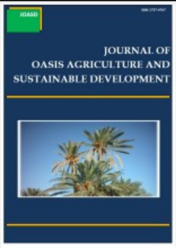

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Impact of irrigation methods using saline water on carrot yield, water productivity and soil salinization

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Abstract

A two-season study (2017-2019) was conducted to assess the effects of surface and drip irrigation methods using saline water (ECi of 7.4 dS/m) on soil salinization, yield, and water productivity of carrot in arid regions of Tunisia. The results indicate that drip irrigation resulted in higher carrot yields (32.6 and 32.5 t/ha) compared to the surface method (30.1 and 30.4 t/ha) due to better soil moisture and lower salinity levels. However, for both methods, no significant differences were observed between the two seasons due to the amounts and distribution of rainfall events. Drip irrigation (6.3 and 6.2 kg/m3) was more water-productive than surface irrigation (5.7 and 5.4 kg/m3), following the same scheduling rule, due to higher yield and reduced water use. The relative difference in WP can have a positive economic impact in terms of farm productivity and sustainability. Compared to initial values, the reduction in soil salinity at harvest was due to salt leaching caused by rainfall. Higher soil salinity was observed with surface irrigation compared to drip irrigation, possibly due to increased evaporation from the soil between the respective irrigation sessions. Therefore, farmers under these conditions should re-think about their common choice of irrigation method.

1. INTRODUCTION

In the context of climate change, the diminishing availability of high-quality water has emerged as a constraint on irrigated agricultural systems in the arid regions of Tunisia. Consequently, farmers are increasingly adopting the use of saline water for irrigation to mitigate this water scarcity. This method involves the application of saline water, with salinity levels ranging from 2 to 5 g/l and beyond, to sustain a diverse array of crops, including but not limited to potatoes, lettuce, faba beans, and carrots, sourced from shallow wells. (Nagaz et al., 2012).

However, using saline water for irrigation in these regions without proper scheduling by farmers could threaten the sustainability of the system. This could lead to decreased water productivity and increased salinity problems. (Nagaz et al., 2012, 2017). Thus, good irrigation management practices are required in order to improve farmers' practices and water use, enhance water productivity and control the risk of soil salinization. Both quantity and quality of water to be used and their effects on the farm productivity need to be precisely known. This can be achieved by determining the water needs of crops and selecting the most suitable irrigation system. Many studies have been directed towards defining the effects of irrigation systems on crop growth and development as well as on soil salinization and water productivity. Machado et al. (2017) reported that drip and subsurface drip irrigation systems allow for better salinity management compared with furrow irrigation method by creating a suitable root-zone salinity. According to Rhoades et al. (1992), drip irrigation is recommended for the use of saline water since it minimizes salinity and matric stresses in the root zone, given salts accumulate in the border of the wetted area and higher levels of salinity in irrigation water can be tolerated compared with surface irrigation method. Moreover, it results in considerable saving in irrigation water and improves yield and water use efficiency (Srivastava et al. 1994; Hanson et al. 1997; Fekadu and Teshome 1998; Sezen et al., 2006; Imtiyaz et al., 2007; Shahid et al., 2013; Ghazouani et al., 2015; Fang et al., 2018; J.Kumar et al., 2019).

In the dry environment of southern Tunisia, Carrot (Daucus carota L.) is considered as an important short-duration root vegetable grown for fresh market food. This crop is grown during autumn and winter periods, which coincide with the rainy season, and is irrigated either by drip irrigation or surface irrigation. Because carrot is high-value crop, the irrigation management strategy seeks to maximize yield by supplying the irrigation requirement of the crop through the appropriate irrigation method. The objective of this study was to evaluate the comparative effect of drip and surface irrigation on water saving, soil salinity, yield and water productivity of carrot under the arid conditions of southern Tunisia.

