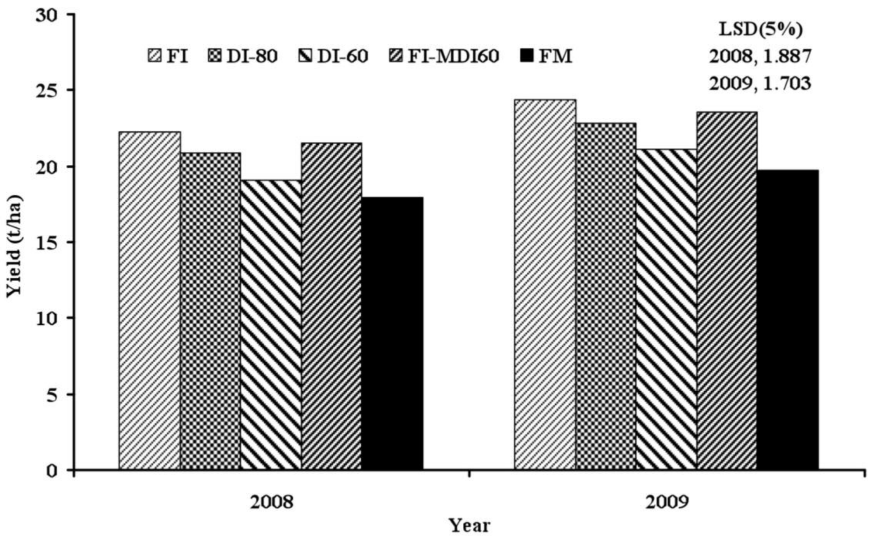


*Figure 5 - Fresh fruit yield under different irrigation treatments.*

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) had proved to be significant ($p<0.05$).

The influence of irrigation treatment on the fruit number and weight were 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 concerning fruit number and weight 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. These two last don't show a statistical difference between them. There was no significant difference between DI-80 and DI-60 treatments 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 Ovtcharrow, 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) result in higher salinity in the rooting zone than the DI-80, FI and FI-MDI60 treatments (Figure 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).

*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%) | 54.867 | 1.114 | 49.740 | 1.107 |

The yield is greatly dependant of 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. He seems to relate irrigation occurrences to days after transplanting rather than to crop growth stages progress. 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, respectively, 94 to 356 mm in 2008; 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 were saved, respectively, in the first and second year. 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/m$^3$, respectively, in the first and second year. TWP values ranged from 2.31 kg/m$^3$ in FM to 4.93 kg/m$^3$ in the DI-60. IWP values varied from a minimum of 2.4 kg/m$^3$ in FM to a maximum of 5.49 in kg/m$^3$ in the DI-60 treatment in the experimental years.

For both 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 be attributed to reduced yields but also to higher irrigation water use.

*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/m³) | TWP (kg/m³) |
|---|---|---|---|---|---|
| | | 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%) | - | - | - | 0.361 | 0.341 |
| | | 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%) | - | - | - | 0.338 | 0.276 |

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

## Conclusions

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, yield and its components parameters of pepper. Full irrigation (FI) and deficit irrigation treatments (FI-MDI60 and DI-80) decreased the soil salinity. Higher soil salinity was maintained in the root zone with DI-60 deficit irrigation and farmer method (FM). Pepper yields were influenced by irrigation treatments in both experimental years. 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 gave also 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 root 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 for pepper yield. The higher salinity associated with the farmer's method and deficit irrigation treatments were sufficient to cause 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 limited quality under mild water deficit conditions. FI-MDI60 and DI-80 saved water by 8-20%, reduced soil salinization and improved irrigation water productivity. Although DI-80 and FI-MDI60 treatments reduced fruit number and weight, fresh fruit yield was maintained compared to well-irrigated treatment Fl 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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