Journal of Agriculture and Environment for International Development - JAEID 2020, 114 (2): 85 – 101
DOI: 10.12895/jaeid.20202.1406

Saline water use for vegetable crops production in smallholders' farms

FATHIA EL MOKH[1], KAMEL NAGAZ[1*], M.M. MASMOUDI[2], N. BEN MECHLIA[2]

[1] Institut des Régions Arides, Médenine, Tunisia

[2] INAT, 43 avenue Charles Nicolle, Tunis, Tunisia

**Correspondence details: nagaz.kameleddine@ira.rnrt.tn*

Submitted on: 2020, October 12; accepted on 2020, December 18. Section: Research Papers

Abstract: Field studies on saline water use (6 dS/m) for carrot, lettuce and pepper production in smallholder's farms were conducted in the arid region of Medenine-Tunisia. The irrigation regimes were full (FI) and deficit (DI-80, DI-60, FI-DI60) irrigated with levels of 100, 80 and 60% of ETc when 40% of total available water in the root zone in the FI treatment was depleted, and farmer method (Farmers). Results show that the greatest values of soil salinity were observed under Farmers (FM) and DI-60 treatments. Relatively low ECe values were also recorded under FI-DI60 and DI-80 treatments. The highest mean yields of carrot (26.8-28.7-29.5 t/ha), lettuce (42.6-45.8 t/ha) and pepper (22.3-24.4 t/ha) were recorded for the FI treatment, that is not significantly different from the FI-DI60 and DI-80 treatments. Compared with FI, significant reductions in carrot, lettuce and pepper yields were observed under the DI60 and Farmers treatments, resulting from a reduction in yield components. The Farmers's method increased soil salinity and resulted in an increase of water use of 43-57% for carrot, 26-29% for lettuce and 11.5-16% for pepper. Water productivity (WP) values reflected the differences in yields and varied between 3.4 (Farmers) and 9.7 kg/m^3 (DI-80) for carrot, 7.5 and 19.1 kg/m^3 for lettuce and 2.4 and 5.5 kg/m^3 for pepper across different years and treatments. The soil water balance-based irrigation method (FI) generated the greatest net income compared to the Farmers treatment in carrot, lettuce and pepper productions under arid environment and the lowest soil salinization. FI scheduling technique is suggested for optimizing saline water use for vegetable crops. Under water scarcity, the adoption of the FI-DI60 and DI-80 strategies results in 4.5 to 20% water savings as compared to FI with small impact on salinity in the root zone and yield and net income reductions.

Keywords: Saline water, irrigation management, vegetable, net return, water productivity, smallholder's farm, arid areas

Introduction

Water is becoming increasingly scarce and this condition will be exacerbated by the global climate change affecting the whole North Africa region. The challenge for the next years will be, therefore, the increasing crop production by using less water, particularly in regions with limited resources and inefficient water use. This is particularly the case of arid part of Tunisia, where saline water could be used to intensify agriculture. Various high economic value crops such as lettuce, carrot, pepper, potato and onion are cultivated in areas irrigated with saline waters (Nagaz *et al.*, 2017) over different periods to optimize water use. Production systems, based on crops that are sensitive to salinity, could not be sustainable without the proper management of both water and salt, in order to reduce the risk of soil salinization in irrigated farming of arid lands, mainly due to the lack of rainfall events useful for natural leaching.

The efficient use of saline water for irrigation needs to take into consideration proper irrigation management of both systems and techniques adopted, so to improve farmer's results and therefore save water resources, besides controlling soil salinization (Fisher, 1980; Munns, 2002). Thus, adequate irrigation plan and the use of localized irrigation methods are two possible choices to enhance water productivity in arid part of Tunisia. The use of drip irrigation systems has been increased in crop productions of these areas, to achieve the twin objectives of higher productivity and optimal use of water.

Yohannes and Tadesse (1998), Cetin and Bilgel (2002), Ayers *et al.* (1986), and Fereres *et al.* (1985) reported that saline water can be effectively used by means of the proper management of drip irrigation, allowing considerable water saving and reducing the risk of soil salinization. Many works have highlighted that yield of potato, onion, lettuce, tomato, cotton and cantaloupe can be improved with drip irrigation (Singh *et al.*, 1977; Sammis, 1980; Wood, 1988; Saggu and Kaushal, 1991; Sener *et al.*, 1994; Weatherhead and Knox, 1997; Hansona *et al.*, 1997; Yohannes and Tadesse, 1998; Daleshwar *et al.*, 2006; Erdem *et al.*, 2006). These potentials of drip irrigation are not yet fully known by farmers in arid part of Tunisia, as local irrigation scheduling practices remain empirical, in terms of irrigation timing and quantities, often leading to water losses during periods with low water needs and, on the other hand, to water deficits during peaks in plant-water demand (Nagaz *et al.*, 2017). Therefore, sound management of irrigation using drip system is required to assist farmers in their decision making-processes.

Vegetable crops, considered as high value crops, are grown in arid part of Tunisia, during the rainy season, which is usually occurring between autumn and spring, in small-scale irrigation schemes and irrigated with underground waters. The optimal irrigation management strategy is to maximize yield by supplying the exact irrigation requirement of the crop. However, irrigation is applied by farmers according to their experience, despite water scarcity.

The present work has the aim of evaluating the effect of irrigation management on yield and water productivity and to determine the irrigation water requirements of carrot, lettuce and pepper crops in an arid region of Tunisia. With the expectation to promote appropriate irrigation scheduling and deficit irrigation methods among farmer's communities, all field work was conducted within local farm and with the farmer's participation.

Materials and Methods

Experimental site and climate

Field experiments were conducted during three years (2007-2010) for carrot, during the years 2009-2011 for lettuce and 2008-2009 for pepper, in a commercial farm situated in the Southern East of Tunisia (33°22' N, 9°06' E; altitude 45 m a.s.l.) in the region of Médenine. The climate is typical of arid areas. Historical mean monthly climatic data (22 years) and climatic data relative to the growing seasons of the period 2007-2011 are presented in Table 1 and Figure 1.

The rainfall registered in 2009/2010 during the growing period of lettuce was 26.5 mm (Table 1), while, only 12 mm was recorded in 2010/ 2011. Reference evapotranspiration (ETo-PM) was 597 mm in 2009/2010, and 587 mm in 2010/2011.

During 2007/2008, rainfall was 57 mm during the growing period of carrot (Table 1). Precipitation amount were 25 and 26.5 mm, respectively, during 2008/2009 and 2009/2010. ETo-PM during the growing period of carrot was 596 mm in 2007/2008, 600 mm in 2008/2009, and 597 mm in 2009/2010.

