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Impact of Deficit Irrigation Strategies Using Saline Water on Soil and Peach Tree Yield in an Arid Region of Tunisia

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Abstract: Sustainable fruit orchard development in arid areas is severely affected by the scarcity of fresh water. To mitigate the lack of fresh water, the use of low-quality water for irrigation is becoming a common practice in several margin areas. However, salinity is considered one of the most important environmental constraints limiting the successful crop production. Therefore, the effects of deficit irrigation strategies using saline water (3.1 dS m^{-1}) on soil water content, soil salinity, and yield of commercial peach orchard were investigated. Three irrigation treatments were considered: a Control, full irrigated (FI); and partial root-zone drying (PRD_{50}); and deficit irrigation (DI) strategies irrigated at 50% ETc. These levels of water supply allowed for contrasting watering conditions with clear distinction between irrigation treatments. The differential pattern in soil moisture was accompanied by that of soil salinity with an increase in all FI treatments (16–25%). The results indicated that soil salinity increased with increasing water supply and evaporative demand during the growing season from January (3.2 dS m^{-1}) to August (6.6 dS m^{-1}). Deficit irrigation strategies (DI, PRD_{50}) induced more soil salinity along the row emitter compared to the Control due to insufficient leaching fractions. By the end of the growing season, the soil salinity under long-term saline drip irrigation remained stable (5.3–5.7 dS m^{-1}). An efficient leaching action seemed to be guaranteed by rainfall and facilitated by sandy soil texture, as well as the high evaporative demand and the important salt quantity supplied, which maintain the deficit irrigation strategies as valuable tools for water saving and improving water productivity. The significant water saving of 50% of water requirements induced a fruit yield loss of 20%. For this reason, DI and PRD_{50} could be reasonable irrigation management tools for saving water and controlling soil salinity in arid areas and on deep sandy soil.

Keywords: *P. persica*; water restriction; low-quality water; salinization; production; warm area

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1. Introduction

Agricultural production needs to increase nearly 60% by 2050 to guarantee global food security [1]. In this scenario, water is key to ensuring this challenge is met [2]. However, in arid and semi-arid regions, water resources are scarce and competition from other sectors is limiting the amount of fresh water allocated for agriculture. In this regard, water scarcity is becoming one of the major limiting factors to economic development and welfare, affecting 40% of the world population and many ecosystems [3]. Conversely, in a large part of the semi-arid regions, agriculture has consumed approximately 80% of the current fresh water [4]. In addition to the increase in pressures on water and land resources due to population growth and increased food demand, climate change has led to an increase in water demand by increasing temperature and decreasing water availability [5].

To mitigate the lack of fresh water, the use of low-quality water, namely saline water, for irrigation is becoming a common practice in several marginal areas. However, salinity is considered one of the most important environmental constraints, limiting successful crop production, particularly when deficit irrigation is considered. Unfortunately, land affected by salinity is increasing steadily in many parts of the world under global climate change [6,7]. In particular, the wide spread of irrigation in intensive orchards during the last decades, and the decrease in water quality for irrigation in most regions, have aggravated more the situation. It has been estimated that more than 50% of arable land will be salinized by 2050 [8]. In Tunisia, soils affected by the natural salinity cover 10% of the national territory and circa 25% of the total arable land surface [9]. These soils are distributed throughout the country, but more frequently in arid and semi-arid areas. This is partially due to saline irrigation water in addition to a poor water management practice [10]. In these regions, salt's effect is often associated with severe climatic conditions, which have induced more deleterious impacts on crop production [11].

With the decrease in precipitation amounts and changes in precipitation patterns, water allocation to agriculture will suffer more limitations. Under these scenarios, water use efficiency for crop production needs to increase to guarantee an improvement in water productivity (WP). The last component varies substantially among crops, climates, and regions. Therefore, several agricultural management strategies to improve WP are required [12]. A deficit irrigation strategy has been implemented as the best solution for irrigation crops in order to sustainably manage limited water resources, guaranteeing economically sustainable production while saving water [13]. Several deficit irrigation strategies have been developed (e.g., regulated deficit irrigation (RDI), sustained deficit irrigation (SDI), or partial root zone drying (PRD), among others), and have shown beneficial impacts both on water saving as well as on WP improvement in arid and semi-arid areas [14–16]. The slight yield losses due deficit irrigation were compensated by an improvement in fruit quality for many fruit species, such as *Prunus persica* [17,18], *Malus domestica* [19], *Vitis vinifera* [20], and *Prunus domestica* [21]. A drip irrigation system is used when applying deficit irrigation and allows for precise control of the water amount applied, especially in the PRD strategy. Additionally, drip irrigation is an efficient system for salinity control by leaching and displacing salts from the active root zone of trees [22,23].

