Impact of deficit irrigation with saline water on yield, soil salinization and water productivity of barley in arid regions of Tunisia

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SUMMARY

Field studies were conducted for two years to determine the effects of irrigation regimes with saline water (7.6 dS/m) on soil salinity, yield and water productivity of barley in the arid region of Tunisia. Barley was grown on a sandy soil and drip-irrigated with well water having an ECi of 7.6 dS/m. For two years, a complete randomized block design with three replicates was used to evaluate five irrigation regimes. Full treatment (FI) was irrigated with an amount equal to 100% of cumulated crop evapotranspiration (ETc), DI-50 treatment irrigated at the same frequency as FI treatment but with quantity equal to 50% of accumulated ETc during growing period and deficit irrigation during tillering stage (DI-Dev), maturity (DI-Mat) and both stages (DI-Dev+Mat). The results showed that soil salinity was significantly affected by irrigation treatments. Higher soil salinity was maintained in the root zone with DI-50treatment than full irrigation (FI). DI-Dev, DI-Dev+Mat and DI-Mattreatments resulted also in low ECe values. This highest soil salinity accompanied with DI-50 treatment reduced barley yield significantly. However, regulated deficit treatments provide acceptable yields compared to full irrigation treatment. Water productivity (WP) obtained in field experiments corresponds with values reported in the literature and was affected by irrigation treatments. The lowest WP values occurred under the FI treatment, while the highest values were obtained under DI-50 deficit irrigation treatment. However, the difference between FI, DI-Dev, DI-Mat and DI-Dev+Mat treatments was not significant. The full irrigation (FI) and deficit irrigation (DI-Dev, DI-Mat and DI-Dev+Mat) strategies were found to be a useful practice for scheduling barley irrigation with saline water under the arid Mediterranean conditions of southern Tunisia.

Key words:arid, salinity, deficit irrigation, barley, yield, water productivity

1. INTRODUCTION

Water shortage is one of the most important factors limiting the crop production in the world (Umar 2006). In the Mediterranean regions, low rainfall and high temperatures along with high salinity of irrigation water often affect agricultural productions as a result of drought and salinity stress (Paranychianakis and Chartzoulakis 2005).This is especially the case in the arid regions of Tunisia where limited supplies of good quality waters and the increasing needs for agriculture intensification are forcing farmers to use high saline waters. Irrigation of a wide range of crops is actually expanding around a shallow well having salinity level more than 5 dS/m. However, productivity is usually low and irrigation is applied on routine basis without scheduling and provision drainage. This may carry the danger of a rapid soil salinization because of increased salt input. Therefore, innovations are needed to increase the productivity of water that is available. One way to overcome the water shortage and optimize saline water use is through development of a new irrigation scheduling such as deficit irrigation which is not necessarily based on full crop water requirements.

Zhang et al. (2004) found that severe soil water deficit (SWD) decreased grain yield of winter wheat, while slight SWD throughout the growing season did not reduce grain yield or water productivity. This result indicates that water supply can be reduced somewhat without significant decrease in grain yield. Moreover, investigations conducted by English (1990) and Zhang et al. (2002) show that deficit irrigation can increase the net farm income.

Barley, considered as a tolerant plant (Maas and Hoffman, 1977), occupies large cultivated areas in arid part of Tunisia. Many experiments have been conducted on barley cultivated in small private farms in southern Tunisia (Nagaz et Ben Mechlia, 2003) and the results demonstrate the potential of irrigation management practices in reducing the effects of salinity on both yield and soil salinity. In addition, Khalil et al. (2007) showed that yield reduction under deficit irrigation during the whole growing season was about 5% and 20% of the total irrigation water was saved. Field study conducted by Nagaz et al. (2008) showed that a reduction of 15% of total irrigation wateroffer significant advantage for both barley yields and WUE and reduce the build-up of salinity compared to a reduction about 50 and 30 % of water in barley production under arid conditions. As result, this restriction of 15% can be used as deficit irrigation strategy of barley in case of situations where water supply is limited.

The objective of this study was to make quantitative assessments of both salt accumulation in the soil and yield response to full and deficit irrigation strategies with saline water in order to derive an irrigation strategy that save water in irrigated barley, reduce salt input and improve water productivity under the arid Mediterranean conditions of southern Tunisia.