2. MATERIAL AND METHODS

The study was conducted for a period of two years (2017 to 2019) in the experimental field of the agricultural Training Center (33°45' N, 10°63' E; altitude 30 m) located in Médenine, South of Tunisia. The local climate is typically dry Mediterranean, with mean annual rainfall of 150 mm, distributed mainly during autumn to early spring, November to February being the wettest months of the year (Nagaz et al., 2017). According to USDA classification, the soil is a sandy soil with 80.6% sand, 6.3% silt and 13.1% clay content. Average values of field capacity (-0.33 bar) and permanent wilting point (-15 bar) in the 60 cm topsoil are, respectively, 0.214 and 0.087 g g-1, organic matter was 7.7 g kg-1 and bulk density was 1.45 g cm-3. The plant's available soil moisture was 75 mm/m. The electrical conductivity (ECe) values measured before sowing were, respectively, 9.74 and 7.28 dS/m for the first and second year.

Carrot seeds (Daucus Carrota. L) were sown on 21st and 23rd October for the first and the second year, respectively. The experiment was carried out using a randomized complete block design with three replications and two irrigation methods, i.e. drip and surface methods, for comparison. The experimental area was divided into two blocks with three plots per block. Each plot consisted of six rows spaced with 0.5 m between lines and 0.4 m between drippers. The dripper discharge rate was 4.0 L h-1. The plant spacing along the line was 5 cm. For the surface irrigation system, the block was divided into three plots with 2 x 2 m^2 areas separated from each other. The irrigation water was delivered to the plots by tube (PVC, 16 mm internal diameter). The same experimental area was used for the two years. Carrot was irrigated with water from a well having an ECi of 7.4 dS/m. The amounts of water delivered to the plots were measured using a water meter.

The crop evapotranspiration (ETc) was estimated for a daily time step by using reference evapotranspiration (ETo) combined with a carrot crop coefficient (Kc). ETo is calculated using daily climatic data collected from the meteorological station close to the field and the FAO-56 Penman-Monteith method (ETo-PM) (Allen et al., 1998). For the drip irrigation, the carrot crop coefficient (Kc) was computed following the recently developed FAO-56 dual crop coefficient approach, i.e. the sum soil evaporation (Ke) and basal crop coefficient (Kcb) reduced by any occurrence of soil water stress (Ks), that provides for separate calculations for transpiration and soil evaporation (Kc = KsKcb + Ke). For surface irrigation, the simple crop coefficient approach was used.

For irrigation scheduling, the method used was the soil water balance, using a spreadsheet program for Excel, developed according to the methodology formulated by Allen et al. (1998). The spreadsheet program estimates the day when the target soil water depletion (readily available water, RAW) would be reached and the amount of irrigation water needed to replenish the soil profile to field capacity. The program calculates the soil water depletion on a daily basis using the soil water balance and projects the next irrigation event based on the target depletion (40% of total available water in the root zone, 40% of TAW). The depth of the effective root zone is increased with time from a minimum depth of 0.20 m at planting date to a maximum of 0.60 m at harvesting date in direct proportion to the increase in the carrot crop coefficient.

The temporal variability of soil salinity was assessed by determining the soil electrical conductivity on saturated extract (ECe) at different crop growing stages. Soil samples were collected from the center of the plot for surface irrigation and under the emitter for drip irrigation at three different depths (0-20, 20-40, and 40-60 cm).

At the end of the seasons, carrot yield was determined. Three sites were randomly selected from each plot for yield measurement. The size of each site was around 1 m2, and the plants were all harvested.

Water productivity (WP) is defined as the yield obtained per unit of water consumed, whether from irrigation or total received, therefore including the precipitation. The WP was calculated as follows: WP (kg/m3) = Yield (kg/ha)/total water received (m3/ha) from planting to harvest; an irrigation of 75 mm applied before sowing was not included in the total.