The use of low-quality water for irrigation has become a common practice in the last few decades due to scarce freshwater resources in the Mediterranean area [24–27]. However, saline water and poor irrigation water management could induce deleterious impacts on soil and crop production, mainly associated with severe climatic conditions such as high temperature, low relative humidity, and intense radiation [10,11]. Thereby, the long-term impact of deficit irrigation strategies with low-quality water on orchards' performances needs to be accompanied by an environmental impact assessment, namely soil salinization, when shifting from freshwater to saline water. In this regard, previous reports have shown soil salinization due to deficit irrigation application in horticulture [28,29]. Interestingly, in olive trees, PRD irrigation associated with saline water (EC 6.7 dS m^{-1}) assured a sustainable long-term yield and resulted in less salt accumulation in the soil than full irrigation [30]. The topic is far from simple, and reported discrepancies are likely to depend on soil characteristics and deficit irrigation managements. Thus, several studies argued that deficit irrigation can be applied in a way that allows for substantial irrigation water savings without contributing to additional salt accumulation in the root zone both in peach and apple production [31,32]. In fact, soil salinization occurs mainly due to the use of low-quality water in irrigation without considering appropriate leaching requirements [33,34], with consequences on food security and sustainability [35].

Nowadays, several countries around the world are forced towards using low-quality water as alternative resources for irrigation in agriculture to overcome the inadequate water supply [36] and sustain agriculture activities. Although low-quality water for irrigated agricultural development could have negative environmental impacts, there is an increasing trend to take accountability for its impacts on the environment, as well as to improve its environmental performance and ensure long-term sustainability [37]. Reducing the amount of total salt, in addition to saving water with little impact on the yield, makes deficit irrigation a very valuable strategy when no drainage systems are used, as is the case of many arid regions [31]. However, it is important to investigate the quantitative relationships between irrigation restrictions, tree growth, yield, and quality of fruit production under conditions of severe water shortages, high evaporative demand, and saline water. The objective is to develop guidelines for deficit irrigation practices suitable for conditions of chronic water shortages and salt control with natural leaching.

The present study aimed at elucidating the impacts of different deficit irrigation strategies using low-quality water on the salt distribution in the soil over three consecutive years of application and their subsequent effect on peach tree performance, especially in dry and desert environments.

2. Materials and Methods

2.1. Orchard Site and Irrigation Treatments

The experiment was conducted in a drip-irrigated commercial orchard located in Ghorthab, Tataouine, southern Tunisia (32°11′47″ N, 10°26′12″ E, and 290 m above the sea). The experimental orchard consisted of four-year-old peach trees (*Prunus persica* L. Batsch), cv. Flordastar was grafted on Garnem rootstock (*P. persica* × *P. dulcis*) and planted at 5 × 5 m spacing (400 trees ha^{-1}) (Figure 1). Trees were grown on deep sandy loam soil with volumetric water content at field capacity and wilting points of 14.8 and 4.9%, respectively, (Table 1) based on texture and the pedo-transfert function of Saxton and Rawls [38]. The physicochemical characteristics of the natural soil within the profile (0–100 cm) are given in Table 1. Trees were trained as open vase. Pest and weed control were performed according to current management practices. The trees were hand-thinned and hand-harvested when fruit reached full commercial maturity. The soil was fertilized in pre-planting by the local organic manure. Throughout the cycle, organic and mineral fertilizers were added by fertigation according the requirement of different phenological stages and the tree age.

Figure 1. Overview of the experimental orchard.

Table 1. Properties of the soil in the experimental field (0–100 cm).

Texture (%)			Bulk Density	pH	OM	ACC	N	P	K
Sand	*Clay*	*Silt*	(g cm^{-3})		(%)	(%)	(%)	(mg kg^{-1})	(mg kg^{-1})
62.5	7	30.5	1.59	8.2	0.8	6.1	0.025	13.90	152.29

OM: organic matter; **ACC**: active calcium carbonate; **N**: total nitrogen.

The region was characterized by a hot desert climate (Bwh) according the Koppen classification, with marked summer drought, warm winter, and a mean annual precipitation and reference evapotranspiration (ETo) of 100 and 1466 mm, respectively. The annual mean temperature is 22.5 °C. The coldest month is January at 11.3 °C and the driest month is August at 30.5 °C.

Irrigation water was delivered using two dripper lines located at 0.5 m from the trunk with four drippers of 2 or 4 L h^{-1} per tree. Three irrigation treatments were applied during four growing seasons (2013–2016) as: (i) Control: fully irrigated with water applied to 100% of ETc for both sides of root zone; (ii) DI: irrigation water applied to both sides of root zone at 50% of ETc; and (iii) PRD_{15}: alternate irrigation switched every 15 days, that supplied 50% of ETc. Water supply was delivered using two dripper lines located at 0.5 m from the trunk. Irrigation scheduling was assured by four drippers of 4 L h^{-1} per tree for the Control and PRD treatments and four drippers of 2 L h^{-1} for DI. The experimental design was a randomized complete block with three replicates, each consisting of one row of 9 trees selected to be similar in potential yield and canopy [14]. The central 5 trees were used for the agronomic measurements.