2. MATERIALS AND METHODS

Field experiments were carried out at the experimental station of Arid Lands Institute (IRA-Médenine) in southern Tunisia during the growing season (2008-2009) and (2011-2012) on a well-drained sandy soil (85 % sand, 5 % clay et 10 % loam) with low organic matter concentration (< 8 g/kg). The soil water content at field capacity and wilting point are 12.3 % and 6.1%, respectively, and a bulk density of about 1.61 g/cm^3. The total available water for an assumed barley root extracting depth 0.8 m is 78 mm.

Five irrigation treatments were set up in a randomized complete block design with three replicates. The full irrigation treatment (FI) irrigated with a quantity equal to 100% of cumulative crop evapotranspiration (ETc); the second treatment irrigated at the same frequency as treatment FI but with quantity equal to 50% of accumulated ETc (DI-50) during the whole growing period. The water restriction was also applied during tillering (DI-dev), maturity (DI-Mat), and both stages (DI-Dev+Mat). Barley (cv. Ardhaoui**)** seeds were sown during second and fourth weeks of November, respectively, for the first and second years in six rows 50 cm apart in each elementary plot. Plants were irrigated using drip system with shallow well water having an ECi of 7.6 dS/m (Table1). Treatments were applied after the plants established. Fertilizers were supplied for both years in the same amounts; before planting, soil was spread with 8.3 $t.ha^{-1}$ of organic manure, Nutrient supply included N, P and K at rates of 300, 300 and 200 $kg.ha^{-1}$, 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.

The crop water requirement was calculated using water balance method by means of spreadsheet program developed for Excel in order to estimate the irrigation timing and amount based on cumulative soil water depletion. The crop evapotranspiration (ET_C) was estimated for daily time step by using ETo combined with a crop coefficient. ETo was estimated daily following the FAO-56 Penman-Monteith method given in Allen et al. (1998) and Kc was computed following the dual crop coefficient approach that provides for separate calculations for transpiration and evaporation from soil. For both years, soil salinity was monitored at initial, middle and harvest of cropping period. The soil salinity in the root zone was expressed by the electrical conductivity of the saturated soil extract, ECe. For each elementary plot, soil was sampled with a 4 cm auger every 20 cm to a depth of 80 cm, at three sites perpendicular to the drip line and at three sites between the emitters. Conceptually, these should be areas representing the range of salt accumulations (Bresler 1975; Singh et al.1977).

Table 1. Chemical composition of irrigation water (meq/l).

ECi ($dS.m^{-1}$)	$Ca^{++}+Mg^{++}$	Na^+	K^+	$Co_3^{2-}+HCo_3^-$	So_4^{2-}	Cl^-	SARiw
7.6	26.4	48.8	1.4	4.2	32.2	40.0	13.4

For both seasons, plant growth was monitoring through measuring the canopy. To this end, one square meter was selected randomly and photos were taken using a numerical camera therefore analyzed to determine the percentage of cover using Green Crop Tracker software.

At harvest, biomass and grains yield for each elementary plot were determined.

WP is generally defined as 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 (kg/ha/mm) = Yield (kg/ha)/applied irrigation (mm) from planting to harvest; an irrigation of 78 mm applied before planting date is not included in the total amount.

Analysis of variance was performed to evaluate the statistical effect of irrigation treatments on soil salinity, barley growth, yield and WP using the STATGRAPHICS *Plus* 5.1. LSD test at 5% level was used to find any significant difference between irrigation treatments means.

3. RESULTS AND DISCUSSION

3.1. Soil water depletion

Figure 1 illustrates soil water depletion, estimated by the spreadsheet program and measured periodically by gravimetric method, under FI and deficit irrigation treatments during second year. The spreadsheet program uses water balance equation and supplies information's on irrigation timing and amount. This figure illustrates 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.

Irrigation scheduling based on SWB method maintains the soil water depletion between threshold (RAW) and field capacity. The slight water deficit observed at the day prior to irrigation was due to the fact that the irrigation is applied only when soil water depletion at the end of the previous day exceeds to the readily available water (RAW). For FI treatment, barley plants were maintained under optimal water conditions by replenishing the root zone to field capacity. Irrigation scheduling based on crop water requirements and soil characteristics results in varying irrigation amounts and intervals adapted to requirements change during crop cycle and then allow for applying water when needed. In the case of DI-50 treatment, the water deficit began approximately 105 days after plantation and it was maintained until the harvest of barley. Thus, with DI-50 treatment where irrigation is applied lower than full crop water requirements will make use of stored soil moisture and the water stored in the soil is gradually depleted by ETc.

