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Irrigation water quality and nitrogen for yield and water-use efficiency of potato in the arid conditions of Tunisia

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Abstract

Field studies were conducted on a sandy soil during spring of 2004 and 2007 in an arid region of southern Tunisia to determine the effect of water quality and nitrogen on yield, yield components and water use efficiency (WUE) of "Spunta", a potato (*Solanum tuberosum* L.) cultivar. Irrigation water of two qualities *viz.,* canal water (3.25 dS m^{-1}) and saline water (5.2 dS m^{-1}) was used. Nitrogen was applied at the rate of 0, 100, 200 and 300 kg ha^{-1}. For all treatments, irrigations were scheduled when readily available water in the root zone (35% of the total available water) was depleted. Yield, yield components, water supply and soil salinity were measured. Findings are globally consistent between the two experiments. Results showed that soil salinity values remained lower than those of ECiw and were lowest under emitters and highest midway to the margin of wetted bands. Potato yield significantly decreased under the use of saline water. The reduction in potato yield was mainly attributed to reduction in the number of tubers per m² and tuber weight. WUE decreased significantly with increasing irrigation water salinity. Potato yield, yield components and WUE increased with an increase in nitrogen rates. The N application rate of 300 kg ha^{-1} gave good yield and higher WUE of potato in Southern Tunisia.

Key words: Potato, salinity, nitrogen, yield, water use efficiency, arid

Introduction

One of the most important factors limiting agricultural expansion is the restricted supply of good quality water. Nowadays, there is an increasing tendency to use saline irrigation water in arid regions of Tunisia, where supplemental water is a need to intensify agriculture. Thus, the need for irrigation water and aggravation of its quality on irrigated farming in arid lands is becoming an increasing problem and the danger of an accumulation of salt in the soils is also increasing (Amaya and Yano, 1994).

Considerable research has been directed towards defining the effects of salts upon crop growth and yield (Wagenet *et al.,* 1980; Maas, 1990; Van Hoorn *et al.,* 1993; Katerji *et al.,* 1996). Potato is relatively susceptible to salinity (Maas and Hoffman, 1977) and cultivation of the crop is expanding to regions where other water sources are restricted and saline water is available. In arid regions of Tunisia, potato is cultivated under drip and furrow irrigation by private shallow wells having a salinity of 2 to 6 dS m^{-1}. Earlier reports by Levy *et al.* (1988), Van Hoorn *et al.* (1993), Nadler and Heuer (1995), Hamdy and Samti (1995), Oueslati (2003) and Bustan *et al.* (2004) show that irrigation with high saline waters caused considerable reduction in potato yield.

The performances of different potato cultivars under different levels of N have been reported by Goffart *et al.* (2002), Feibert *et al.* (1998), Ünlü *et al.* (2006), Halitligil *et al.* (2002) and Waddel *et al.* (1999). These studies demonstrated the positive role of nitrogen fertilizer for growth, yield and quality of potato. The response of crop plants to irrigation with different water qualities and nitrogen fertilizer has been the subject of numerous studies. A field experiment conducted by Al-Tahir *et al.* (1997) showed that barley yield increased with an increase in nitrogen up to 350 kg ha^{-1} under irrigation with fresh canal and saline waters. Substantial reduction in barley yields occurred with saline water for each nitrogen level. They also found that barley yields with fresh canal water and nitrogen rate of 250 kg ha^{-1} were comparable to yields with saline water and nitrogen level of 350 kg ha^{-1}. Barley grain yield produced under irrigation with saline water (11.7 dS m^{-1}) and 180 kg N ha^{-1} was similar to the yield obtained with canal water (3.4 dS m^{-1}) and 120 kg N ha^{-1} and higher than that obtained under irrigation with canal water and nitrogen level of 60 kg ha^{-1} (Nagaz and Ben Mechlia, 2000). Hamdi and Samti (1995) noted that potato irrigated with saline water (6 dS m^{-1}) produced higher yield than that obtained with fresh water (0.8 dS m^{-1}) and without nitrogen fertilizer (0 kg ha^{-1}) and similar to that obtained with saline water (3 dS m^{-1}) and 60 kg N ha^{-1}. However, in arid regions of Tunisia, little information is available on interaction effects of irrigation with different water qualities and nitrogen in sandy soil which are generally been found to be low in nitrogen. Thus, a two-year study was conducted with the objective to determine the effects of two water qualities and nitrogen on yield and water use efficiency of potato under arid conditions of southern Tunisia.