The analysis of variance (ANOVA) is appropriate to the experimental design to evaluate the effects of the irrigation methods on soil salinity, yield and water productivity. XLSTAT was used to conduct ANOVA. (https://www.xlstat.com)

A comparison between treatment means was conducted using a test for least significant difference at a P=0.1 significance level. (https://www.xlstat.com)

3. RESULTS AND DISCUSSION

3.1. Irrigation and rainfall

Fig. 1 shows the rainfall events that occurred during the two growing seasons and the applied irrigation water under drip and surface irrigation methods. Total rainfall in the years 2017-2018 and 2018-2019 was 234 mm and 176 mm, respectively. The most significant rainfall events occurred during the initial crop stage, with 159 mm falling 22 days after sowing (DAS) in the first year and 49.4 mm at 19 DAS for the second year. This variation in the distribution and amount of rainfall highlights the need for an effective irrigation strategy to

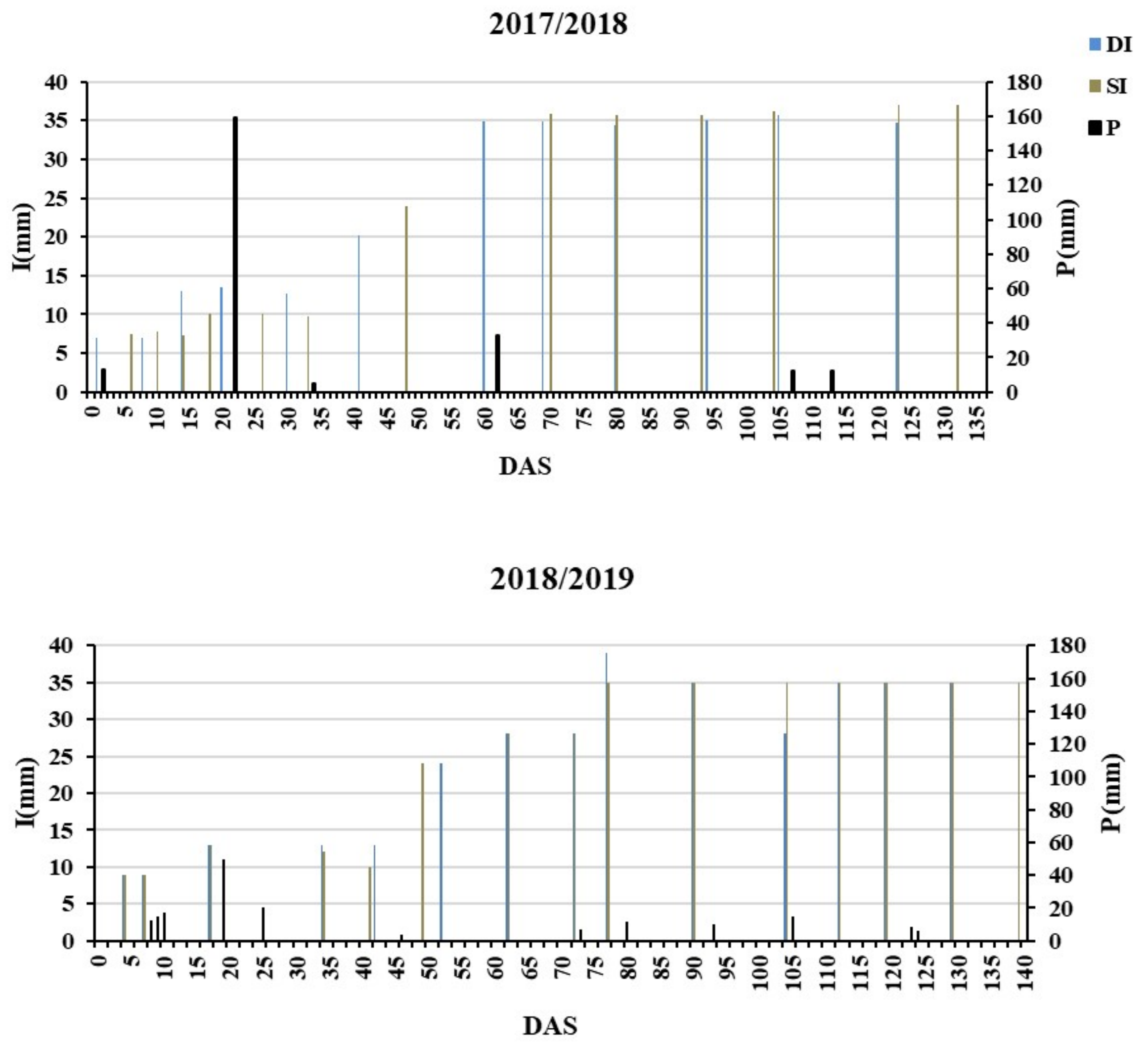

Fig. 1. Rainfall (P) and irrigation water (I) under surface (SI) and drip (DI) method during the 2017/2018 and 2018/2019 seasons.