The evolution of soil water depletion was compared between two methods (SWB model and gravimetric) for full irrigation treatment (FI). It was observed that there is a good agreement between two methods with R^2 of 0.95 (Figure 2) and the differences doesn't seem to be significant. Therefore, the developed model appears to be reliable to predict the soil water depletion in order to provide information for an adequate water management.

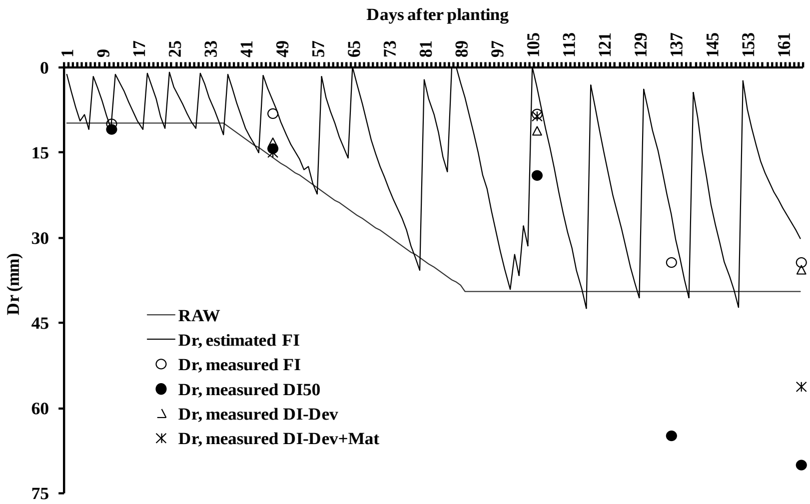

Figure 1. Estimated and measured soil water depletion during second barley cropping period

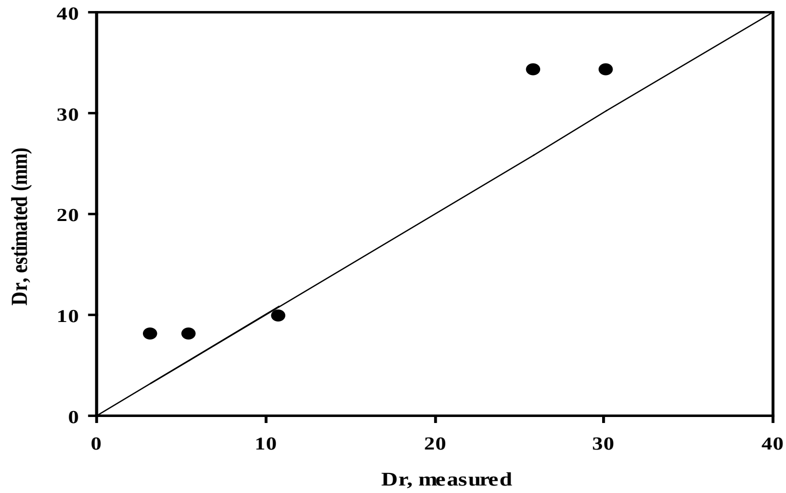

Figure 2. Soil water depletion (Dr) comparison between SWB model and gravimetric method.

3.2. Soil salinity

Soil salinity was determined before and during the cropping cycle for both seasons to evaluate the impact of deficit irrigation strategies on the soil salinization (Figure 3). The initialsoil salinity values measured at sowing were 5.7 and 8.1dS/m, respectively, for the first and second seasons. The highest ECe value observed in the second season could be explained by continuous irrigation with saline water during previous years.

The results show that there was a decrease in soil salinity measured in the root zone (0-80 cm) for the majority of irrigation treatments compared to initial soil salinity. During the first year, the ECe decreases from 5.7 at plantation to approximately 5.2 dS/m at the mid-season stage for FI and DI-Mat treatments.

Full irrigation treatment (FI) registered in the second year a small decrease in ECe from 8.1 to 7.7 dS/m in 106 DAS and also for DI-Dev+Mat treatments. These results show that full irrigation (FI) and deficit treatments (DI-Dev, DI-Dev+Mat and DI-Mat) seem to benefit from leaching of added salts by rains received (89.5 mm) during initial and development stages during the first year and mainly in the mid-season stage (70 mm) in second year (Figure 3). The ECe value (8.5 dS/m) recorded under DI-50 at 106 DAS could be also explained by leaching ensured by rains received during the mid-season stage (Figure 3).