Materials and methods

Experimental site, design and climate: Experiment was carried out during spring season of 2004 and 2007 in the Southern East of Tunisia in a commercial farm situated in Saadane near the "Institut des Régions Arides de Médenine". Potato (*Solanum tuberosum* L. cv. Spunta), was planted on sandy soil with an ECe of 1.95 and 1.50 dS m^{-1} (0-60 cm depth of soil) for first and second year, respectively. The total soil water, calculated between field capacity and witling point for an assumed potato root extracting depth of 0.60 m, was 75 mm. The level of available nitrogen in the soil was very low (less than 0.007 %) and thus was not taken

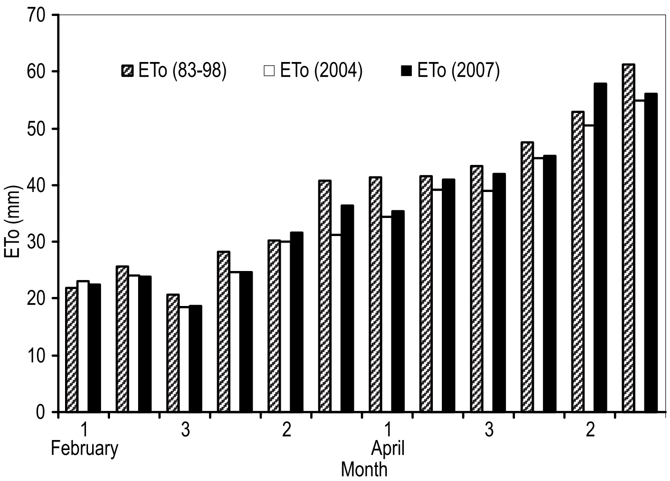

Fig. 1. Ten days reference evapotranspiration, year 2004 and 2007 and period 1983-1998.

into consideration while calculating the fertilizer for different treatments. The treatments, consisting of two irrigation water qualities (canal and well waters) and four levels of nitrogen as ammonium nitrate (0, 100, 200 and 300 kg/ha), were arranged in a randomized complete block design with four replicates.

The values of ten days reference evapotranspiration (ETo) which define the weather conditions prevailing during the study are shown in Fig. 1. These data, which only cover the period when experiment took place, are compared to the average values for the period 1983-98. The evolution of ten days ETo was similar, though with slightly lower values for 2007, with an average of 36.2 mm as compared to 37.9 mm. The ten days ETo during the period under experiment for 2004 was also relatively lower, 34.5 mm as opposed to 37.9 mm in the period (1983-1998). The rainfall received during the cropping period was 35.5 and 62 mm, respectively for 2004 and 2007.

Crop management: Planting was done on 5 and 7 February 2004 and 2007, in 0.70 m row spacing with plants spaced 0.40 m apart. The experimental area was divided into four blocks with four elementary plots per block. Each elementary plot consisted of five rows. All plots were drip irrigated with water from canal and a shallow well having an ECi of 3.25 and 5.2 dS m^{-1} (Table 1). Each dripper had a 4 L h^{-1} flow rate. Water for each block passed through a water meter, gate valve, before passing through laterals placed in every potato row. A control mini-valve in the lateral permits use or non-use of the dripper line. Fertilizers were supplied for the cropping periods in the same amounts which were adopted from the local practices; before planting, soil was spread with 17 t ha^{-1} of organic manure. The P and K fertilizers were applied as basal dose before planting at rates of 300 and 200 kg ha^{-1}, respectively. Nitrogen was divided and delivered with the irrigation water in all treatments during early vegetative growth. After tubers initiation stage, 120 kg ha^{-1} of potassium nitrate was applied for all treatments.

For all treatments, irrigations were scheduled when soil water content in the root zone was depleted by the crop to specific fraction of TAW (*e.g.*, irrigation at 35% of TAW) and plants in these treatments received 100% of accumulated crop ETc. In order to differentiate between the treatments, the amount of irrigation water was kept the same in all treatments.