Low water quality (EC 3.17 dS m^{-1}) from a ground water source was used. The water's chemical composition is described in Table 2. Saline water with a pH of 7.7 had a mineral composition of 361 mg L^{-1} Na^+, 18 mg L^{-1} Cl^-, 37 mg L^{-1} K^+, 15 mg L^{-1} Mg^{2+}, and 189 mg L^{-1} Ca^{2+}. The irrigation of the three treatments started at the same time. The applied water was monitored by mean of water meters.

Table 2. Chemical and physical properties of irrigation water.

EC dS m^{-1}	pH	Mineral Elements								
		Na mg L^{-1}	K mg L^{-1}	Mg mg L^{-1}	Ca mg L^{-1}	N mg L^{-1}	HCO_3 (meq L^{-1})	Cl (meq L^{-1})	Fe mg L^{-1}	Zn mg L^{-1}
3.17	7.7	361.0	37.0	15.4	189.4	1	1.2	18	0.2	0.02

Daily meteorological data were collected by an automatic weather station (BWS 200, Campbell Scientific, Loughborough, UK) located at 15 km, coupled with an automatic data logger CR200X (Campbell Scientific, Loughborough, UK). Daily climatic data were used to estimate the reference evapotranspiration (ETo) based on the Penman–Monteith method [39]. Crop evapotranspiration (ETc) was determined by using the single crop coefficient (Kc) method and based on reference tree growth stages: initial, development, mid season, and late season. Crop coefficient values of 0.5, 0.9, and 0.5 were, respectively, adopted for initial, mid, and late seasons [39]. Consequently, ETc was calculated under standard conditions with the following formula:

$$\text{ETc} = \text{Kc} \times \text{ETo} \quad (1)$$

where ETo: Penman–Monteith reference evapotranspiration, and Kc: single crop coefficient.

2.2. Soil Water Content and Salinity Assessment

The soil water content (SWC) was determined by using the gravimetric method. Samples were taken using soil auger up to 0.8 m in depth. For each sampling point, four sub-samples were obtained at 0.2 m intervals. Three replications were taken per treatment during 2016 cropping seasons: the subsequent three successive years of irrigation treatments' application from 2013. Three reference sampling periods were considered: (i) at the beginning of the growing season with low evaporative demand in winter (January); (ii) at the high evaporative demand period in summer (August); and (iii) by the end of the growing season with low evaporative demand in December. Soil samples were taken at different positions from the emitter on the tree row and between the drip lines.

For soil salinity assessment, for each tree, soil samples were realized at 40, 60, 80, 100, and 250 cm from the trunk and were, respectively, distant by 0, 20, 40, 60, and 250 cm from the dripper. The measurements were taken at 0.2 m increments from the soil surface to a depth of 0.8 m. Soil moisture was obtained using the gravimetric method after drying at 105 °C and bulk density. The same soil samples taken from the tree root zone during the periods of low (winter) and high (summer) evaporative demand were also used to determine the electrical conductivity (EC) of the soil solution extracted from the saturated paste. Salinity distribution through the 0.8 m soil depth was characterized in relation to irrigation treatments. The initial soil salinity was determined in December 2012 before the application of deficit irrigation treatments.

2.3. Environmental Impact

Under water scarcity, the use of saline water for irrigation in arid areas increases the total dissolved salt delivered to soil, which could induce harmful impacts on soil and fruit yield. To estimate the environmental impact of using saline water for irrigation on a peach tree orchard, a common function relating the total dissolved salt (TDS) and the specific electrical conductivity (EC) [40,41] was used:

$$TDS = a \times EC; \ a = 0.64 \tag{2}$$

where TDS is the total dissolved salt content (g/L) and EC is the electrical conductivity (mS/cm).

2.4. Fruit Yield

The fresh fruits yield harvested each experimental year was computed for selected trees. Fruits were picked at three harvesting dates, starting from the middle of April each year, and the total yield per tree was determined as kg tree^{-1}.

2.5. Statistical Analysis

The data collected were subjected to an analysis of variance using STATIGRAPHICS software. Multiple comparisons were performed using the LSD test ($p < 0.05$). All graphs were constructed using GraphPad Prism software version 5.03. The EC contour maps were plotted using Surfer 8.2 (Golden Software, Golden, CO, USA) and the Kriging method for spatial interpolation.

3. Results

3.1. Climatic Data and Applied Water

Contrasting watering conditions occurred during the four-year monitoring (2013–2016). Reference evapotranspiration (ETo) and precipitation showed interannual variation over the experimental period (Figure 2). Precipitation presented high seasonal variation, with most of the rainfall occurring between October and April and very little or no rain occurring in the summer, while ETo showed an inverse pattern with peak values occurring during the summer. The annual precipitation was 39, 63, 53, and 60 mm in 2013, 2014, 2015 and 2016, respectively, and mainly occurred in the winter season. However, high evaporative demand characterized the target region, with an annual ETo of 1430, 1465, 1596, and 1596 mm during the four successive years. Consequently, the experimental field was subjected to severe climatic conditions characterized an aridity index (P/ETo) of less than 0.05.