Rainfalls received during the growing periods of pepper (May-October) were 30 and 45 mm, respectively (Fig. 1). The ETo-PM values were slightly lower with a total of 922 and 888 mm for 2008 and 2009, respectively, as compared to 928 mm, the long-term ETo-PM during the pepper growing period. Greatest ETo-PM occurred during July-August (Fig. 1).

Table 1 – Monthly climatic data of the growing period for the long term period (22 years) and for the years of carrot and lettuce field experiments.

	September	October	November	December	January	February
			Air temperature (°C)			
Long term	23.0	21.5	19.5	10.5	10.5	12.0
2007/2008	25.5	22.5	22.9	11.0	11.5	12.7
2008/2009	27.5	24.9	23.8	12.0	12.5	13.3
2009/2010	26.5	24.0	23.1	11.5	12.1	13.0
2010/2011	28.7	26.2	24.4	11.7	11.9	12.8
			Relative humidity (%)			
1979-2002	54	57	63	66	66	60
2007/2008	54	60	59	67	64	60
2008/2009	55	67	64	65	64	54
2009/2010	63	58	65	73	61	66
2010/2011	55	52	62	60	51	55
			Rainfall (mm)			
Long term	17	27	19	25	21	18
2007/2008	20	7	0	13	17	0
2008/2009	11	0	0	0	14	0
2009/2010	7	12.5	0	0	7	0
2010/2011	0	0	0	0	12	0
			ETo-PM (mm)			
Long term	141	109	70	53	55	68
2007/2008	166	129	69	67	80	85
2008/2009	162	131	76	66	75	90
2009/2010	165	128	77	67	74	86
2010/2011	171	135	82	63	66	70

The soil of experimental field is sandy soil with 87.9% sand, 8.9% silt and 3.9% clay. Average water content values in the 80 cm topsoil for field capacity and permanent wilting point are, respectively, 0.179 m^3 m^{-3} and 0.054 m^3 m^{-3} and organic matter content is less than 0.7%. The total soil available water for an assumed root depth of 1.00 m was 125 mm.

Crop management and experimental design

Fertilizers were supplied according to usual levels used by farmers for vegetable production in the region of Médenine, Tunisia. Before planting of carrot and transplanting of lettuce and pepper crops, respectively 16, 2.5 and 9.5 t/ha of organic manure were applied to the soil. Inorganic nutrients were applied as N, P_2O_5 and K_2O at rates of 200, 200 and 150; 250, 250 and 150; 200, 150 and 150 kg/ha respectively, for carrot, lettuce and pepper. All treatments plots received the same amount of fertilizer.

Carrot was planted on 15th of September, in 70 cm rows with plants spaced 40 cm apart, in a randomized complete block design, with four replicates and five irrigation treatments. Plants of lettuce and pepper were transplanted each year into the blocks on 24th of September and 1st of May. Each plot consisted of eight rows and was drip irrigated with groundwater having a salinity (ECi) of 6 dS/m. Each dripper flow rate was of 4 l/h. Water for each plot was accounted by means of a water meter and gate valves, before passing through laterals.

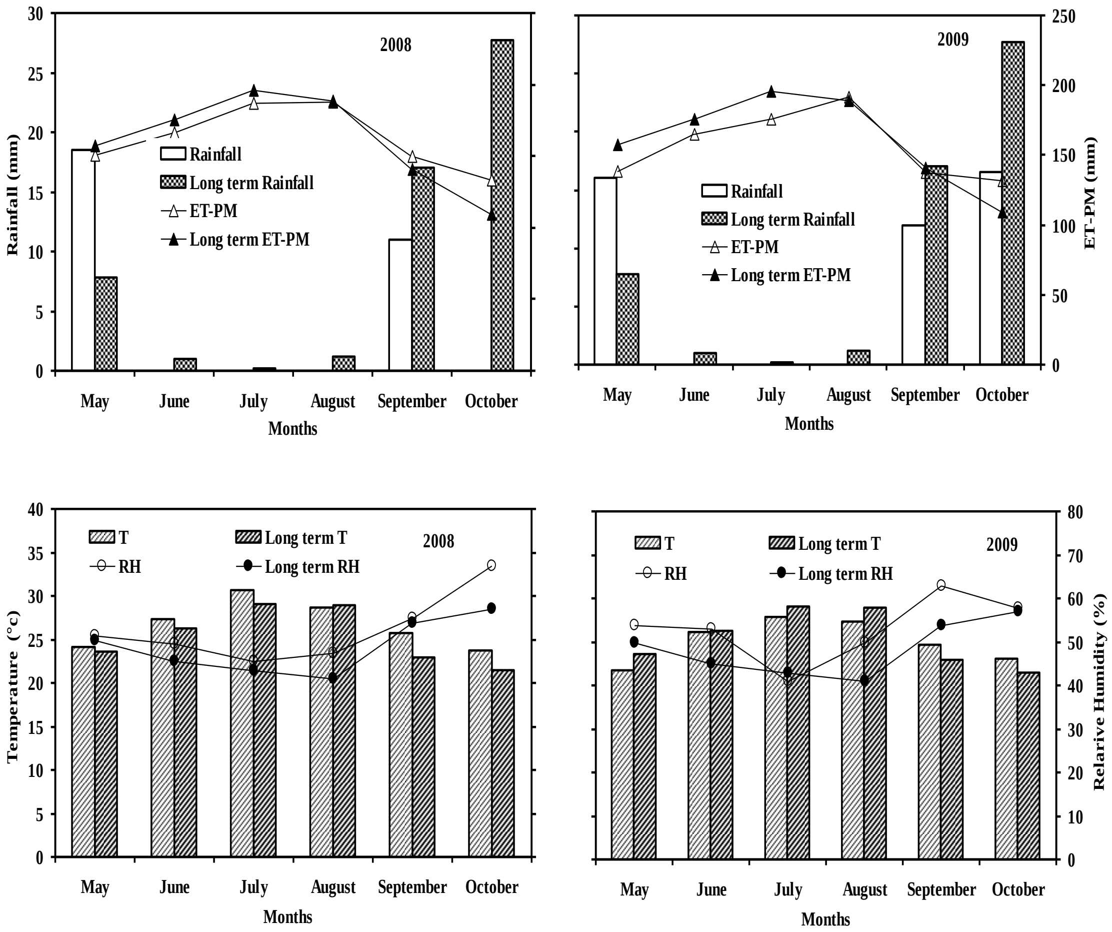

Figure 1 - Monthly climatic data of the growing period for the long-term period (22 years) and for the two years of pepper field experiments (2008 & 2009).