Table 1. Chemical composition of irrigation waters (meq/L)

Waters	ECi (dS m^{-1})	Ca^{2+}+ Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	CO_3^{2-} +HCO_3^-	SARiw
Saline	5.2	27.4	23	1.6	21	28.2	2.8	4.75
Canal	3.25	23.4	8.2	0.9	6.4	21.6	4.5	2.57

The crop evapotranspiration (ETc) was estimated for daily time step by using reference evapotranspiration (ETo) combined with a potato crop coefficient (Kc). The ETo was estimated from daily climatic data collected from the Institute meteorological station, located near the experimental site (data not presented) by means of the FAO-56 Penman-Monteith method given by Allen *et al.* (1998). The potato crop coefficient (Kc) was computed following the recently developed FAO-56 dual crop coefficient approach, 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 irrigation scheduling, the method used was the water balance, by means of a spreadsheet program in 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 daily basis using the soil water balance and projects the next irrigation event based on the target depletion (35% of total available water in the root zone, 35% of TAW). The soil depth of the effective root zone is increased with the program from a minimum depth of 0.15 m at planting to a maximum of 0.60 m in direct proportion to the increase in the potato crop coefficient.

Measurements and water-use efficiency: Potato was harvested on 29 and 31 May in the first and second year, respectively. Twenty plants per row within each plot were harvested by hand to determine potato yield, tuber number m^{-2} and tuber weight. Soil samples were collected after harvest. The soil was sampled with a 4 cm auger every 15 cm to a depth of 60 cm, at four sites perpendicular to the drip line at distances of 0, 10, 20 and 30 cm from the line, and at four sites between the emitters (0, 7, 15 and 20 cm from the emitter). Conceptually, these should be areas representing the range of salt accumulations (Bresler, 1975; Singh *et al.,* 1977). Samples were air-dried and ground to pass a mesh of 2 mm size and were analyzed for ECe.

Water-use efficiency (WUE), defined as the yield obtained per unit of water consumed, whether from irrigation or total received, including the precipitation, was calculated as follows: WUE (kg ha^{-1} mm^{-1})= Yield (kg ha^{-1}) / total water received (mm) from planting to harvest; an irrigation of 75 mm applied before planting is not included in the total.

Statistical analysis: Analysis of variance was performed to evaluate the statistical effect of the treatments on potato yields and components, WUE and soil salinity using the STATGRAPHICS *Plus* 5.1 (www.statgraphics.com). LSD test at 5% level was used to find any significant difference between treatment means.

Results and discussion

Evapotranspiration estimates and soil water balance: Fig. 2 shows computed Kc (KsKcb+Ke) during the cropping period in 2004 and 2007. The potential Kc values were about 1.1-1.3

following rain or irrigation events when the soil surface layer was wetted. The Ke spikes represent increased evaporation when irrigation or precipitation has wetted the soil surface and has temporarily increased ETc values (Fig. 3). During the initial stage, the Ke spikes reach a maximum values of 1-1.1 following wetting by rainfall. Some of the evaporation spikes were lower during this period since only fraction of the soil surface was wetted only by irrigation. The wet soil evaporation spikes decrease as the soil surface layer dries and the value of Ke became zero during the growing periods when the soil surface was dried.

Fig. 3 illustrates the course of daily ETc relative to ETo for the potato crop. During the first 25 days after plantation high ETc values where observed when the soil surface layer was wetted by irrigation or precipitation. Most of the daily crop ET consisted of soil evaporation, controlled mainly by soil hydraulic properties and solar radiation. This period is characterized by mean values of daily ETc of about 1.25 and 1.39 mm, respectively for the first and second year. As the crop canopy grew, ETc increased and reached its highest mean value at mid-season stage (3.8 and 4.0 mm day^{-1}). The mean ETc values at the late stage were about 3.92 and 3.98 mm day^{-1}, respectively for 2004 and 2007. At the later stage, where the canopy senescence began, the high ETc values were principally attributed to the important soil evaporation induced by the frequency of irrigation or precipitation and to the high evaporative demand.

Fig. 4 illustrates soil water depletion, estimated by the spreadsheet program during the cropping period of full irrigated potatoes for the first and second year. The spreadsheet program develops a water balance and supplies information on the timing and amounts of irrigation events. Figure also illustrates also the effect of an increasing root zone on the readily available water. The rate of root zone depletion at a particular moment in the season is given by the net irrigation requirement for that period. Each time the irrigation water is applied, the root zone is replenished to field capacity. Because irrigation is not applied until the soil water depletion at the end of the previous day is greater than or equal to the readily available water, occasionally plants could be subject to a slight stress on the day prior to irrigation.