optimize carrot growth during the rainy season, especially in the wet periods of the seasons. According to Elmokh et al. (2013), farmers in the area of study tend to cultivate short-cycle crops during the rainy season to maximize the productivity of both irrigation and rainwater and to control soil salinization.

For both years, the irrigation event was more frequent during the initial stage, with smaller amounts which did not exceed 13 mm. In the development stage, there was a slight increase in the depths of water applied with a maximum of 24 mm due to the initiation of carrot root forming. During the mid-season stage until harvest, there was a steady increase in water applied, where the maximum irrigation depths reached 37 mm. This is mainly because of the formation and maturity of carrot roots increasing the water crop demand.

For the first year, total irrigation volumes of drip and surface irrigation were, respectively, 283 and 294 mm. For the second year, these volumes were increased by 61 mm and 84 mm for drip and surface irrigation methods, respectively. The total irrigation volume for the surface method was higher by 11 mm and 34 mm than the drip method for the first and second year, respectively. According to Elmokh et al. (2013) and Nagaz et al. (2012), in the arid conditions of southern Tunisia, fully-irrigated carrot crops grown over the fall-winter period used 328-330 mm of irrigation water.

3.2. Soil salinity

Fig. 2 and 3 show the vertical distribution and the temporal evolution of soil salinity (ECe) under drip and surface irrigation methods measured at the initial, development, mid-season, and harvest period of carrot.

Initial soil electrical conductivity values were 9.7 and 7.2 dS/m in the first and second years, respectively. Moreover, the ECe values, measured at the development stage, decreased to 5 and 3 dS/m as compared with initial values for the first and second year, respectively. This decrease is attributed principally to the natural leaching of salts by rainfall events (159 and 49 mm) (Fig. 1). Nagaz et al. (2012) and El Mokh et al. (2015) reported that the capacity of fall-winter rainfall to leach salts in the region is variable and depends on the total amount and distribution of rainfall events. Indeed, the results show an increase in ECe values measured at mid-season due to the lack of rain events in that period used for natural leaching and the fact that