Four irrigation methods based on the soil water balance to determine irrigation quantities and timing were compared to Farmers' method. Soil Water Balance (SWB) strategies consisted in compensating ETc when readily available water is depleted with levels of 100% (FI), 80% (DI-80) and 60% (DI-60). FI represents the full irrigation, while DI-80 and DI-60 are the deficit treatments. The regulated deficit treatment corresponding to 40% of restriction during ripening stage (FI-DI60) was also used. Farmers treatment (FM) consisted in delivering fixed amounts of water to the crop with given intervals.

ETc was computed by means of the Penman Monteith method-determined reference crop water use (ETo) (Allen *et al.,* 1998), using daily climatic data collected from the meteorological station located near the research plot, with a dual crop coefficient (Kc) approach.

A SWB model developed in Excel for managing irrigation of annual crops was used to schedule irrigation (Nagaz *et al.*, 2012; El Mokh *et al.*, 2013, 2014). The model integrates the effects of climatic and crop data, soil characteristics, irrigation system and management to simulate and provide daily values of soil evaporation, transpiration, ETc, drainage and soil water depletion. Simulation starts with soil water content at field capacity at planting. Irrigation occurs when cumulative water depletion drops under a threshold value, corresponding to the readily available water (RAW), 40% of total available water (TAW) in the root zone, so that suggested amounts of irrigation are intended to replenish root zone to field capacity.

Measurements and Water-use efficiency

At harvest, carrot yield was determined for each treatment. Plants were harvested in the first week of February to determine root yield (t/ha), number/m² and average weight (g/root).

Lettuce plants were harvested in the second week of January to determine marketable head weight (yield), number of leaves per plant, head diameter and plant dry weight. Dry matter was determined by weighing the plant material immediately after harvesting for moisture determination. Dry weights were recorded after oven drying plant samples at 70 °C for 72 h. In order to assess the total soluble solids (TSS) content of lettuce, four plants per treatment were divided longitudinally into two equal parts and one part per plant was sampled, after being washed with tap and distilled waters. The sampled leaves were macerated in a blender and the content of TSS (°Brix) was measured over the extracted juice using a manual refractometer (N.O.W., Nippon Optical Warks Co. model 507-I, Tokyo, Japan).

Sections of pepper plots were harvested to determine fresh fruit yields, fruit pepper number and weight each year. The first harvest was made on day after transplanting (DAT) 107, the second harvest was on DAT 133 and final picking was made on DAT 170 in 2008; the corresponding figures for the second year (2009) were DAT 112, DAT 136 and DAT 170, respectively. The total mass from each treatment was weighted in order to assess fresh fruit yield (t/ha) and individual fruits were counted. Fruits number was obtained dividing counted fruits by the area of land harvested for each treatment (fruit number/ha). Fresh fruit from each treatment were weighted to establish average fruit weight (g/fruit).

Soil samples were taken each year, before planting and after harvest, with a 4 cm auger from five different depths for lettuce and from four depths for carrot and pepper, and then analyzed for ECe.

Water productivity (WP) was calculated as follows: WP (kg/m^3) = Yield (kg/ha) / irrigation water (m^3/ha) from planting to harvest; 62 and 100.5 mm irrigation were applied before planting of lettuce, carrot and pepper for all treatments, in order to start with root zone layer at field capacity.

The net income was computed for each irrigation treatment by subtracting total production costs from the gross income. The production costs included tillage, seed, fertilizer, irrigation, insecticide and human labour. Gross return was calculated by multiplying the yield for its market price.

Statistical analysis

Treatment effects on crop yields and components, WP and soil salinity were analyzed using analysis of variance (ANOVA) procedure of STATGRAPHICS Plus 5.1. The LSD test at 5 % level was used to find any significant difference in the above-mentioned criteria, between treatment means.

Results and discussion

Soil water balance

Figure 2 presents soil water depletion estimated by means of the soil water balance model, in the FI treatment during the growing periods of carrot, lettuce and pepper for the first year. The water depletion from the root zone is considered as the net water requirement. The root zone is replenished to field capacity at each irrigation. Since irrigation was applied only when cumulative water depletion, at the end of the previous day exceeded the readily available water, plants may have suffered a slight stress on the day before irrigation.

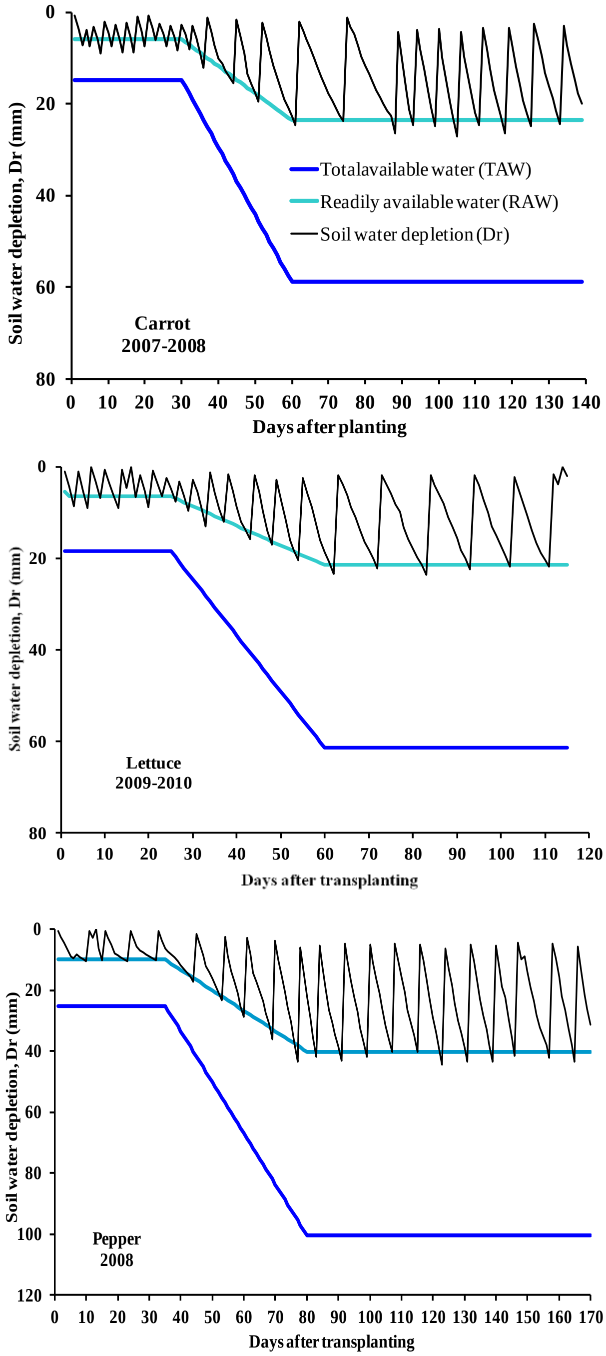

Figure 2 - Daily values of water depletion from root zone for the FI irrigation treatment during the cropping periods of carrot (2007-2008), lettuce (2009-2010) and pepper (2008).