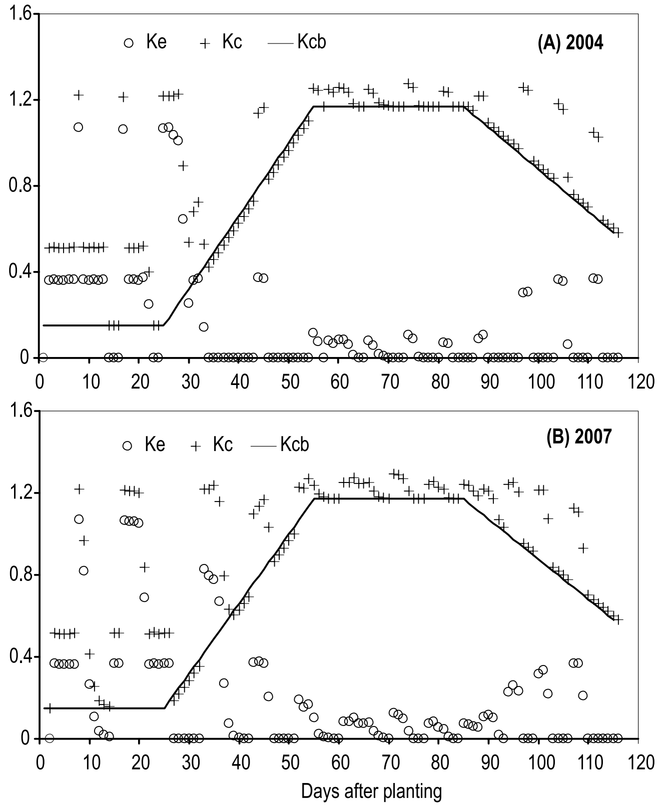

Fig. 3. Estimated daily ETc for potato crop during the cropping season (A) 2004 and (B) 2007

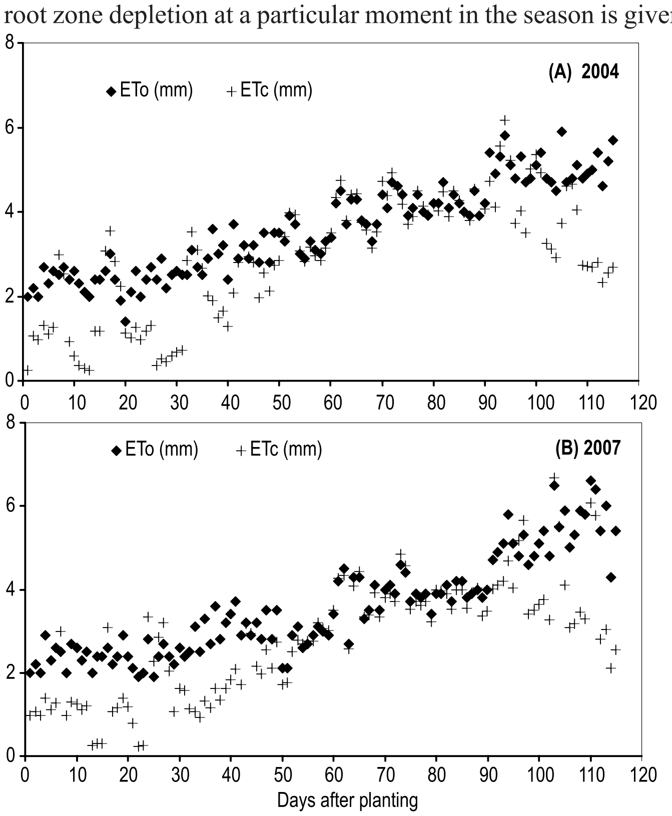

Fig. 2. FAO 56 crop coefficient curves for potato crop during the cropping season (A) 2004 and (B) 2007