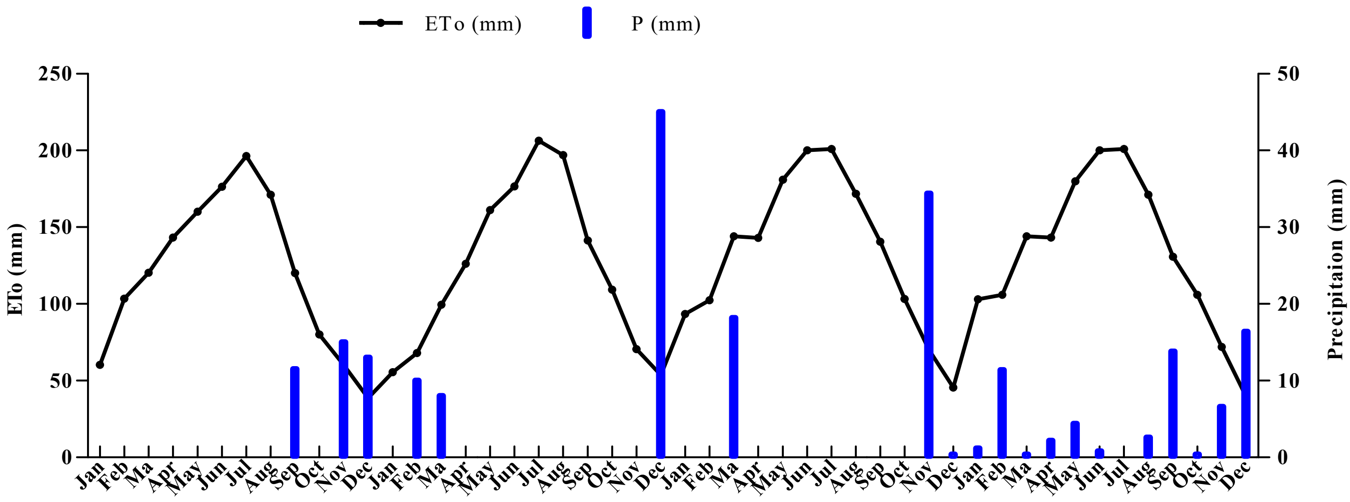

Figure 2. Monthly values of precipitation (columns) and ETo (lines) at the experimental site during 2013, 2014, 2015, and 2016 growing seasons.

Due to scarce rainfall, the water requirements of the peach orchards were fully covered by irrigation. The amounts of water applied in the three irrigation treatments over the experimental period are summarized in Table 3. The water applied varied highly across phenological stages (Table 3). The post-harvest period was the highest water consumer, at around 50% of total irrigation (499–597 mm). In contrast, the initial stage (bud break–full bloom) did not require a high quantity of irrigation water compared to other stages (71–90 mm). The total water applied was in the range of 857–982 mm for the Control fully irrigated, and 50% of that for DI and PRD treatments.

Table 3. Irrigation applied (mm) for each treatment (FI, DI, and PRD_{50}) during the four monitoring years.

Year	Treatment	AI (mm)					Total Salt (Ton ha^{-1})
		BB-FB	FB-FS	FS-H	Post-H	Total	
2013	FI (100% ETc)	71	96	190	500	857	17.3
	DI (50% ETc)	33	49	92	262	435	8.8
	PRD_{50} (50% ETc)	40	50	95	260	445	9.0
2014	FI (100% ETc)	79	92	178	512	861	17.4
	DI (50% ETc)	36	48	89	256	429	8.7
	PRD_{50} (50% ETc)	40	50	90	236	416	8.4
2015	FI(100% ETc)	91	100	175	514	880	17.8
	DI (50% ETc)	39	56	90	251	436	8.8
	PRD_{50} (50% ETc)	35	68	95	233	432	8.7
2016	FI (100% ETc)	85	103	197	598	982	19.9
	DI (50% ETc)	42	51	98	300	491	9.9
	PRD_{50} (50% ETc)	42	51	98	300	491	9.9

Abbreviations: BB: bud break; FB: full bloom; FS: fruit set; H: harvest; Post-H: post-Harvest.

3.2. Soil Water Content

During the last year of the deficit irrigation strategies application, the soil water content (SWC) was determined during three reference periods: beginning, mid, and end of the growing season. As a result, the irrigation treatments had significant effects on soil water content (Figure 3). The mean SWC values were higher in the FI (16.3–24.8%) treatment than the deficit irrigation strategies DI and PRD_{50}, especially during the active growing stages and increasing tree water demand (January and August). Full-irrigation treatment induced the highest SWC as a consequence of the high quantity of water applied (Table 3). Deficit irrigation strategies DI and PRD_{50} displayed similar SWCs over the three reference sampling periods. By the end of the season (December), low SWC values were obtained without significant differences between the Control (FI) and deficit irrigation strategies (DI and PRD_{50}) (5.7–6.6%).