Soil salinity

Figure 3 shows soil salinity values witnessed during the field trials at planting and harvest of carrot, lettuce and pepper for the experiment’s years. The results show a decrease in ECe values at harvest for carrot, when compared to initial soil salinity. This suggests leaching of salts by rain events (57 mm) might have occurred (Table 1).

Values of ECe in 2009 and 2010 were relatively higher than the initial ECe for DI-60 and farmer’s treatments, despite fall and winter rain events, whilst its value decreased for FI, DI-80 and FI-DI60 treatments. The lower ECe values were recorded in the first year corresponding to the highest amount of rainfall during the growing period of carrot (Table 1) that especially contributed to the leaching of salts.

Initial soil salinity values determined at transplanting of lettuce were 3.1 and 2.9 dS/m respectively, in the first and second year. During the year 2009/2010, ECe values decreased under FI, DI-80 and FI-DI60 treatments in comparison to initial soil salinity whilst their values were relatively higher than the initial ECe for DI-60 and Farmers treatments. In 2010/2011, an increase in ECe values has been witnessed for all treatments as compared to initial soil salinity, due to the absence of leaching of salts by rainfall.

For pepper trials, the results showed an increase in ECe values at harvest under all treatments in comparison to initial soil salinity (3.1 and 2.7 dS/m) during the two years. This may be due to the high evaporative demand existing during the growing period and to the fact that water supply was provided mostly through irrigation. The lowest ECe observed in the second year were due to the relatively low initial soil salinity and the leaching of salts by occurred rainfall (Fig. 1). The precipitations during pepper growing season in that year (2009) were the highest of the two years (Fig. 1).

ECe data (Fig. 3) show that there were decreases in the ECe with FI treatment. Low ECe values were also recorded with FI-DI60 and DI-80 treatments. The difference between FI, FI-DI60 and DI-80 treatments was not significant; however, higher ECe values were observed in DI-60 and Farmers treatments when compared to FI. The higher soil salinity observed with DI-60 treatment is due to the absence of leaching under DI conditions, as reported by Geerts *et al.* (2008b) who highlighted the risk of soil salinization increase under DI due to reduced leaching. The greatest ECe values were observed with the farmer's method, although more water was applied in this treatment. Adopting fixed amounts and frequency during the whole growing season may result in applying excess water during the first growing stage and insufficient water during mid and late season. Under such a situation, leaching of salts could not take place and salts accumulated in the root zone.

Crop yield

Results on yield during the years of experimentation are presented in Figure 4 and Tables 2, 3 and 4, respectively. Yields were highest in the first year of carrot and lettuce experiments as a consequence of the low soil salinity and the higher amounts of rainfall (57 and 26.5 mm); however, yields were largest in the second year for pepper, corresponding to the highest rainfall occurred (44.5 mm) and low soil salinity.

These data show that crop yields were affected by irrigation treatments (Fig. 4). FI treatment resulted in the greatest crop yields. FI-DI60 provided also greatest crop yields being not significantly different when compared to FI, similarly to what has been found by González-Dugo *et al.* (2007), Hartmann *et al.* (1986), Sale (1966) and Nagaz *et al.* (2012).

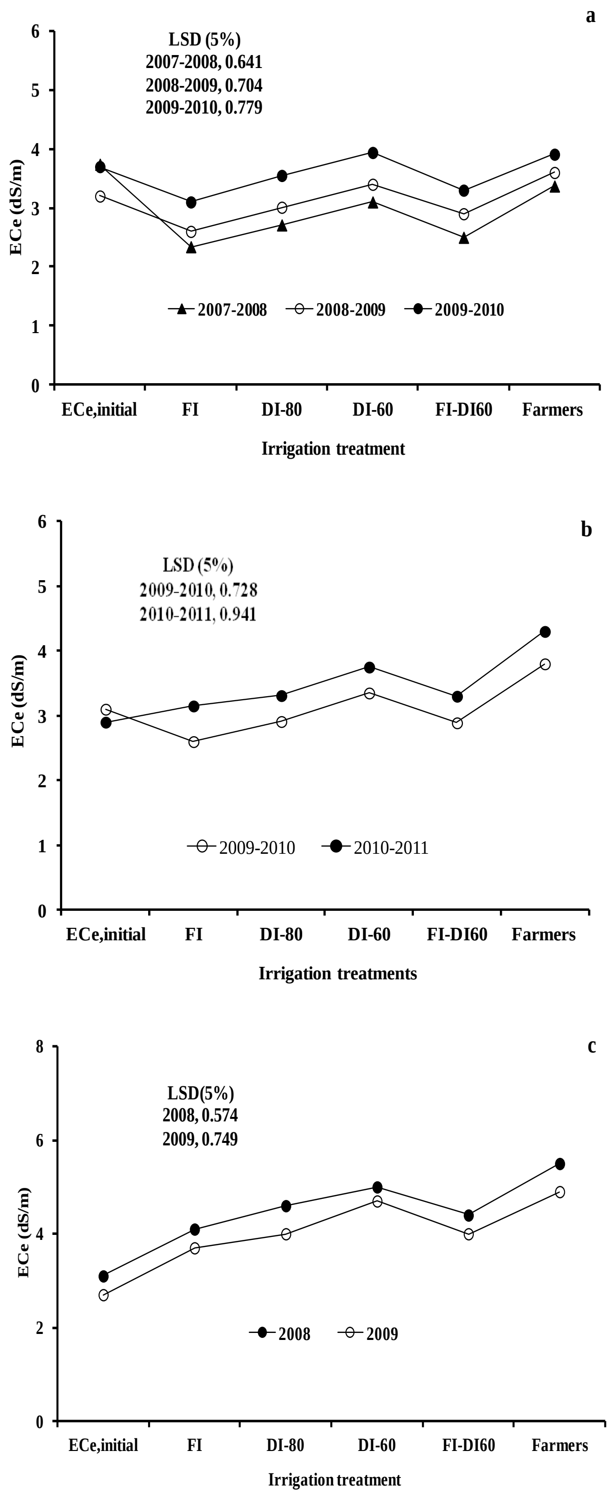

Figure 3 - Soil salinity (ECe, dS/m) under different treatments of carrot (a), lettuce (b) and pepper (c).

Bazza (1999), after conducting DI trials on vegetable crops, concluded that reducing water supply during final stage of the growing period does not affect considerably the crop yield. Thus, restrictions of water supply during the ripening stage, according to our experience as well as to that of other researchers (Jordan, 1983; Howell *et al.*, 1990; Nagaz *et al.*, 2012), could be applied without causing any quantitative or qualitative losses (Fig. 5, Tables 2, 3 and 4). Yields obtained under Farmers treatment were significantly different ($p<0.05$) than those obtained with FI treatment. Crop yields of FI and DI-80 treatments were not significantly different and poorer yields were recorded with Farmers and DI-60 treatments.