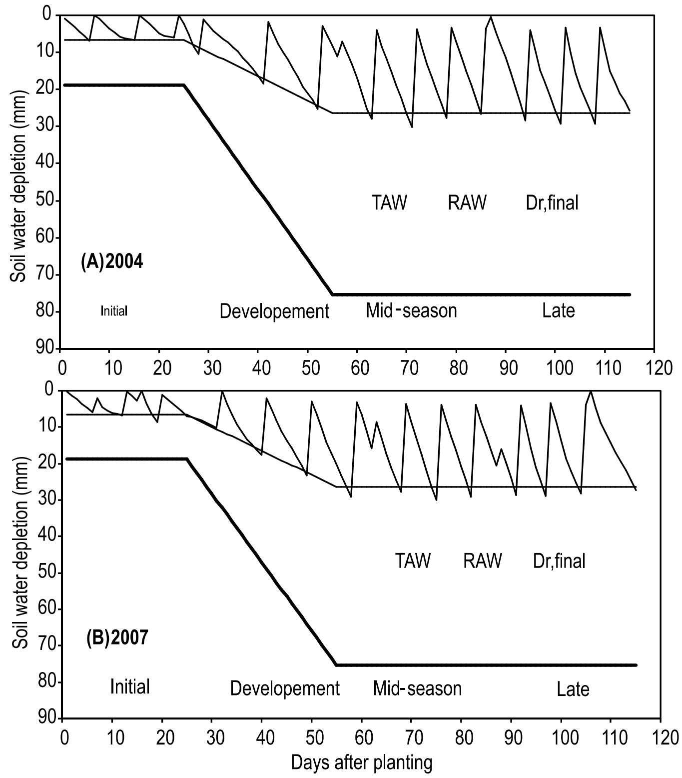

Fig. 4. Estimated daily soil water depletion for drip irrigated potato during the spring season (A) 2004 and (B) 2007. Dr, final represent the soil water depletion at the end of each day.