The soil salinity measured at harvest was higher in the second year as a consequence of cumulative salt accumulation besides the increase of soil evaporation and the absence of rainfall events during the sampling period. The capacity of winter rainfall to leach salts is variable and depends on the total amount and distribution of rainfall events. This is illustrated by the lowest ECe values observed in the first year which corresponds to the amount rainfall received at the end of season (Figure 3) that seemed to be effective in removing salts accumulated in the root zone.This increase can be explained by sampling date which corresponds to period of high evaporation demand.

Continuous deficit irrigation practice (DI-50) increases the salts accumulation in the root zone. The ECe values increases from 5.7-8.1 dS/m to 7.4-9.2 dS/m for the 1^{st} and 2^{sd} year, respectively. The increase in soil salinity for DI-Mat seems however to be less important than that observed with DI-Dev and DI-Dev+Mat treatments (Figure 3). Although salts amount added to the soil with FI are higher than DI-50, the soil salinity remains lower than the deficit irrigation treatment. This is probably due to a situation of drainage which ensures the evacuation of salts beyond the studied depth of 80 cm. A deficit of 50% during maturity stages keeps low salinity value in the root zone with limited impact on the yield. 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.

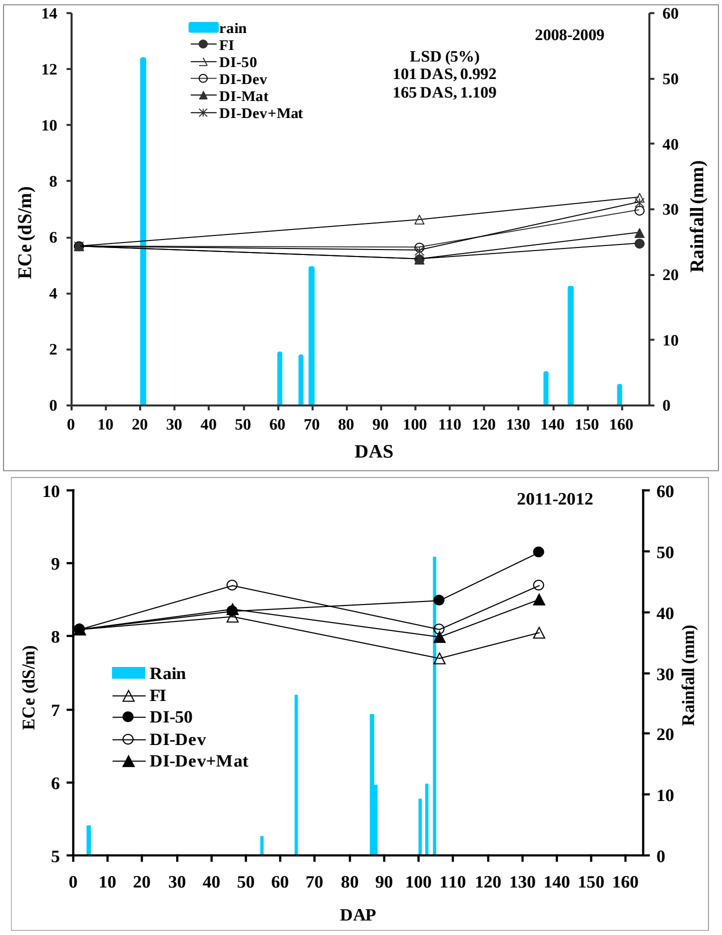

Figure 3. Soil salinity under different irrigation treatments for both years (2008-2009 and (2011-2012) with rainfall distribution.

3.3. Canopy cover

Figure 4 show barley growth expressed by canopy cover (CC) measured under different irrigation treatments (2011-2012). The maximum canopy cover (74.8%) was reached in the 98 day for all treatments. There is a significant difference between the full treatment and the more restrictive one (DI-50) while for the CC values measured in 134 DAS the difference were significant between FI and other treatments. This difference could be explained by the early senescence induced by the water stress for the deficit treatment (DI-50, DI-Dev, DI-Dev+Mat and DI-Mat). This result was also mentioned by Araya et al. (2010) and Salemi et al. (2011).