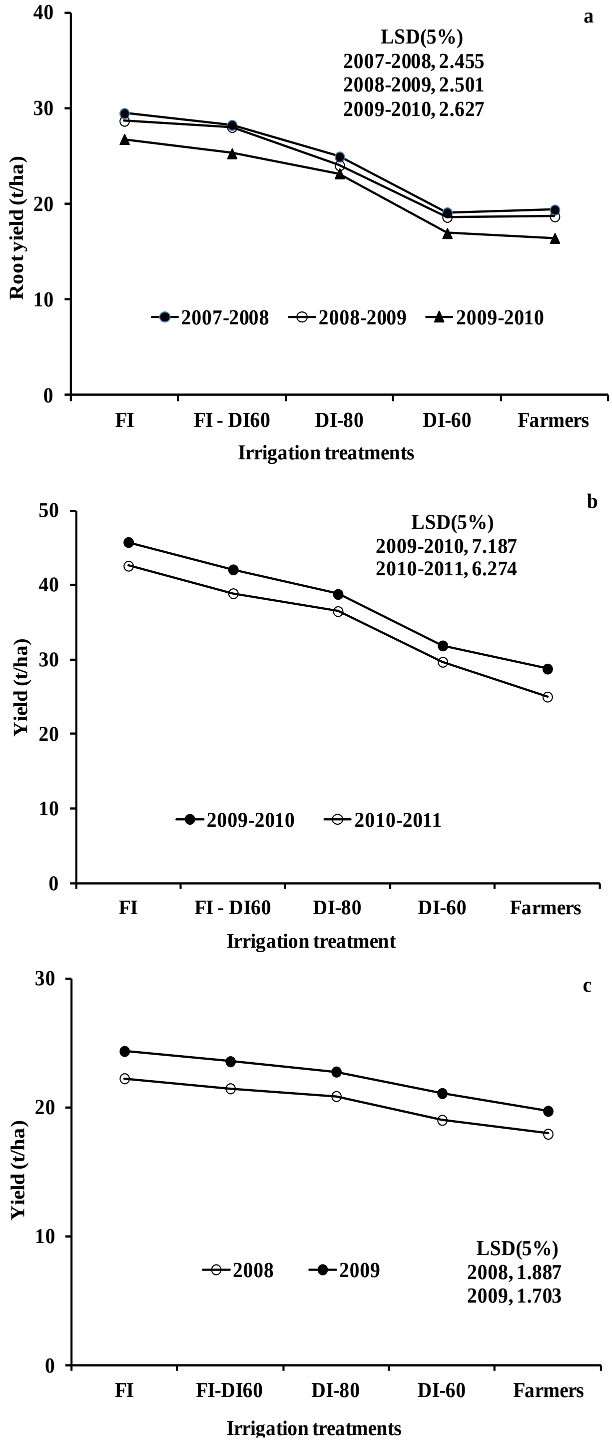

Figure 4 - Yield (t/ha) under different treatments of carrot (a), lettuce (b) and pepper (c).

A significant reduction in crop yields occurred with the DI-60 as compared to FI treatment (Fig. 4). Statistically significant differences ($p<0.05$) were found between the DI-80 and DI-60 treatments. Amongst the DI-60 and Farmers, crop yield of Farmers treatment was the lowest but the difference was not significant. The difference between the Farmers and other treatments (DI-80 and FI-DI60) had proven to be significant ($p<0.05$).

The smaller yields obtained within the Farmers treatment were related with smaller yield components (Tables 2, 3 and 4) as a result of water deficit during the period between flowering and harvest, the most critical periods of vegetable crops for irrigation (Imtiyaz *et al.*, 2000; Singh and Alderfer, 1966; Dorji *et al.*, 2005). Consequently, the higher yields obtained under the FI, FI-DI60 and DI-80 treatments were due to better growth and yield components. Yield and its components of FI and FI-DI60 treatments were not significantly different. Restriction of irrigation water during ripening stage by 40% (FI-DI60) seems to have low impacts on soil salinity and crop yields, as compared to FI treatment. The farmer's strategy resulted in poorer yields than the FI strategy based on SWB method for managing irrigation water. The greater ECe values related with the farmer's strategy (Fig. 3) caused significant decrease in yield of crops; the smaller yields may be due to the fact that the farmers are delivering more water than the effective needs of the crop. The corresponding irrigation practices, distinguished by periods of over and under-irrigation, may result in low water availability during stages with high water needs, thus limiting crop growth and yield.

In previous studies, Nagaz (2007) and Nagaz *et al.* (2012), El Mokh (2016, 2017) suggested the use of the SWB strategy for conditions similar to those of the current work. Therefore, irrigation scheduling based on effective plant water needs is convenient, indicating a good opportunity for the optimal use of irrigation water in farms with a private water source, such as in arid part of Tunisia where irrigation is provided by means of shallow underground waters.

Table 2- Yield components of carrot under different treatments (2007-2010).

Treatment	Yield component/Year					
	Root number/m^2			Average root weight (g/root)		
	2007-2008	2008-2009	2009-2010	2007-2008	2008-2009	2009-2010
FI-100	71	70	67	41.3	41.0	40.0
DI-80	64	59	59	35.4	40.7	39.3
DI-60	60	55	52	24.2	33.9	32.6
FI-DI60	70	68	63	36.2	41.2	40.2
Farmers	62	57	52	23.7	32.8	31.6
LSD (5%)	4.3	5.2	5.0	3.60	2.77	3.11

Table 3- Yield components and quality of lettuce under different irrigation regimes (2009-2011)

Treatment	Head diameter (cm)	Leaves number /plant	TSS (°Brix)	Plant dry matter (g/plant)
		2009-2010		
FI	32.8	33.5	4.09	14.30
DI-80	29.2	32.0	4.12	14.24
DI-60	26.3	30.4	4.16	14.20
FI-DI60	30.4	32.5	4.10	14.25
Farmers	22.4	27.4	4.00	13.80
LSD (5%)	5.559	3.266	0.319	0.538
		2010-2011		
FI	30.7	31.2	3.95	13.21
DI-80	28.9	30.3	4.00	13.15
DI-60	24.4	28.0	4.07	12.97
FI-DI60	29.1	30.1	4.02	13.10
Farmers	20.3	25.4	3.91	12.79
LSD (5%)	4.310	3.001	0.293	0.477

Table 4- Yield components of pepper under different treatments (2008-2009).

