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Impact of deficit irrigation on yield and fruit quality of table olive (*Olea europaea* L., *cv. Meski*) in Southern Tunisia

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Abstract

An experiment on deficit irrigation (DI) was performed in a drip-irrigated table olive orchard (cv. Meski) during 2013 and 2014 in farm field situated in Médenine, Tunisia. Four irrigation treatments were applied: Full irrigation (FI), which was irrigated at 100% of ETc for the whole season; DI75 and DI50 deficit irrigation treatments, which received 25 and 50% less water than FI. These treatments were compared with a traditional farming (FM). Significant differences were found in fruit yield between DIs, FM and FI treatments. There were no significant differences between DI50 and FM treatments. WP was the highest in DI50 treatment and the lowest in Full strategy. FI treatment generated the highest net income and was found to be reasonable in areas with no water shortage. Under water scarcity conditions, DI75 treatment provides promising irrigation strategy for optimizing olive irrigation and increasing water productivity, allowing water savings up to 25% with some reduction in yield (11%) and net income (17%). The results would be helpful in adopting deficit irrigation in ways that enhance net financial returns.

Keywords: table olive, deficit irrigation, drip irrigation, yield, water productivity, net income, arid

INTRODUCTION

Olive is an important crop in the Mediterranean arid region of southern Tunisia that has traditionally been cultivated under rain-fed conditions. However, the water demand for irrigation is increasing in olive orchards because of enhanced yields and profits, leading to the use of low-quality water resources. More recently, new orchards are drip-irrigated with private wells having a total dissolved salts (TDS) more than 2 dS m^{-1} and are planted at higher densities achieving greater yields and resulting in less alternate-bearing behavior. However, most of olive growers apply water inefficiently with lower or higher than required quantities. In addition, the lack of drainage systems in most of the irrigated lands, and the resulting accumulation of salts in the root zone are seriously compromising the sustainability of irrigated olive trees in arid regions.

Good management of water application is required for farmers to save water, improve production and reduce risks of soil salinization. Therefore, the way to address the issue of water shortage is through the development of new irrigation scheduling techniques such as full irrigation and deficit irrigation, which are not necessarily based on full crop water requirement. Deficit irrigation (DI) is a valuable and sustainable production strategy for dry regions (Geerts and Raes, 2009). It is one way of the maximizing water productivity for higher yields per unit of irrigation water applied (Fereres and Soriano, 2007).

Deficit irrigation (DI) is particularly important for olive orchards which are frequently

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subject to chronic water shortages during the dry season for many successive years. Olive trees can respond favorably to low volumes of water received during the dry season, improving consistently their production (Masmoudi et al., 2010). Several studies have been carried out to assess the response of table and oil olive trees grown under full and deficit irrigation conditions (Iniesta et al., 2009; Masmoudi et al., 2010; Palese et al., 2010; Martin-Vertedor et al., 2011a).

Table olive trees represent an important component of the productive farming system in the irrigated lands in southern Tunisia. However productivity is usually low and irrigation with waters having more than 1.5 g L^{-1} of TDS is practiced without provision of drainage. Due to chronic water shortage and soil degradation hazards in irrigated orchards, there is a need to develop strategies that may help to save water and control salinity. In the absence of drainage systems and under conditions of high evaporative demand and chronic shortages of water, techniques based on irrigation restrictions seem to be reasonably appropriate. However, the grower must have prior knowledge of the table olive yield responses to deficit irrigation. The present work examined the response of yield and fruit quality of table olive trees to DIs applied over two consecutive years to define the best irrigation program based on DI with saline water of table olive trees adapted to the arid conditions of Tunisia.

MATERIALS AND METHODS

The experiment was carried out in a commercial orchard of table olive trees (*Olea europaea* L., cv. Meski) located in Médenine, Southern Tunisia (33º 19'N, 10º 27' E, altitude 146 m). Trees were planted 14 years ago, spaced 7 m x 7 m, and were irrigated with drip line with four self-compensating drippers per tree (4 L h^{-1}), 1 m apart, using irrigation waters of about 2.2 dS m^{-1}. The soil is a sandy loam with 62% sand, 29% silt, and 9% clay. The mass basis water content at field capacity and permanent wilting point are 17 and 9.2%, respectively, and bulk density was 1.41 gcm^{-3}. The total soil available water for an assumed table olive root extracting depth of 1 m, was 110 mm. The local climatology is typically dry Mediterranean, with an average annual precipitation of 150 mm and annual reference evapotranspiration (ETo-PM) is about 1450 mm, resulting in an average water deficit of 1300 mm.