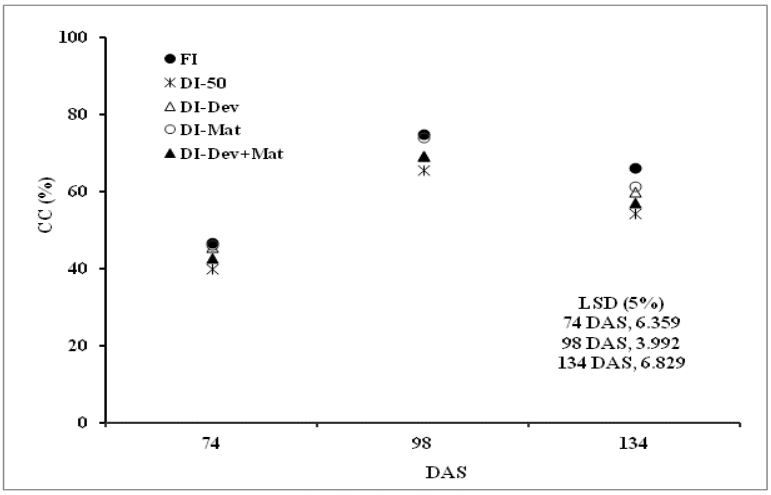

Figure 4. Barley green canopy cover percentage under different treatments.

3.4. Crop yields

The analysis of variance shows a significant effect of the applied treatments on the final biomass and grain yield. The results show that the highest grain yield and biomass were obtained with FI treatment (3.8-3 t/ha and 8.4-8.6 t/ha) followed by DI-Mat (3.7-2.7 t/ha and 8.1-7.7 t/ha) and DI-Dev (3.5-2.6 t/ha and 7.7-7.5 t/ha) in the first and second years, respectively. Thus, Barley biomass was affected significantly under continuous deficit irrigation (DI-50) compared to FI and DI-Mat. Previous studies have shown that moderate water deficit during the vegetative and maturity stages don't have significant effects on dry matter accumulation of barley and wheat (Jamieson et al., 1995).

The reduction in grain yield associated with the treatment DI-50 was mainly attributed to a significant reduction in yields components (data not presented) as a consequence of water shortage during flowering and grains formation. Indeed, continuous deficit irrigation (DI-50) caused a reduction in the tillers number and subsequently a reduction in the number of spikes per m².

Due to its effect of reducing the build-up of salinity the DI-Mat and DI-Dev treatments resulted in barley yields comparable with those obtained under FI treatment. Barley crop productivity is most sensitive to water stress during jointing, flowering and grain filling (Sepaskhah, 1978; Weltzien and Srivastava, 1981; Ceccarelli, 1987; Baheri et al., 2005). Note that the DI-50 and DI-Dev+Mat deficit irrigation strategies result in higher salinity in the rooting zone than full irrigation strategy (Figure 3). The higher salinity associated with deficit irrigation strategies (DI-50 and DI-Dev+Mat) were sufficient to cause reduction in yield of barley.

Water deficit conditions can aggravate the stress placed on plants growing under saline conditions. Successful use of saline waters for irrigation purposes will be linked to irrigation management that eliminates soil moisture deficit conditions (Bresler *et al*., 1982; Shalhevet, 1984). Barley has been described as a highly salt-tolerant crop (Maas and Hoffman, 1977). Therefore, under conditions of water shortage, the irrigation of the barley can be reduced during development and/or maturity stages.

Yields obtained under regulated deficit irrigation (DI-Mat, DI-Dev and DI-Dev+Mat) are slightly lower those obtained with full irrigation (FI). However, the difference increases significantly with continuous deficit irrigation treatment (DI-50). Thus, deficit irrigation applied during development and maturity stages (DI-Mat, DI-Dev and DI-Dev+Mat) provides a means of reducing water use (Table 2) without affecting significantly the yields. These results obtained under the prevailing climatic conditions support the practicality of the DI-Mat, DI-Dev and DI-Dev+Mat irrigation strategies to facilitate the use of saline water for irrigation of barley.