Treatment	2008		2009	
	Fruits number (1000/ha)	Average fruit weight (g/fruit)	Fruits number (1000/ha)	Average fruit weight (g/fruit)
FI	1046	21.297	1061	23.011
DI-80	1006	20.278	1012	22.201
DI-60	991	19.219	1004	21.102
FI-DI60	1022	21.039	1026	23.005
FM	983	18.290	998	19.997
LSD (5%)	54.867	1.114	49.740	1.107

Water Productivity

Data regarding the amounts of irrigation water supply provided under the different irrigation treatments of carrot, lettuce and pepper are presented in Figure 5. For carrot crop, irrigation supplies were comparable for FI treatment with 328 mm in 2007/2008 and 2009/2010; and 330 mm in 2008/2009. The irrigation water supply for FI-DI60 strategy was reduced by 31, 15 and 29 mm, respectively, in 2007/2008, 2008/2009 and 2009/2010. DI-80 and DI-60 treatments resulted in water savings of 66 and 131 mm, respectively, in comparison to FI treatment. For lettuce crop, the FI treatment used 278 mm in 2009/2010 and 293 mm in 2010/2011. The water savings from the DI-80, DI-60 and FI-DI60 were 56, 111 and 33 mm in 2009/2010 and 59, 117 and 35 mm 2010/2011 as compared to FI. For pepper crop, the irrigation water supplied to FI, DI-80, DI-60, FI-DI60 were, respectively, 656, 525, 394, and 579 mm for 2008 and 654, 523, 392, and 601 mm in 2009. The net saving in irrigation water with DI-80, DI-60 and FI-DI60 were, respectively, of 20, 40, and 11.7-8.1% in 2008 and 2009, in comparison to FI.

For all crops, more irrigation water was used with the Farmers' method than the FI and DI treatments. Surplus was, respectively, 143 to 188 mm for carrot, 78 to 80 mm for lettuce, and 77-94 mm for pepper crop.

Irrigation Water Productivity (IWP) ranged from 9.7 to 3.4 kg m^{-3} for carrot, 19.1 to 7.5 kg m^{-3} for lettuce and 5.5 to 2.7 kg m^{-3} for pepper, respectively, for D-60 and Farmers treatments, showing a decrease with increasing irrigation water supply (Fig. 5). IWP data showed a linear correlation with the irrigation water supplied, with r^2 ranging between 0.80 and 0.91 (Fig. 5). Nagaz *et al.* (2017) reported that the IWP values of orange under FI above the regression line and those of Farmer's (FM) below it indicate a better water use by FI and a poorer irrigation scheduling by the farmer.

These results prove the potential of DI treatments for improving IWP in terms of yield and irrigation water. The greatest IWP values were observed in the DI-60 treatment whilst the smallest IWP were recorded under Farmers, due to reduced yields and higher irrigation water use.

For all experiments, the IWP values registered with FI treatment were considerably different from those observed with DI-60 and Farmer's treatments, but not significantly different from those recorded with DI-80 and FI-DI60 treatments. Values of IWP were significantly different between farmer's method and DI-80 and DI-60 treatments ($p<0.05$). The difference was not significant between the last two treatments.

Yield and IWP levels of carrot, lettuce and pepper using suitable irrigation scheduling, without deficit, were respectively of 28.3, 44.1 and 23.4 t ha^{-1} and of 8.5, 15.7 and 3.6 kg m^{-3}. Reduction of irrigation supply by 20% (DI-80) and 40% (FI-DI60) resulted in a reduction of yield for carrot, lettuce and pepper by 4.6, 8.4, 3.4% and 14.6, 14.7, 6.3%, respectively, for FI-DI60 and DI-80. Such strategy could turn out to be an interesting option for irrigation of these crops in the context of increasing water scarcity, when economically profitable.

Economic evaluation

The economic analysis (Fig. 6) showed that the greatest net return was observed under FI treatment with irrigation water supplies of about 328-330 mm, 278-293 mm and 654-656 mm, respectively for carrot, lettuce and pepper. The net returns recorded with FI treatment were in the range of 4.7 to 5.5 thousands USD/ha for carrot, 10.8-12.8 thousand USD/ha for lettuce and 8.5-9.8 thousand USD/ha for pepper. Reducing irrigation water (DI-60) below 200 mm for carrot and lettuce and 400 mm for pepper considerably affects the farmer net returns. The decreases in net returns were about 53-62, 46-49 and 14-16%, respectively, for carrot, lettuce and pepper. On the other hand, a small restriction of irrigation water during ripening stage of about 4.5-12% (FI-DI60) compared to that of FI treatment caused a reduction in net returns of 2-8.7, 11.7-13.2 and 3-3.5%, respectively, for carrot, lettuce and pepper. The moderate water restriction of about 20% (DI-80) resulted in a decrease of economic return of 20-25% for carrot, 20-22% for lettuce and 6.3-6.8% for pepper. However, providing more irrigation water for all crops (360-750 mm) with Farmers method resulted in considerable reduction in the net returns.

For all crops, the greatest net return was observed with the FI treatment followed by the FI-DI60 and DI-80 treatments, whereas DI-60 and FM treatments showed the lowest net return across years. High values of net return under the FI, FI-DI60 and DI60 treatments were due to better yields, as compared to farmers and DI-60 treatments.

According to the economic analysis, the net income from the FI treatment was found to reasonable for carrot, lettuce and pepper production when there is no water scarcity. The FI-DI60 and DI-80 treatments could be applied in smallholder's farms allowing water savings of up to 20% with some reduction in yield and in the economic return (2-13.2 and 6.3-25% reduction). This suggests a more widespread adoption of FI-DI60 and DI-80 strategies for growers in the region.