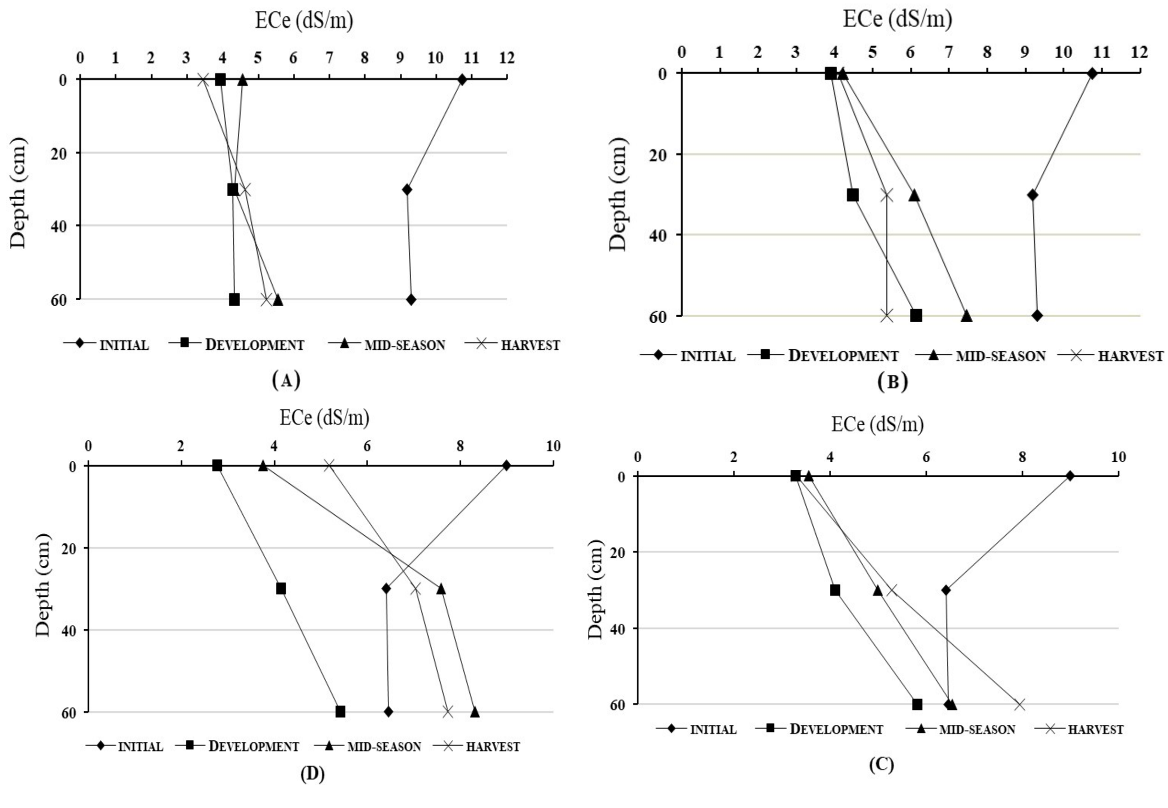

Fig. 2. Vertical salinity distribution in soil profile for the drip (a: season 2017/2018, c: season 2018/2019) and surface (b: season 2017/2018; d: season 2018/2019) irrigation methods.

water is supplied mainly by irrigation.

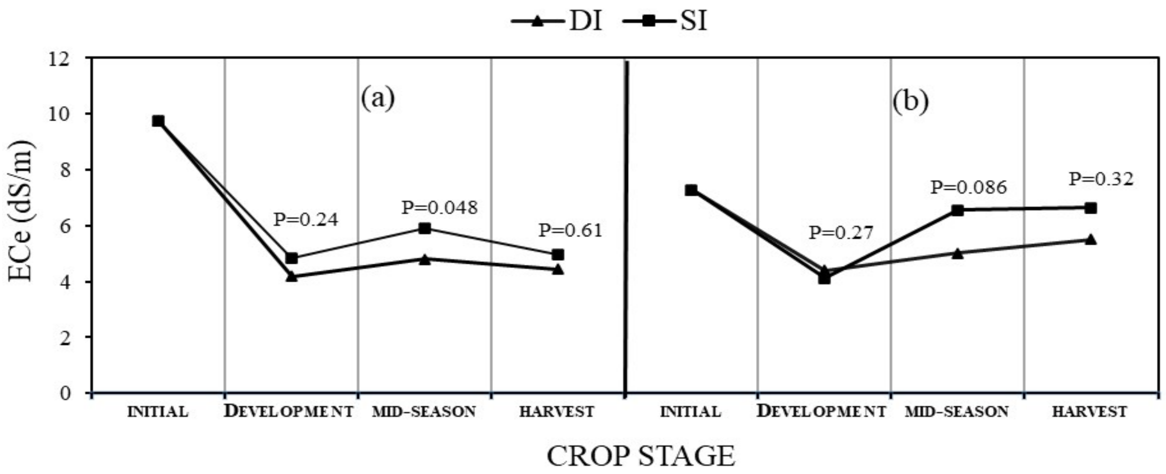

Fig. 3. Temporal variability of average soil electrical conductivity, ECe, under drip (DI) and surface (SI) irrigation methods during 2017/2018 (a) and 2018/2019 (b) seasons.