The trial included four treatments; each treatment contained four rows with 16 trees/row with three replicates, each one with four trees. Water for each treatment passed through a water meter and gate valve before passing through laterals placed in every table olive row. Four irrigation treatments were applied: full treatment (FI) irrigated during the watering season to provide trees with their full water requirement based on crop evapotranspiration (ETc) calculations. Deficit treatments irrigated with irrigation water quantities that cover 75% and 50% of ETc (DI75 and DI50) and traditional farming (FM) irrigated according to farmer irrigation practice. This method consisted in giving the irrigation amount once a week during watering season.

An application developed in Excel for managing irrigation of fruit trees was used to determine water and irrigation requirements. This application required data on reference evapotranspiration (ETo), crop coefficient (Kc), soil water deficit coefficient (Kd), rainfall and growth stage lengths. ETc was calculated from Penman Monteith method-determined reference crop water use (ETo-PM) (Allen et al., 1998), using long term climatic data from a weather station located 6 km from the plot, with crop coefficient (Kc) estimated from Allen et al. (1998).

The FM, DI and full treatments were implemented from early February to the end of December. Irrigation treatments were scheduled weekly because irrigation of table olive adopted by farmers at the study area is on a weekly basis. Therefore, an irrigation frequency of once a week was adopted using different amounts of water across the different amount treatments. Nutrient supply was applied according to the levels of fertilizer used by farmers for table olive production in study area, being 400-150-150 $kgha^{-1}$ of N, P_2O_5 and K_2O, respectively. Nitrogen was applied at a rate of 1/3 during the period February-March and 2/3 applied during the post-harvest period. P2O5 and K2O were applied regularly weekly from

February through May.

For both years, soil water content was monitored by gravimetric method (θ_g) to determine the soil water depletion. Soil samples were taken with a 4 cm auger close to trees at 20 cm from the drip head and perpendicularly oriented to the drip-lines, at 20 cm depth intervals to a maximum depth of 100 cm. Soil salinity was also monitored by sampling soil at different points around trees. Each sampling consists in extracting soil samples every 20 cm to a depth of 100 cm and this at different distances from dripper. The sampling concerned an elementary surface representing one quarter of the area covered by a tree.

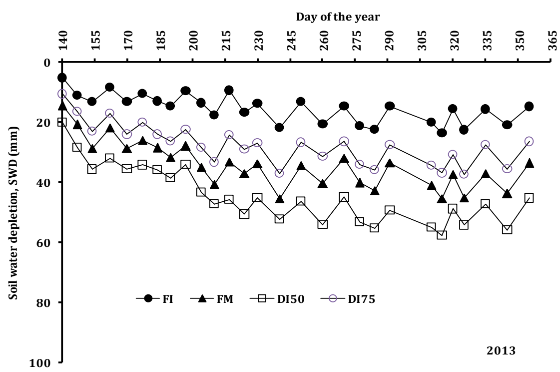
At the end of each season, the yield was determined for each individual control tree by weighing the table olive fruits with a digital scale with an accuracy of ± 0.01 g and the irrigation water productivity (IWP) was calculated by dividing the final yield ($kgha^{-1}$) by the volume of irrigation water applied. Fruit-quality characteristics were analyzed at harvest in samples from the trees studied (50 fruits per tree) including fruit weight and size.

The net income for each treatment was computed by subtracting all the production costs from gross incomes. All calculations were done based on a unit area of 1ha. Production costs include fertilizer, irrigation system and harvesting costs. Gross return was calculated by multiplying the total amount of product by its market price.

RESULTS AND DISCUSSION

Soil water depletion

The soil water depletion (SWD) variation showed clear differences in SWD between different irrigation treatments in accordance with the irrigation rates (Figure 1). The Full treatment (FI) had smaller values of SWD indicating that the soil water content was maintained nearer to field capacity than the other treatments. For the DI75, DI50 and FM treatments, soil water depletion increased gradually with time. This increase was always more accentuated in the DI50 than in the FM and DI75 treatments. The SWD levels in the DI75 treatment remained smaller compared to those for the FM and DI50 treatments.



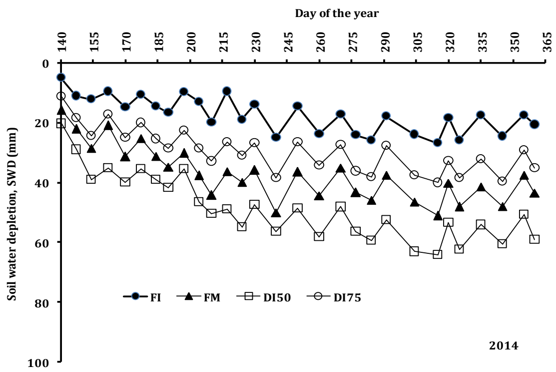


Figure 1. Soil water depletion (SWD, mm) in 2013 and 2014.