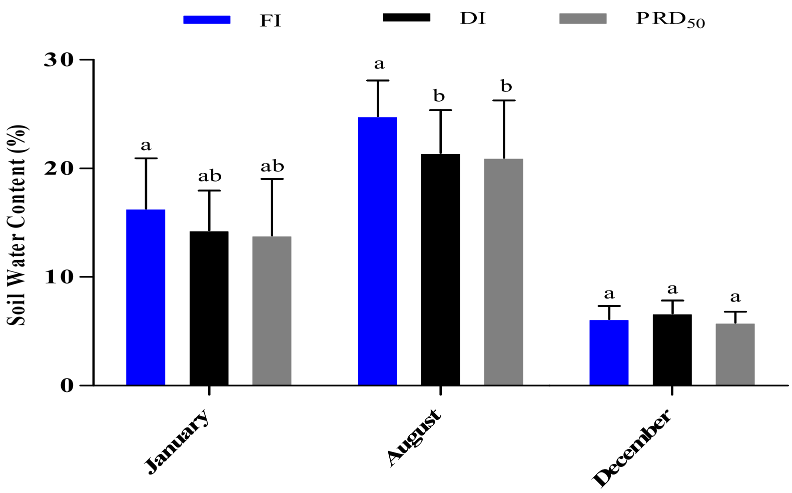

Figure 3. Soil water content (SWC) in January, August, and December 2016 under FI, DI, and PRD_{50} irrigation treatments. Different letters refer to significant differences tested using Duncan's multiple range test ($p < 0.05$).

3.3. Soil Salinity Distribution

The initial soil salinity was determined in December 2012, before the beginning of the irrigation treatments (Figure 4). With conventional irrigation practices in the commercial orchards, the salinity varied between 8.6 dS m^{-1} in the 0–20 cm layer and 5.9 dS m^{-1} in the last layer, with a mean soil salinity of 6.85 dS m^{-1} by the end of the growing season. After three successive years of irrigation treatments' application, low soil salinity was observed at the beginning of the growing season (January) and ranged between 3.2 and 4.8 dS m^{-1} (Figure 5). These values were less than the initial mean soil salinity recorded in 2012 and could be explained by the start of the irrigation season and the important rainfall recorded in the end of 2015. As the evaporative demand increases, the irrigation water applied increases, and soil salinity increased significantly at the second reference sampling period (August). During the summer, the mean soil salinity reached 6.6, 7.1, and 7.6 dS m^{-1} under FI, DI, and PRD_{50}, respectively. By the end of the growing season, the mean soil salinity decreased to reach 5.0 dS m^{-1} for full irrigation FI and 5.8 dS m^{-1} for DI and PRD_{50}.

The spatial salinity distribution along the row at different distances from the emitter and up to 0.8 m in depth is presented in Figures 6–8. The salinity distribution was different between soils layers, with a global decrease in electrical conductivity (EC) marked in different irrigation treatments under the three reference-sampling periods. Along the emitter row, the mean EC of FI samples taken at the beginning of the growing season (January) was 44% lower than the EC of summer samples (August). In the surface layer (0–20 cm), deficit irrigation strategies DI and PRD_{50} induced soil salinity increases by 29% and 61%, respectively, compared to the Control in January. A similar trend was observed during the high evaporative demand (August). Soil salinity increase reached 5.2 and 6.3 dS m^{-1} for the FI and DI soil samples, respectively. The application of deficit irrigation strategies (DI and PRD_{50}) increased the soil salinity and increased the risk of secondary salinization under our experimental conditions. At the end of the growing season (December), soil samples taken along the irrigation row revealed no noticeable differences in EC between FI, DI, and PRD_{50} (5.3–5.7 dS m^{-1}). During this period, the peach orchard was not irrigated. However, soil salinity highly increased in each point outside the wetting zone (60 and 250 cm from the emitter) in all period samples under FI, DI, and PRD_{50} (Figures 6–8).

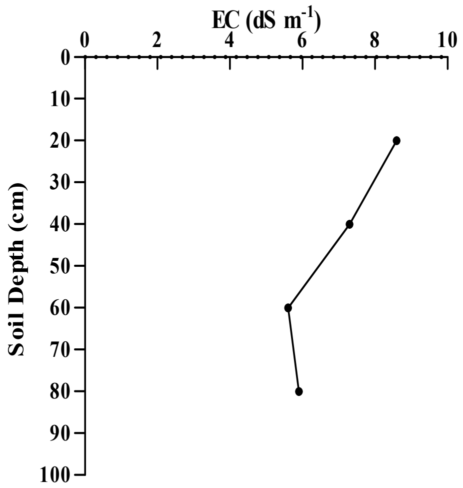

Figure 4. Initial soil salinity at different soil depths determined in December 2012. Each point is the mean of three soil profiles.