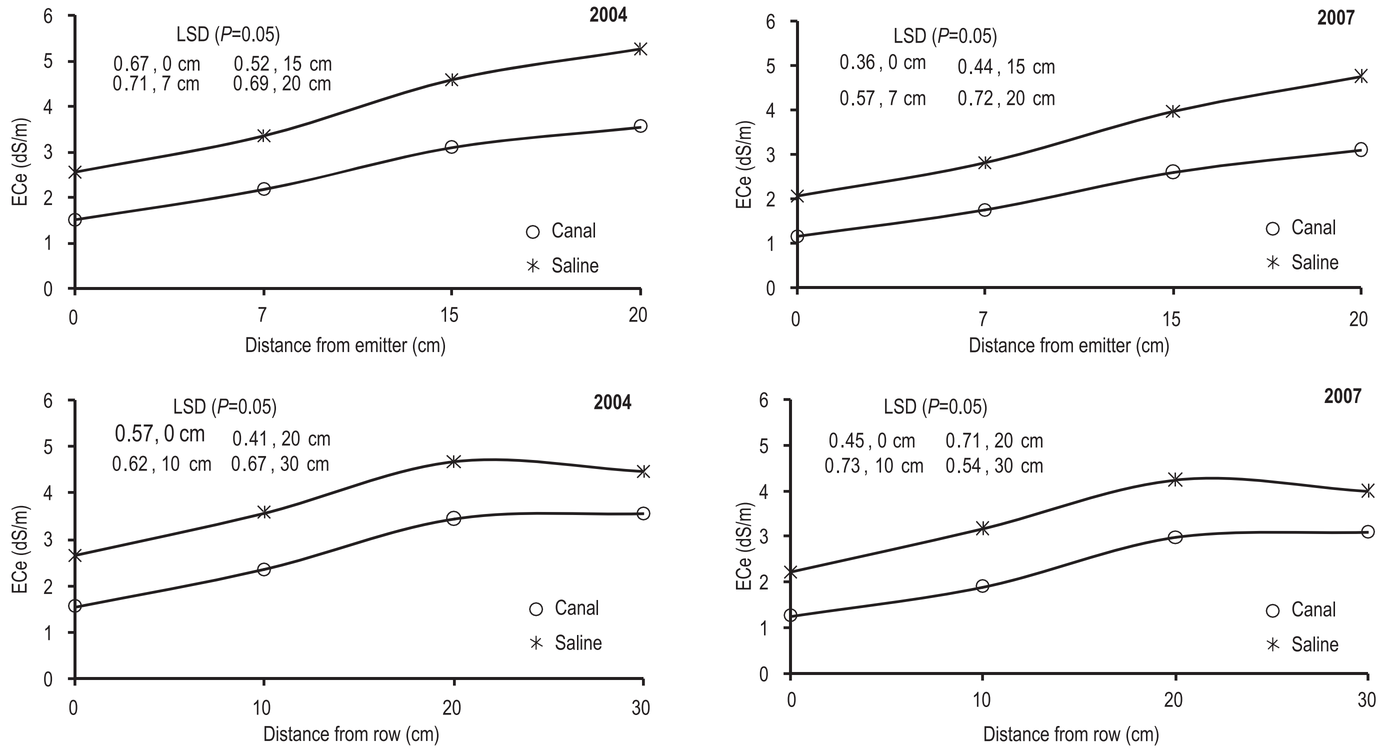

Fig. 5. Soil salinity (ECe, dS m^{-1}) under irrigation with two water qualities along the row and across row

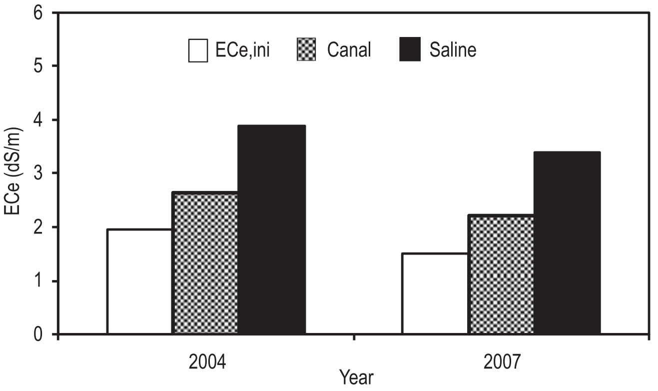

Fig. 6. Mean soil salinity values under irrigation with two water qualities. ECe, ini is the ECe at the time of planting

Soil salinity: The final ECe values at different distances from emitter and drip line under irrigation with two water qualities are presented in Fig. 5. On the row, the highest ECe values for both irrigation waters were found to have occurred at a distance of 15 and 20 cm from the emitter. Values of 1.55 and 2.60 dS m^{-1} were recorded below the emitter in 2004 under irrigation with canal and saline water, respectively. The corresponding ECe values were 1.2 and 2.1 dS m^{-1} in 2007. Between rows, the greatest values of ECe were recorded at distances of 20 and 30 cm from drip line and decreased to 1.6 and 2.7 dS m^{-1}, respectively beneath the emitter in 2004 and to 1.3 and 2.2 dS m^{-1} in 2007. Soil salinity was highest midway between the emitters (20 cm) and towards the margin of wetted band (20 to 30 cm). Nagaz *et al.* (2007), Singh *et al.* (1977) and Laosheng (2000) reported similar result.

The mean ECe values after two years of experimentation are shown in Fig. 6. Use of saline water increased the ECe as compared with canal water. The average ECe values under irrigation with canal and saline waters were lower than the ECe of the irrigation water used. Singh and Bhumbla (1968) observed that the extent of salt accumulation depended on soil texture and reported that in soils containing less than 10% clay the ECe values remained lower than ECiw. Low values of ECe under the prevailing climatic conditions were due to the leaching of soluble salts with the received rainfall (35.5 and 62 mm) and also to the low initial soil salinity (1.95 and 1.50 dS m^{-1}).

Yield and yield components: For analyzing the effect of water quality and nitrogen on the final yield, three criteria were considered: tuber yield, tuber number m^{-2} and tuber weight. The data are presented in Tables 2 and 3.

The data shows that for both experiments mean tuber yield was significantly affected by water quality. Mean potato yield was significantly decreased by using saline water (Table 3). The reduction in fresh tubers yields with saline water was 19 and 18.2 %, respectively, in 2004 and 2007 in comparison with that using canal water. The reduction in potato yield was attributed to reduction in tubers number and weight (Table 2).