In both years, it was observed that soil salinity was higher when utilizing the surface irrigation method as opposed to the drip method. Furthermore, a notable increase in the ECe values was evident during the mid-season period of the drip and surface irrigation methods when water application was based on irrigation due to the absence of rainfall. The highest soil salinity values measured under the surface irrigation method were due to higher water losses through soil evaporation. Malash et al. (2008) found similar results for a tomato irrigated with drip and furrow system, and they reported that drip irrigation maintained optimal water levels in the soil and reduced salinity in the root zone when compared with furrow irrigation.

3.3. Crop yield

The results of carrot yield during the two years of experimentation are presented in Fig. 4. From a statistical point of view, the differences in crop yield were not significant between the treatments (P < 0.1). The crop was harvested on 127 and 132 DAS for drip and surface methods, respectively, for the first year. For the second year, the harvest was carried out on 128 and 136 DAS for drip and surface methods. For both years, the surface irrigation method retarded the harvest for an average of a week compared with the drip method. In fact, salinity depressed the plant by reducing the physiologic activities that in turn retarded the crop growth and the maturity of carrot root.

Furthermore, for both years, higher cop yield (32.9 and 32.4 t/ha) was obtained in the drip irrigation method. A reduction of 2.64 - 2.03 t/ha was observed in the surface irrigation method (30.3 and 30.4 t/ha). This reduction is due to the poor soil moisture distribution and high salinity levels maintained with this method. Previous studies have also reported yield reductions with the surface irrigation method compared with the localized irrigation method. Imtiyaz et al. (2007) found 38.6 t/ha root carrot yield under drip irrigation against 29.5 t/ha under the surface method. Fang et al. (2018) indicated that using drip irrigation for wheat winter crops to double the irrigation application numbers improved yield by 12% as compared with the one irrigation application using the flooding irrigation method.

However, for both methods, no significant differences were observed between the two years due to the amounts and distribution of

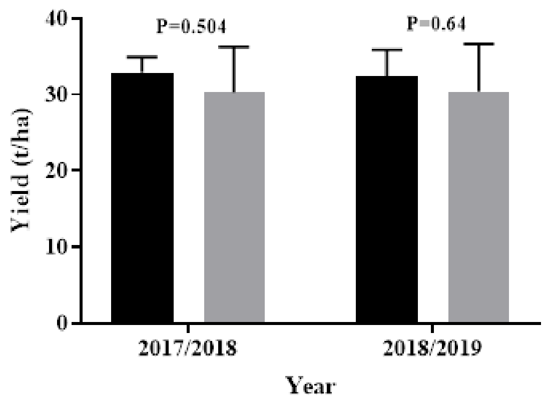

Fig. 4. Carrot yield for drip (DI) and surface (SI) methods during the two seasons of experimentations

rainfall events.

3.4. Water productivity

Water productivity (WP) based on carrot root production was expressed as the ratio of root yield at harvest to the water supply. The results of total water productivity (TWP) and irrigation water productivity (IWP) are given in Fig. 5 for surface and drip irrigation methods for the two seasons.

There was no significant difference between the two years for the TWP due to the similar crop yield obtained and total amount of water supplied. However, the values of IWP show a decrease between the years; they varied typically around 11.6 - 9.4 for drip method and 10.3- 8.04 kg/m^3 for surface method, respectively, in the first and second seasons. The increase in irrigation water supplies reflects this difference. This increase was from 283 to 344 mm for drip method and from 294 to 378 mm for surface method, respectively in first and second seasons.

Despite there was no significant difference between the two irrigation methods, the highest WP was observed with drip irrigation method. The TWPs are 6.4 and 6.2 kg/m^3 for drip irrigation against 5.7 and 5.5 for surface method, respectively, in the first and second years. As the amount of irrigation applied was higher for surface method, the water was used less efficiently in this method where the decrease of carrot yields gave a lower IWP compared to the drip method. A greater WP through drip method has been found in eggplant by Aujla et al. (2007) and in tomato by Malash et al. (2008) compared with furrow method. Moreover, Imtiyaz et al. (2007) reported similar results in carrot crop and found that drip irrigation method gave higher irrigation water productivity with a value of about 13.3 kg/m^3 against 9.9 kg/m^3 for surface irrigation method. In recent studies, Kumar et al. (2019) found that irrigating with drip irrigation could improve irrigation water used by crops efficiently compared to the flooding irrigation method.