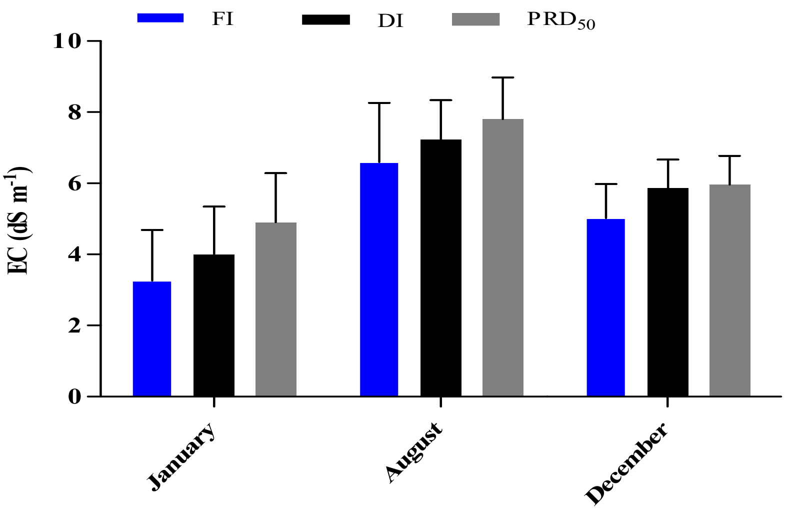

Figure 5. Mean soil salinity measured in FI, DI, and PRD50 irrigation treatments at three different periods (January, August, and December).

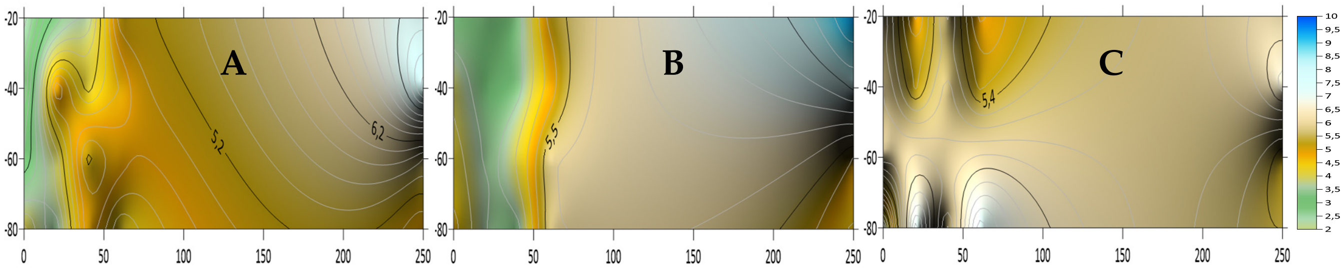

Figure 6. Soil salinity distribution along the row under FI (**A**), DI (**B**), and PRD_{50} (**C**) irrigation strategies at the beginning of the growing season (January) after 3 years of irrigation treatments' application.

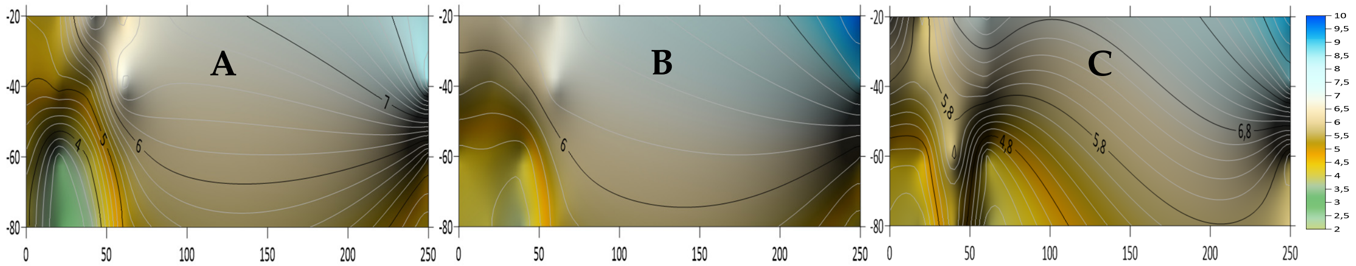

Figure 7. Soil salinity distribution along the row under FI (**A**), DI (**B**), and PRD_{50} (**C**) irrigation strategies during the high evaporative demand period (August).

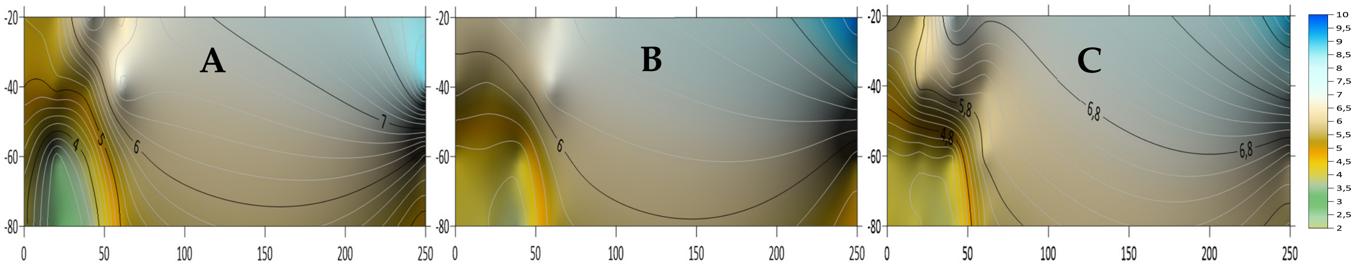

Figure 8. Soil salinity distribution along the row under FI (**A**), DI (**B**), and PRD_{50} (**C**) irrigation strategies by the end of the growing season (December).