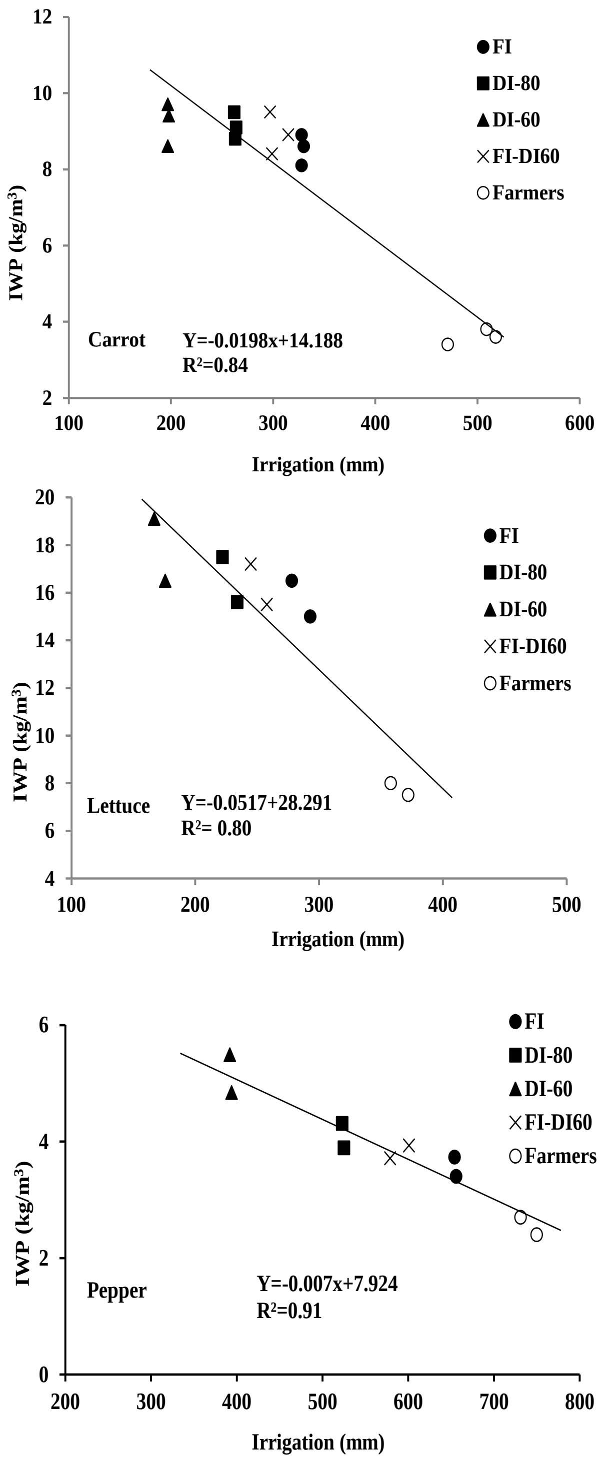

Figure 5 - Irrigation water productivity (IWP, Kg/m^3) of carrot (2007-2010), lettuce (2009-2011) and pepper (2008-2009) as related to irrigation water supply for five irrigation strategies: full irrigation supplying 100% ETc (FI), deficit irrigation supplying 80% ETc (DI-80), 60% ETc (DI-60 & FI-DI60) and local farmers irrigation method (FM).

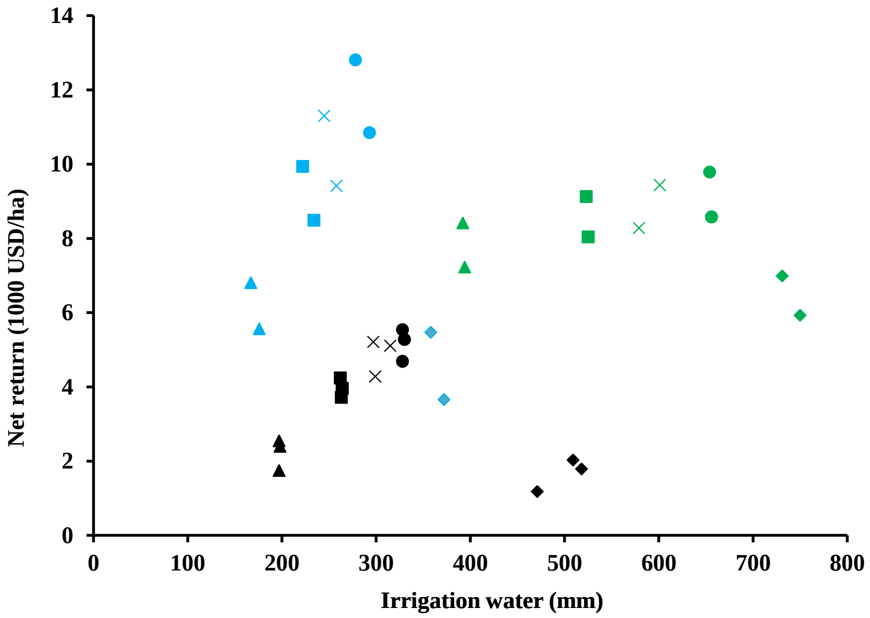

Figure 6 - Net return of carrot (black), lettuce (blue) and pepper (green) production under full (FI), deficit (DI-80, DI-60, FI-DI60) and local farmer's (Farmers) irrigation methods. FI (●), DI-80 (■), DI-60 (▲), FI-DI60 (x) and Farmers (♦).

Conclusions

Results of field experiments showed that carrot, lettuce and pepper under full irrigation in the arid conditions of the trials used, respectively, about 330, 286 and 655 mm of in-season irrigation water. Water quantities can be reduced by adopting regulated and moderate deficit irrigation (FI-DI60 and DI-80). Deficit irrigation treatment (DI-60) resulted in lowest yields and highest soil salinity. The Farmer's strategy registered the lowest yields, i.e., 34-38%, 30-31% and 13-14.5% less than FI with 43-57%, 26-29% and 11.5-16% more irrigation water, respectively, for carrot, lettuce and pepper and presented the higher soil salinity. High IWP observed for the most restricted irrigation regime (DI-60) is compensated by decreased yield. Regarding the results of the economic evaluation, it can be concluded that DI-60 and Farmers treatments caused a reduction in the net income of about 53-62, 46-49 and 14-16%, and 63-74, 57-62 and 28-31%, respectively, for carrot, lettuce and pepper, in comparison with FI treatment. Full irrigation scheduling technique (FI) could be recommended for irrigation of carrot, lettuce and pepper crops under the arid climate of Tunisia. The water supply could be reduced up to 20% (DI-80) and 40% during ripening stage (FI-DI60) in case of water scarcity, with relatively small impact on salinity in the root zone and some yield and net income reductions.

References

Allen R.G., Perreira L.S., Raes D., Smith M., 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper N° 56 FAO Rome, Italy.

Ayers J.E., Hutmacher R.B., Schoneman R.A., Vail S.S. and Felleke D., 1986. Drip irrigation of cotton with saline drainage water. Trans. Am. Soc. Agric. Eng., 29: 1668-1673.

Bazza M., 1999. Improving irrigation management practices with water-deficit irrigation. In: Kirda, C., Moutonner, P., Hera, C., Nielsen, D.R. (Eds.), Crop Yield Response to Deficit Irrigation, Developments in Plant and Soil Sciences, vol. 84, Kluwer Academic Publishers, pp. 49-71.

Cetin O., and Bilgel L., 2002. Effects of different irrigation methods on shedding and yield of cotton. Agric. Water Manag. 54: 1-15.

Daleshwar R., Manjunath M.V., Rajkumar G.R., Hebbar M., and Minhas P.S., 2006. Comparative effects of drip and furrow irrigation on the yield and water productivity of cotton (Gossypium hirsutum L.) in a saline and waterlogged vertisol. Agric. Water Manage., 83: 30-36.