Soil salinity

The average ECe values under the different treatments are presented in Figure 2. Initial soil salinity values determined early February were, respectively, 2.7 and 2.4 dSm^{-1} in the first and second year. During both year, a decrease in ECe values measured at harvest was observed under all irrigation treatments compared to initial soil salinity. The decrease of ECe values was attributed to the leaching of soluble salts by rains (52 and 59 mm) received during the experiment periods. Figure 2 shows a decrease in ECe values for FI treatment. Higher ECe values have been observed for the first year due to the higher initial ECe. DI75 treatment resulted also in low ECe values at harvest without significant difference ($p<0.05$) with FI. ECe values were significantly smaller in the FI treatment as compared to that in FM. The latter was not significantly different with the DI50 treatment. The higher soil salinity levels were observed for DI50 treatment. This result may be explained by the fact that even less salt is added in plots irrigated with 50% less irrigation water (DI50) as compared to the water applied for FI treatment, its concentration in a lower volume of the wetted sphere under the emitters is higher. Apparently the layout used for soil sampling fails to represent average salts concentration. Kaman et al. (2006) reported that deficit irrigation may contribute to greater risk of increased soil salinity due to reduced leaching. ECe values under the different treatments were generally lower than the ECiw used. Singh and Bhumbla (1968) reported that in soils containing less than 10% clay the ECe values remain lower than ECiw. Low values of ECe under the current climatic conditions were also due to the natural leaching of soluble salts by rainfall events.

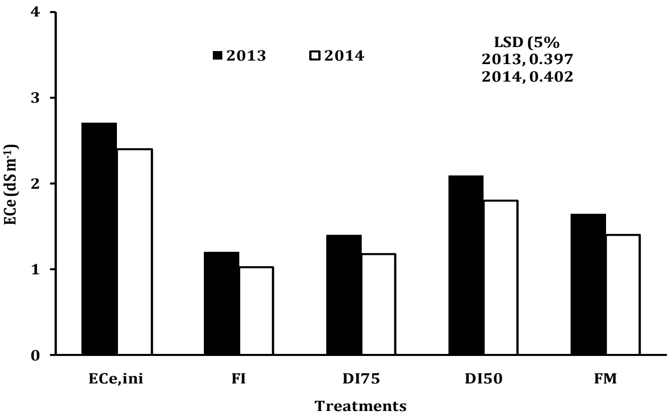


Figure 2. Soil salinity (ECe, dS m^{-1}) under different irrigation treatments.

Yield

The yield and fruit-quality parameters during the study years are presented in Figure 3 and Table 1. For both years there is significant difference among tested irrigation treatments on table olive yield, fruit weight and size ($p<0.05$). The higher yield was obtained in FI treatment with 4,20 and 4,62 t ha^{-1} (Figure 3). Significant differences between the FI and other treatments were observed. Yields were also significantly different between the DI75 and FM treatments. The yield was least for DI50with 29-35% reduction in the fruit yield compared to that for the FI treatment, while DI75 and FM have reduction on the table olive yield of 10-12% and 23-25% in comparison with FI, respectively. The difference was not statistically different between DI50 and FM. The low yield in DI50 and FM treatments was due to a lower fruit set in this treatment. Vita et al. (2011) found that deficit irrigation at 50% of ETc decreased yield by 26%. Goldhamer (1999) found that a reduction by 44%, decreased yield by 20%.

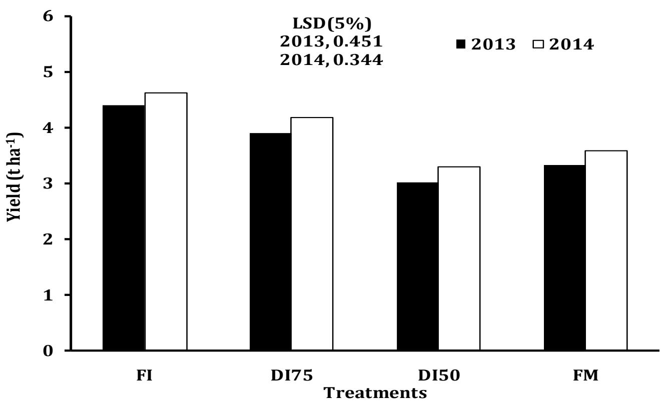


Figure 3. Fruit yield under irrigation strategies for the study period.

Weight and fruit size were comparable between the FI and DI75 treatments (Table 1). In both parameters, the DI50 treatment were significantly smaller than those obtained under the full (FI) treatment and statistically different to DI75 treatment. However, fruit weight and size were not significantly different between the DI50 and FM treatments. The differences in fruit weight and size may be due to the different fruit load among treatments. Moriana et al. (2007) found that fruit weight decreased drastically in response to the level of water stress and fruit load. They also report that during severe deficit irrigation, fruit diameter growth slowed.