The crop was found to be responsive to increasing nitrogen fertilizer level (Table 3). Mean tuber yield increased up to 300

Table 2. Yield components under different water qualities and nitrogen applications

Water quality	Tubers number m^{-2}		Tuber weight (g)	
	2004	2007	2004	2007
Canal	33.50	34.62	99.38	101.81
Saline	31.21	32.37	94.63	96.78
LSD (*P*=0.05)	1.939	2.132	8.053	8.312
Nitrogen (kg/ha)				
0	29.25	30	80.98	82.87
100	31.13	32.25	94.84	96.55
200	33.04	34.5	102.11	106.40
300	36.00	37.25	110.09	111.11
LSD (*P*=0.05)	1.504	1.613	3.127	3.772

Table 3. Effect of water quality and nitrogen interaction on potato fresh tuber yield (t ha^{-1})

Water quality	2004					2007				
	Nitrogen (kg ha^{-1})					Nitrogen (kg ha^{-1})				
	0	100	200	300	Mean	0	100	200	300	Mean
Canal	26.14	31.56	34.28	41.00	33.25	28.91	35.23	37.75	44.13	36.51
Saline	20.97	25.84	30.09	33.15	27.51	22.75	28.64	30.82	37.30	29.88
Mean	23.56	28.70	32.18	37.08		25.83	31.94	34.29	40.72	
LSD (*P*=0.05)										
Water quality				3.732					4.082	
Nitrogen				3.646					3.825	
Water quality x Nitrogen				1.794					1.748	

kg ha^{-1}. The difference in tuber yield was significant between different fertilizer rates except 100 and 200 kg N ha^{-1}, where it was not significant. The increase in tuber yield may be attributed to improved growth and yield components due to nitrogen application. There were differences between two experiments in potato yields. Yields were highest in the second year because of the low initial soil salinity.

The interaction effect between water quality and nitrogen on fresh tuber yield is presented in Table 3. In both experiments, yield response to nitrogen is more pronounced under irrigation with canal water than that with saline water. It is noteworthy that under both saline and canal water irrigation maximum yield was obtained with 300 kg N ha^{-1}. The yields decreased as the rate of nitrogen decreased. Fresh tubers yields decreased as the salinity of irrigation water increased for each nitrogen level. Without nitrogen application (0 kg N ha^{-1}), tuber yields obtained in 2004 were 26.14 and 20.97 t ha^{-1} for canal and saline waters, respectively. However, the reduction in yields due to increasing salinity was counteracted by increasing the nitrogen level. The tuber yield obtained with canal water and 0 kg N ha^{-1} (26.14 t ha^{-1}) was the same as the yield obtained with saline water when the nitrogen increased from 0 kg N/ha with canal water to 100 kg N ha^{-1} with saline water. The tuber yield attained 30.09 t ha^{-1} when the nitrogen level increased to 200 kg ha^{-1} under irrigation with saline water. That yield was not significantly different from the yield obtained with canal water and 100 kg N ha^{-1}. The tuber yield obtained under irrigation with saline water and 300 kg N ha^{-1} was 33.15 t/ha which is similar to the yield obtained with canal water and 200 kg N ha^{-1} and higher than that obtained under irrigation with canal water and nitrogen level of 100 kg ha^{-1}. For the second year experiment, the highest value (44.13 t ha^{-1}) was obtained with canal water and 300 kg N ha^{-1}. The tuber yield showed its lowest value (22.75 t ha^{-1}) with saline water and 0 kg N/ha. However, under irrigation with saline water and nitrogen levels of 200 and 300 kg ha^{-1} the yields were higher than those obtained with canal water and 0 and 100 kg N ha^{-1} applications. The tuber yield obtained under irrigation with saline water and 300 kg N ha^{-1} (37.3 t ha^{-1}) was similar to that obtained with canal water and 200 kg N/ha (37.75 t ha^{-1}). Thus, the reduction in yields due to increasing irrigation water salinity could be compensated by increasing nitrogen application. The findings of Hamdy and Samti (1995), Nagaz and Ben Mechlia (2000), Al-Tahir *et al.* (1997), Dregne and Mojallal (1969), Broabent and Nabashima (1971) also confirm these results.

Water use efficiency: Data on the amount of applied irrigation water (both canal and saline water) during the growing period are presented in Table 4. Total water supply from planting to harvest was 350.5 and 385 mm for first and second year experiments, respectively. The amount of irrigation water in the two experiments were similar to those reported by Singh *et al.*

Table 4. Total water supply (mm) under irrigation with canal and saline waters

Year	Irrigation[(1)] (mm)	Precipitation (mm)	Total water received (mm)
2004	315	35.5	350.5
2007	321	62.0	385.0

[(1)] an irrigation of 75mm supplied just before planting is not included in these totals

Table 5. IWUE and TWUE for fresh tuber yield under different water qualities and nitrogen applications