Dorji K., Behboudian M.H., and Zegbe-Dominguez J.A., 2005. Water relations, growth, yield, and fruit quality of hot pepper under deficit irrigation and partial rootzone drying. Sci. Hortic., 104: 137-149.

El Mokh F., 2016. Irrigation management with saline water in dry environment. Doctoral Thesis in Agricultural Sciences, INAT, Tunisia 127 p.

El Mokh F., Nagaz K., Masmoudi M.M, and Ben Mechlia N., 2017. Irrigation management to improve smallholder's incomes for saline conditions. International Journal of Crop Science and Technology, 3(2): 51-58. DOI:10.26558/ijcst.347891.

El Mokh F., Nagaz K., Masmoudi M. M., and Ben Mechlia N., 2013. Soil salinity and water productivity of carrot-millet system as influenced by irrigation regimes with saline water in arid regions of Tunisia. Journal of Agriculture and Environment for International Development (JAEID), 107(2), 179-199. https://doi.org/10.12895/jaeid.20132.135

El Mokh F., Nagaz K., Masmoudi M., and Ben Mechlia N., 2014. Effects of surface and subsurface drip irrigation regimes with saline water on yield and water use efficiency of potato in arid conditions of Tunisia. Journal of Agriculture and Environment for International Development (JAEID), 108(2), 227 - 246. https://doi.org/10.12895/jaeid.20142.258

Erdem T., Erdem Y., Orta H., and Okursoy H., 2006. Water-yield relationships of potato under different irrigation methods and regimes. Sci. Agric., 63(3): 226-231.

Fereres E., Cuevas R., and Orgaz F., 1985. Drip irrigation of cotton in southern Spain. Proc. Third Drip/Trickle lrrig. Publ. 10-85, ASAE, St. Joseph, Mi., pp. 185-192.

Fisher R.A., 1980. Influence of water stress on crop yield in semiarid regions. In: Turner, N.C., Kramer, P.J. (Eds.), Crop Water Requirements. Conf., 11-4 September 1984, Paris, INRA, Paris, pp. 221-234.

Geerts S., Raes D., Garcia M., Condori O., Mamani J., Miranda R., Cusicanqui J., Taboada C., and Vacher J., 2008b. Could deficit irrigation be a sustainable practice for quinoa (Chenopodium quinoa Willd.) in the Southern Bolivian Altiplano? Agricultural Water Management, 95: 909-917.

González-Dugo V., Orgaz F., and Fereres E., 2007. Responses of pepper to deficit irrigation for paprika production. Sci. Hortic., 114: 77-82.

Hansona B.R., Schwankl L.J., Schulbach K.F., and Pettygrove G.S., 1997. A comparison of furrow, surface drip, and subsurface drip irrigation on lettuce yield and applied water. Agricultural Water Management, 33 (2-3): 139-157.

Hartmann H.D., Werum H., Bruckuer U., and Zengerle K.H., 1986. Effect of irrigation on carrot yield. Gemuse, 22, 62-65.

Howell T.A., Cuenca R.H., and Solomon K.H., 1990. Crop yield response. In: Hoffman, G.J., et al. (Eds.), Management of Farm Irrigation System, Monograph, vol. 9. St. Joseph, MI, pp. 93-122.

Imtiyaz M., Mgadla N.P., Manase S.K., Chendo K., and Mothobi E.O., 2000. yield and economic return of vegtable crops under variable irrigation. Irrigation Sci. J. 19 (2), 87-93.

Jordan W.R., 1983. Whole plants response to water deficit: an overview. In: Taylor, H.M., Jordan, W.R., Sinclair, T.R. (Eds.), Limitations of efficient water use in crop Production. ASA, CSSA and SSSA Inc., Madison, WI, pp. 289-317.

Munns R., 2002. Comparative physiology of salt and water stress. Plant Cell Environ., 25: 239-250.

Nagaz K., 2007. Gestion de l'irrigation à l'eau salée en milieu steppique. Thèse de doctorat en sciences agronomiques, INAT, Tunisia 164p.

Nagaz K., El Mokh F., Ben Hassen N., Masmoudi M.M., Ben Mechlia N., Baba Sy M.O., Belkheiri O., and Ghiglieri G., 2017. Impact of deficit irrigation on yield and fruit quality of orange trees (*Citrus Sinensis* L. Osbeck CV. Meski Maltaise) in Southern Tunisia. Irrigation and Drainage, DOI:10.1002/ird.2201

Nagaz K., El Mokh F., Masmoudi M.M., and Ben Mechlia N., 2017. Soil Salinity under deficit drip irrigation of potato and millet in an arid environment. Journal of Agriculture and Environment for International Development, 111(1): 207-223. DOI: 10.12895/jaeid.20171.600

Nagaz K., Masmoudi M. M., and Ben Mechlia N., 2012. Yield response of drip-irrigated onion under full and deficit irrigation with saline water in arid regions of Tunisia. ISRN Agronomy, vol. 2012, Article ID 562315, 8 pages. doi:10.5402/2012/562315.

Nagaz K., Masmoudi M. M., and Ben Mechlia N., 2012. Effects of deficit drip-irrigation scheduling regimes with saline water on pepper yield, water productivity and soil salinity under arid conditions of Tunisia. Journal of Agriculture and Environment for International Development (JAEID), 106(2), 85-103. https://doi.org/10.12895/jaeid.20122.60

Saggu S.S. and Kaushal M.P., 1991. Fresh and saline water irrigation through drip and furrow method. Int. J. Trop. Agric., 9: 194-202.

Sale P.J.M., 1966. The response of summer lettuce to irrigation at different stages of growth. J. Hort. Sci., 41: 43-52.

Sammis T.W., 1980. Comparison of sprinkler, trickle, subsurface and furrow irrigation methods for row crops. Agron. J., 72: 701-704.

Sener S., Schafer W., Zu E., and Yurdem H., 1994. Determine the effects of different irrigation methods on yield and development of potato during the period of 1989-1991 in Menemen. Research Institute of Menemen. General Publication No: 205. 64 pp.

Singh R., Alderfer R.B., 1966. Effects of soil-moisture stress at different periods of growth of some vegetable crops. Soil Sci., 101: 69-80.

Singh S.D., Gupta J.P., and Singh P., 1977. Water economy and saline water use by drip irrigation. Agronomy J., 70, 948-951.

Weatherhead E.K. and Knox J.W., 1997. Drip irrigation revisited. Irrigation News, 25: 11-18.

Wood M., 1988. Underground drip irrigation yields record tomato harvest, Agric. Res., August, 14.

Yohannes S., and Tadesse T., 1998. Effect of drip and furrow irrigation and plant spacing on yield of tomato at Dire Dawa. Ethiopia. Agricultural. Water Management, 35: 201-207.