3.4. Peach Yield

The irrigation water restriction of 50% induced a significant decrease in peach production by 20 to 25% in all experimental years (Figure 9). The yield losses were attributed to the decrease in fresh fruit weight, fruit diameter, and tree load. Likewise, the peach production increased with tree age, with the highest yield recorded in 2016 compared to previous experimental years (2013, 2014, and 2015). The two deficit irrigation strategies (DI and PRD_{50}) exhibited similar performances, with insignificant differences in fruit yield over the four monitoring years (2013–2016).

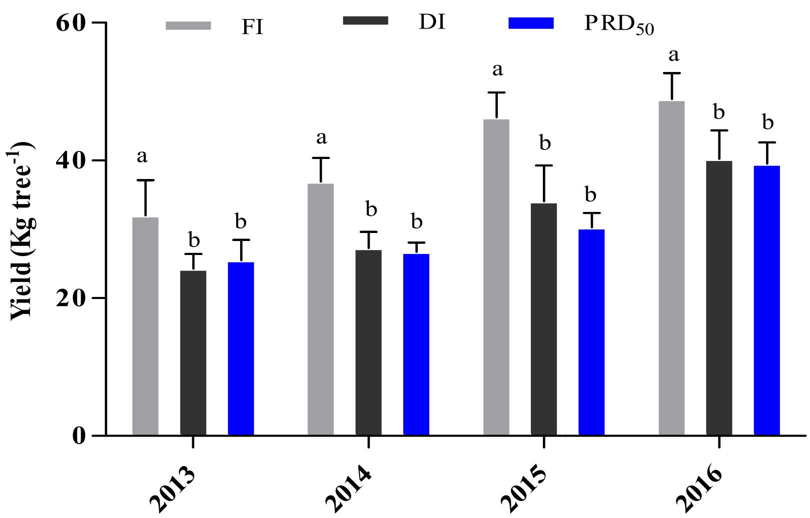

Figure 9. Peach fruit yield in the irrigation treatments (FI, DI, and PRD_{50}) during 2013–2016 growing seasons. Different letters refer to significant differences tested using Duncan's multiple range test ($p < 0.05$).

3.5. Environmental Impact

In our case, the correlation factor 'a' was considered to be equal to 0.64 [40,41], and then the total salt applied via irrigation water was estimated. Deficit irrigation strategies induced more soil salinity compared to full-irrigated treatment. However, the soil salinity level was lower (EC 5.3–5.7 dS m^{-1}) than the initial value measured before the application of deficit irrigation strategies (EC 6.85 dS m^{-1}). The increasing of soil salinity was not yet correlated to the total salt delivered in soil by the respective irrigation treatments. Subsequent full irrigation, a total salt quantity around 17.5 Tons ha^{-1} was supplied yearly compared to about 9 Tons ha^{-1} delivered by DI and PRD_{50} (Table 3). It seems that after four years of experiment with deficit irrigation strategies, the amount of total salt reduced, in addition to saving water and maintaining a stable soil salinity level while no drainage systems were used. It also had little impact on the yield, which makes these irrigation strategies a valuable tool for our arid regions.

4. Discussion

The use of saline water for the irrigation of fruit tree orchards is widely common in arid and semi-arid areas. In this investigation, an irrigated peach tree orchard using saline water was considered. The average amount of irrigation water applied over the 4-year experiment was 895 mm for FI and did not exceed 500 mm for the deficit irrigation strategies, DI and PRD_{50}. The precipitation average was very low. The applied water was in the range of peach water requirements previously reported [42,43]. These levels of water supply allowed for contrasting watering conditions with a clear distinction between irrigation treatments. These treatments using a low quality of irrigation water differently influenced the soil water status and salinity distribution in the sandy deep soil of peach tree orchards. The irrigation treatments had significant effects on soil water content, with higher mean SWC values under the FI treatment during the active growing stages and increasing tree water demand (from January to August) compared to the deficit irrigation strategies, DI and PRD_{50}. These deficit irrigation strategies displayed similar SWCs over the three reference sampling periods. Differences in soil moisture values between the irrigation treatments were significant for the levels recorded in summer and autumn. By the end of the season (December), low SWC values were obtained with insignificant differences observed between the irrigation treatments. Similar trends were also reported when using deficit irrigation strategies in fruit crops, such as olive and peach [16,30]. Moreover, it was reported that the difference between DI and PRD and the efficiency of alternating irrigation depended on the frequency of the switch, which was determined according to soil type and other factors such as rainfall, temperature, and evaporative demand [44–47].