Water quality	Nitrogen (kg ha^{-1})									
	IWUE (kg ha^{-1} mm^{-1})					TWUE (kg ha^{-1} mm^{-1})				
	0	100	200	300	Mean	0	100	200	300	Mean
2004										
Canal	8.29	10.02	10.88	13.02	10.55	7.46	9.00	9.78	11.70	9.49
Saline	6.66	8.20	9.55	10.52	8.73	5.98	7.37	8.60	9.46	7.85
Mean	7.47	9.11	10.22	11.77		6.72	8.19	9.18	10.58	
LSD (*P*=0.05)										
Water quality				1.184					1.065	
Nitrogen				1.577					1.040	
Water quality x Nitrogen				0.569					0.612	
2007										
Canal	9.01	10.98	11.76	13.75	11.37	7.51	9.15	9.81	11.46	9.48
Saline	7.09	8.92	9.60	11.62	9.31	5.91	7.44	8.01	9.69	7.76
Mean	8.05	9.95	10.68	12.68		6.71	8.29	8.91	10.58	
LSD (*P*=0.05)										
Water quality				1.271					1.060	
Nitrogen				1.191					0.993	
Water quality x Nitrogen				0.745					0.654	

(1977), Fabeiro *et al.* (2001), Onder *et al.* (2005) and Erdem *et al.* (2006).

Under saline conditions, the same amount of seasonally applied water did not provide the same water use efficiencY (Table 5). The mean WUE for fresh tuber production (IWUE; TWUE) were the lowest under irrigation with saline water and the highest under irrigation with canal water. Decreased WUE under irrigation with saline water is a consequence of significant yield reduction (Table 3). The mean WUE of potato increased with an increase in nitrogen up to 300 kg N ha^{-1}. The WUEs values obtained for both experiments are comparable with those obtained in other field studies (Erdem *et al.,* 2006, Fabeiro *et al.,* 2001, Ferreira *et al.,* 1999, Singh *et al.,* 1977). The higher mean WUE of potato as a result of N fertilization was due to a considerable increase in potato yields. These results are in close agreement with those of Hamdi and Samti (1995) and Hussain and Al-Jaloud (1998).

Interaction effect of water quality x nitrogen showed that significantly higher WUE for fresh tubers production were observed with nitrogen rate of 300 kg ha^{-1} under both canal and saline waters. The WUE of potato decreased significantly as the rate of nitrogen fertilizer decreased. For each nitrogen level, the WUE decreased as the salinity of irrigation water increased. However, the values of WUE, based on fresh tuber yield, with canal water irrigation and nitrogen rates of 0 kg ha^{-1} were considerable lower than the WUE obtained with saline water and nitrogen levels of 200 and 300 kg ha^{-1}. This variability could be attributed to low yield as shown in Table 3. It was also noticed that the WUE values under irrigation with saline water and nitrogen rates of 100, 200 and 300 kg ha^{-1} were not significantly different from those obtained with canal water and nitrogen rates of 0, 100 and 200 kg ha^{-1}. These results agree with those reported earlier by many investigators.

Under the arid conditions of southern Tunisia, the use of saline water for irrigation increased ECe and hence caused a further reduction in fresh tuber yield compared with canal water. The data show that factors such as tubers number.m² and tuber weight are significant for potato yield. A considerable reduction in WUE of potato was observed under irrigation with saline water. Under both canal and saline waters, the effect of nitrogen fertilizer was also substantial with increasing levels. The yield, yield components and WUE increased significantly up to 300 kg N ha^{-1}.

Application of nitrogen at 300 kg N ha^{-1} gave good yields and water-use efficiency in potato. However, yield and WUE increases due to fertilizer nitrogen were reduced as the salinity of irrigation water increased. The reduction in potato yields due to increasing irrigation water salinity was compensated by increasing nitrogen rate. This conclusion is consistent with the experimental results of Hamdy and Samti (1995), Nagaz and Ben Mechlia (2000), Dregne and Mojallal (1969), Al-Tahir *et al.* (1997), Broabent and Nabashima (1971). The significant interaction effect between water quality and nitrogen levels suggests that the nitrogen application to potato should be related to the salinity of irrigation water. Thus, saline water could be another alternative for irrigation under similar experimental conditions especially with high rates of nitrogen (200-300 kg ha^{-1}), which could eventually save more canal irrigation water for other cultivated crops.

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