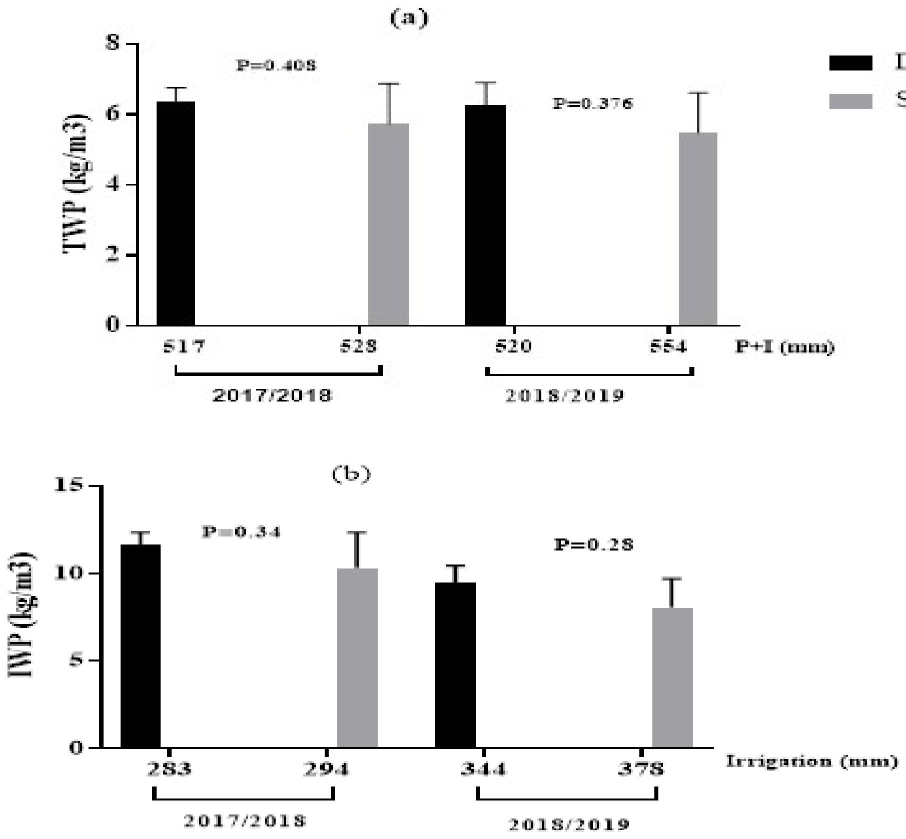

Fig. 5. Total water productivity (TWP) **(a)** and irrigation water productivity (IWP) **(b)** under drip and surface irrigation methods during the two seasons

4. CONCLUSIONS

This work was conducted to assess, over two years (2017-2019), the effect of irrigation methods on soil salinity, yield, and water productivity of carrot under arid conditions. The results show that the highest salinity in the rooting zone was observed under surface irrigation in comparison to drip system. As the salinity increased, there was a reduction in crop yield under surface irrigation compared to drip irrigation. Irrigation water productivity for drip irrigation was increased compared with that of surface irrigation following the same irrigation scheduling rule for both. Higher water productivity in the case of drip irrigation treatment was obviously due to higher yield associated with lower irrigation water supply with the drip method.

As expected, the drip-irrigated treatment required less water than the surface-irrigated treatment and resulted in saving irrigation water. Local farmers were recently involved in a demonstration showcasing the effectiveness of the irrigation facilities, as well as the outcomes of a field experiment on drip irrigation. The demonstration offered insights into the significant increase in crop yield and water conservation achieved through the implementation of drip irrigation methods. As a result of this research, the drip irrigation method is recommended for the irrigation of carrot cultivation. Also, the yield improvement associated with conversion to drip irrigation was substantial and further economic analysis should be done to establish the economic feasibility of converting large areas of carrot production from surface to drip irrigation.

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