The differential pattern in soil moisture among the irrigation treatments was accompanied by that in soil salinity. Using saline water induced low soil salinity at the beginning of the growing season (3.2–4.8 dS m^{-1}) after four successive years of irrigation treatments' application, less than the initial reference mean value. A trend of increasing soil salinity with increasing water supply and evaporative demand occurred, reaching the range of 6.6–7.6 dS m^{-1} in the summer and then decreasing to 5.0–5.8 dS m^{-1} for irrigation treatments. Moreover, the spatial salinity distributions revealed differences between soils layers. In the surface layer, deficit irrigation strategies induced soil salinity increases compared to the Control during the growing season. The salinity maps show the highest salt accumulation with DI and PRD_{50} and in the drying zone along the row emitter. The surface layer was the most affected by salt accumulation due to the direct evaporation of water. A high typical spatial variability in EC was determined at different sampling points from the emitter. A similar finding was reported for a Calrico peach orchard grown in sandy loam soil and irrigated with moderately saline water [22]. Water and salt dynamics in the soil depended on the applied water and precipitations. The seasonal variation in soil salinity levels showed that it was significantly lower during the wet season than in the summer period. The best estimation of the salinity and soil moisture under field conditions is the average within the root zone because uniformity does not normally exist [48]. Soil salinity depends on water salinity level, irrigation system, soil texture, and climatic conditions [26,49]. Melgar et al. [26] have reported that salt was leached by rainfall occurring at the end of the irrigation period. For Mediterranean-type climates with seasonal rainfall, Shalhevet [48] has suggested that winter rainfall annually leaches the salts accumulated in the soil profile, inducing a similar EC value under FI and deficit irrigation strategies. This efficiency of leaching action depends on precipitation regime. With rainfall of about 400 mm year^{-1}, Metochis [50] has reported that soil salinity under saline drip irrigation remained stable after nine years, while there was a high risk of soil salinization with rainfall less than 250 mm, as in our case. However, soil texture could be an essential factor in determining soil salinity and crop salt response. Leaching of salts seems to be facilitated by sandy soil texture allowing for free water circulation through the soil. The lower level of soil salinity registered in the wet season in comparison to the summer suggests the leaching of salts by rainfall occurring in autumn and winter, as similarly observed in other experimental sites with a Mediterranean climate, such as in southern Tunisia and Spain [26,30]. The higher EC value observed in the upper soil layer was due to higher evaporation occurring in the surface, as previously reported [51].

When considering the total salt supplied by irrigation with saline water, it seems that deficit irrigation strategies, in addition to saving water, delivered less salt. The drip irrigation systems seemed to play a great role in the distribution of soil salinity via the exclusion of salt outside the root zone and, consequently, the maintenance of plant water status at an acceptable level [52]. Previous work has reported that PRD saving 20% of water kept the soil salinity of the rooting zone below the maximum crop tolerance threshold and could be a cost-effective pathway which guarantees the sustainable application of diluted seawater in the irrigated sunflower lands [53].

Irrigation water quality is among the most predominant factors affecting deficit irrigation (DI) strategies' efficiency. Although a rational solution under water scarcity, substituting freshwater with saline water may alter DI results. In arid areas with high evapotranspiration and the importance of salt quantity supplied, efficient leaching action is needed. Thus, the change in precipitation trends (with reduced rainy days with high intensity) plays a key role in leaching salts. As previously observed in arid and warm conditions, efficient leaching has been guaranteed by rainfall and facilitated by sandy soil texture, which maintain the deficit irrigation strategies as valuable tools for saving water and improving water productivity [30]. Isidoro and Grattan [53] have reported that rainfall distribution is a key factor in controlling soil salinity in the root zone. The deficit irrigation treatments (DI and PRD_{50}) allowed for significant water saving of around 20%, with fresh yield losses of around 20. This finding is in agreement with previous reports on many fruit crops, such as peach [42] and apple [54]. Leib et al. [54] have reported that deficit irrigation strategies with 50% of ETc applied in an apple orchard provided water saving with no penalties in yield. A PRD irrigation strategy improved olive oil production for 'Chemlali' Tunisian local cultivar irrigated with saline water [27]. The yield parameters of 'Valencia' orange cultivar were not affected when trees were submitted to long-term PRD treatment [55].

5. Conclusions

With increasing water scarcity, deficit irrigation strategies are widely recommended in arid and semi-arid areas to valorize the limited water availability. In these areas, irrigation using saline water is becoming a common practice, and salinity is considered one of the most important environmental constraints limiting successful crop production. In our case, deficit irrigation strategies (DI and PRD_{50}) seemed to be promising techniques for saving water and guaranteed the economic yield of a peach orchard in an arid and warm area of southern Tunisia. Using saline water, the differential pattern in soil moisture among the irrigation treatments was accompanied by that of soil salinity. A trend of increasing soil salinity with increasing water supply and evaporative demand during the growing season occurred. By the end of the growing season, the soil salinity under the long-term saline drip irrigation application remained stable. Although the high evapotranspiration and the quantity supplied were important, efficient leaching action was guaranteed by rainfall and facilitated by the sandy soil texture, which maintain the deficit irrigation strategies as valuable tools for saving water and improving water productivity. A significant water saving of 50% of water requirements induced a fruit yield loss of 20%. For this reason, DI and PRD50 could be reasonable irrigation management tools for saving water and controlling soil salinity.

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