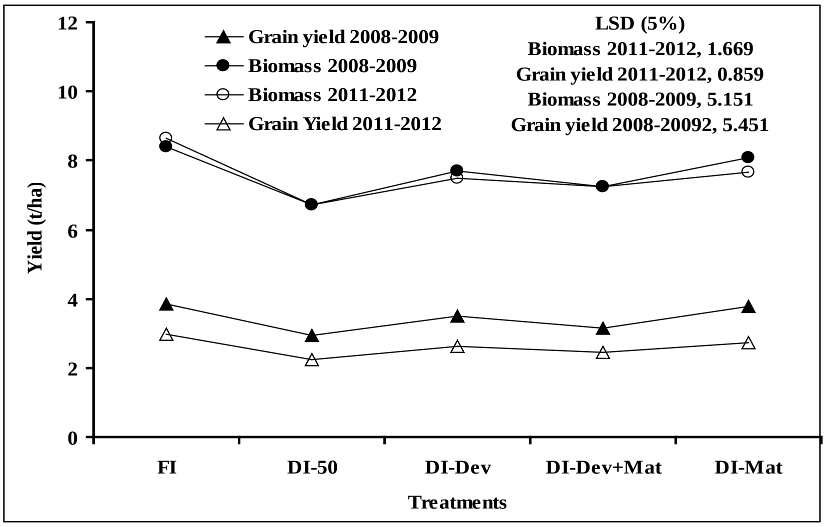

Figure 5. Grain yield and biomass under different irrigation treatments

3.5. Water productivity

The WP for grain yield and dry matter production (WPg, WPd) is presented in Table 2. The highest irrigation and total water productivity (IWP, TWP) values were obtained in the second season (2011-2012) with, respectively, 35.4 and 18.1 kg/m^3. Higher IWPg values were observed in the second season despite the reduction of grain yields. They ranged between 14.3 and 18.6 kg/m^3 across different

treatments. This is mainly due to the reduction of irrigation amount that was compensated by the increase and well dispersion of rainfall that occurred during the season 2011-2012 (138 mm).
For both seasons, WPg values were highest for DI-50 treatment although there is no significant differences ($p<0.05$) between FI, DI-Dev, DI-Mat and DI-Dev+Mat treatments. The values of WP based on dry matter in 2011-2012 season were higher than those observed during the first season's as consequence of important amount of rain recorded (138 mm). The WP values obtained are comparable with those obtained in other field studies (Bhutia and Singh, 1990; Hussain and Al-Jaloud, 1998; Nagaz and ben Mechlia, 1998, 2000) and were affected by irrigation treatments.
Barley yields obtained under FI treatment are comparable with those obtained with DI-Dev and DI-Mat treatments. The last two treatments gave also high IWP values as compared to full treatment (FI). The deficit irrigation treatment with less irrigation water of about 22% (DI-Dev+Mat) gives WP values comparable with those obtained under FI, D-Dev and DI-Mat treatments. Therefore, the results show that irrigation water requirements for barley crop can be reduced without a significant yield reduction by adopting deficit irrigation strategies during development and maturity stages (DI-Mat, DI-Dev and DI-Dev+Mat).

Table 2. Water productivity (WP, kg/ha/mm) under different irrigation treatments

Treatments	IWPd	IWPg	TWPd	TWPg
		2008-2009		
FI	13.47	11.36	10.04	8.47
DI-50	22.36	17.32	13.28	10.30
DI-Dev	13.82	11.48	10.01	8.32
DI-Mat	14.58	12.71	10.50	9.15
DI-Dev+Mat	15.53	12.00	10.78	8.33
LSD (5%)	1.844	1.317	1.839	1.289
		2011-2012		
FI	24,46	14,38	15,7	9,23
DI-50	35,4	18,62	18,12	9,53
DI-Dev	25,82	14,87	1711	9,01
DI-Mat	30,35	16,39	17,12	9,24
DI-Dev+Mat	27,1	15,58	16,46	9,46
LSD (5%)	7.497	6.601	5.384	3.301

4. CONCLUSIONS

This two-year field study indicated that barley yield was affected by irrigation treatments. Barley grain yields obtained under DI-50 deficit treatments were significantly lower than those obtained with full irrigation treatment (FI). Dry matter production was affected by irrigation treatments especially with DI-50. The higher salinity associated with the deficit irrigation treatments were sufficient to cause reduction in barley yield and yield components. The water productivity (WP) for grain yield was significantly affected by irrigation treatments. The lowest values occurred under FI treatment, while the highest values were obtained under DI-50 deficit treatment. The relatively high yields and water productivity values noted under DI-Dev, DI-Mat and DI-Dev+Mat treatments indicate the high potential of barley crop to valorize irrigation waters of limited quality under arid conditions.
Based on results, it can be concluded that the full irrigation (FI) and regulated deficit irrigation (DI-Dev, DI-Mat and DI-Dev+Mat) strategies offer significant advantage for both barley yields and WP and reduce the build-up of salinity compared to DI-50 irrigation strategy in barley production under arid conditions. As a result of this research, full irrigation scheduling technique (FI) is recommended for irrigation of barley crop under the arid conditions of southern Tunisia. In case of situations where water supply is limited, irrigation of barley could be scheduled using DI-Dev, DI-Mat and DI-Dev+Mat, deficit irrigation strategies. The deficit irrigation presents a great potential to improve the water productivity and the control of soil salinization by exploiting the natural leaching of salts by the rain. Future studies should be undertaken to evaluate the efficiency of the fall-winter rains for natural leaching.

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