Table 1. Fruit weight and size under different irrigation treatments.

Treatments	Fruit weight (g)		Fruit size (mm)	
	2013	2014	2013	2014
FI	5.49	6.01	18.50	19.93
DI75	5.05	5.52	18.30	19.40
DI50	4.08	4.59	16.50	16.98
FM	4.51	4.93	17.10	18.10
LSD[1]	0.411	0.635	1.234	1.507

[1]LSD: Least significant difference.

Water productivity

Irrigation water supply was reduced by 1700, 2030 and 3380 m^3 ha^{-1}, and 1690, 2010 and 3280 m^3 ha^{-1}, respectively, for DI75, FM and DI50 treatments in 2013 and 2014 with different yields in comparison to the FI treatment (Table 2). With the FM treatment less water was applied (473 and 491 mm) than that in the FI treatment, indicating that a farmer without knowing practices DI.

Irrigation water productivity (IWP) ranged from 9.0 to 6.5 kg ha^{-1} mm^{-1} for the DI50 and FI treatments, respectively. The largest IWP values were observed in the treatment (DI50); whereas the lowest IWP was obtained under FI due to the larger amount of applied irrigation water. Increasing IWP may be a means of achieving efficient water use. Strategies such as DI have shown that water productivity can be enhanced (Ali et al., 2007) and could be associated with acceptable commercial production. Because water consumption was substantially reduced (average of 25%) with approximately 11% reduction in yield, the application of deficit irrigation (DI75) provides a promising irrigation strategy for table olive irrigation if water is limiting.

Table 2. Irrigation supplies, water saving and productivity under different strategies.

Treatments	Irrigation (mm)		Water saving (m^3 ha^{-1})		IWP[2] (kg ha^{-1} mm^{-1})	
	2013	2014	2013	2014	2013	2014
FI	676	692	-	-	6.5	6.7
DI75	506	523	1700	1690	7.7	7.9
DI50	338	364	3380	3280	8.9	9.0
FM	473	491	2030	2010	7.0	7.3
LSD1	-	-	-	-	1.013	1.211

[1]LSD: Least significant difference.
[2]IWP: Irrigation water productivity.

Net income

Economic analysis was done by using averages of 2 years (Table 3). The results show that the greatest net return was observed with the FI treatment followed by the DI75 treatment, whereas the FM and DI50 treatment showed the smallest net return. Larger values of net income under the FI treatment were due to enhanced yields as compared with the DI75, DI50 and FM treatments. The greater net income produced by the FI treatment is reason to recommend it for table olive production when there is no water scarcity. The reduction in the net income of the FM and DI50 treatments was significant and seemed to be non-profitable. The DI75 treatment resulted in a better economic return than resulted from the FM and DI50 treatments; and the DI75 treatment could be applied in table olive orchards allowing water savings of up to 25% with some reduction in yield (11%) and in the economic return (17% reduction). This supports the more widespread adoption of DI75 strategies for table olive growers in the region who would accept a 17% reduction in net income.

Table 3. Production costs and net return of table olive production under different treatments (US$ ha^{-1}).

Treatments	Production costs ($)	Gross returns ($)	Net incomes ($)
FI	2172	3916	1744
DI75	2049	3500	1451
DI50	1933	2728	795
FM	2026	2992	966

CONCLUSIONS

The following conclusions can be drawn from the study:

– The impact of deficit irrigation on yield and fruit quality of drip-irrigated table olive (cv. Meski) was studied using field experiments conducted in southern Tunisia during 2013and 2014. The findings were that irrigation amounts applied in table olive orchards where irrigation is scheduled according to traditional farming (FM) was much less than actually needed. While the recommended irrigation water requirement is 100% of ETc, the traditional farming (FM) applied 30% less than the FI treatment, indicating that farmers practice a form of unintended deficit irrigation. When DI was applied using 25% less water than FI, table olive yield was significantly reduced. There were significant differences between DI75, DI50 and FM treatments.

– Significant differences were not observed between DI50 and FM treatments even though numerically smaller yield was observed in the former (DI50) as compared to the latter (FM). DI50 treatment caused significant decrease in table olive yield with a reduction in size and weight. The irrigation water productivity (IWP) was significantly affected by irrigation treatments. The smallest IWP was recorded under the FI treatment, while the largest IWP was obtained under the deficit irrigation treatment (DI50).

– The DI50 and FM treatments significantly reduced the economic return compared to the full treatment (FI), While the DI75 treatment resulted in a better economic return than did DI50 and FM. Full irrigation (FI) could be recommended for table olive irrigation under the arid climate of southern Tunisia.

– Nevertheless, the treatment DI75 can be applied as a strategy under water scarcity conditions in commercial table olive orchards allowing water savings up to 25% but with 11% reduction in yield and 17% in the economic return.

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