ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Journal of Agronomy 6 (2): 324-330, 2007
ISSN 1812-5379

Soil Salinity and Yield of Drip-Irrigated Potato under Different Irrigation Regimes with Saline Water in Arid Conditions of Southern Tunisia

[1]Kamel Nagaz, [2]Mohamed M. Masmoudi and [2]Netij Ben Mechlia
[1]Institut des Régions Arides, 4119 Médenine, Tunisia
[2]INAT, 43 Avenue Charles Nicolle, 2083 Tunis, Tunisia

Abstract: A field study was conducted in southern Tunisia to determine the effect of irrigation regimes with saline water (3.25 dS m^{-1}) on soil salinity, yield and water use efficiency of potato (*Solanum tuberosum* L., cv. Spunta) grown during autumn, winter and spring seasons. Irrigation treatments consisted in water replacements of accumulated crop evapotranspiration (ETc) at levels of 100% (100 L) 80% (80 L) 60% (60 L) and 40% (40 L), when the readily available water in the control treatment (100 L) is depleted. A daily irrigation regime at 100% of ETc (100 D) was also used. Results show that salinity was lowest under emitters and highest midway to the margin of wetted bands. Under emitters it increased gradually between 100 and 40 L from 1.0 to 2.3 dS m^{-1} in autumn, from 0.65 to 1.97 dS m^{-1} in winter and from 0.75 to 2.55 dS m^{-1} in spring. Highest ECe values were found to occur at about 20 and 10 cm from emitters, respectively for 100 and 40 L. Yields were highest under 100 L although no significant differences were observed with 100 D. From values of 30.4, 22.7 and 39.6 t ha^{-1}, respectively for autumn winter and spring, yields decreased almost linearly when applied water was reduced. However, reduction in quality was significantly important for 60 and 40 L. The analysis outcome of the crop sensitivity to salt indicated, respectively for autumn, winter and spring seasons that thresholds are close to the value calculated from published salt tolerance data (1.9, 1.55, 1.85 vs. 1.7 dS m^{-1}) but the slopes are considerably steeper (34, 54, 47 vs. 12%), apparently because of the combined effect of salinity and water stresses. Water Use Efficiency (WUE) reflected differences between seasons, it varied typically around 8-9, 6-8 and 11-14 kg m^{-3}, respectively for autumn, winter and spring. Full irrigation with daily application resulted in the lowest WUE values, most likely because of higher evaporative losses.

Key words: Arid, salinity, water management, potato, yield, water use efficiency

INTRODUCTION

During the last few years, irrigated potato has been expanding rapidly in the arid part of Tunisia around shallow wells having a salinity of 2 to 6 dS m^{-1}. The reason of this new development is an easy access to subsidized drip irrigation equipment made possible recently and because temperature conditions allow to produce potato over the autumn, winter and spring seasons. Potato species is considered relatively susceptible to salinity (Maas and Hoffman, 1977) and normally is not suited for stressful conditions. However, recent research findings questioned these established facts. For instance Patel *et al.* (2001) working on field lysimeters under simulated arid conditions in Canada claimed that there was no significant effect of either initial soil salinity or subirrigation water salinity on total tuber weight and concluded that successful production could be obtained by using brackish water having salinity of 1 to 9 dS m^{-1} or even higher. Also working on covered lysimeters, Katerji *et al.* (2000) noticed a fairly good tolerance of this crop to salinity.

Concerning the interaction with weather conditions, globally cruel environments seem to make crops of greater sensitivity to salinity (Shalhevet, 1994). With high temperature and low humidity the threshold salinity decreases and the slope increases (Katerji *et al.*, 2000). Under desert environments, Bustan *et al.* (2004) reported that tuber yield was most sensitive to combined salt and heat stress when heat waves occurred at 40-60 days after emergence.

The limited capacity of potato to exploit the water-holding capacity of the soil could explain its salt sensitivity as suggested by Katerji *et al.* (2000). It can also explain its sensitivity to irrigation management. Waddel *et al.* (1999) obtained the best result with surface drip irrigation in comparison with sprinkler and buried drip irrigation in central Minnesota. In the East Mediterranean region of Turkey, surface drip was also found to have more advantages than subsurface drip

---

Corresponding Author: Kamel Nagaz, Institut des Régions Arides, 4119 Médenine, Tunisia

method (Sermet *et al*., 2005). According to these last authors, water deficiency more than 33% of the irrigation requirement could not be suggested under the Turkish conditions, whereas Fabeiro *et al*. (2001) advised on avoiding regimes that lead to deficit in the ripening stage as well as at growth or tuber bulking in the semi arid environments of Albacete, Spain. The objective of present research is to investigate the possibility of using drip irrigation regimes with saline water to produce potato during the autumn, winter and spring seasons under the arid Mediterranean conditions of southern Tunisia. Using the same experimental layout for the three cropping periods, we intend to make quantitative assessments of both salt accumulation in the soil and yield response to water supply in relation to different irrigation strategies.

MATERIALS AND METHODS

The experiments were carried out at a farmer site located near the Institut des Régions Arides de Médenine. Potato (*Solanum tuberosum* L. cv. Spunta) was planted on sandy soil with low organic matter content and an ECe of 1.35, 2.01 and 3.45 dS m^{-1} for spring, winter and autumn seasons, respectively. The rainfall received during the cropping periods was 26.7, 59 and 72 mm. 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.

Planting took place on 5 February 2000, 1 November 2001 and 1 September 2002 for the spring, winter and autumn seasons respectively, in 70 cm rows with tubers spaced 40 cm apart, in a randomized complete block design with four replicates and five irrigation treatments. The experimental area was divided into four blocks with five elementary plots per block. Each elementary plot consisted of four rows. All plots were drip irrigated with water from a well having an ECi of 3.25 dS m^{-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 seasons in the same amounts; before planting, soil was spread with 17 t ha^{-1} of organic manure. Nutrient supply included N, P and K at rates of 300, 300 and 200 kg ha^{-1}, respectively, which were adopted from the local practices. The P and K fertilizers were applied as basal dose before planting. 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.

The experiments consisted of five distinct irrigation treatments: 100 L treatment irrigated when readily available water in the root zone has been depleted and plants in that treatment received 100% of accumulated crop ETc; three additional treatments were irrigated at the same frequency as treatment 100 L, but with quantities equal to 40, 60 and 80% of accumulated ETc (40, 60 and 80 L). These treatments were identified as deficit irrigation treatments. The fifth treatment (100 D) was irrigated daily with amounts equal to 100% of the previous day's estimated ETc.

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 in 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 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) for the treatment 100 L 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.

Potato was harvested on May 29, 2000 for the spring crop, 23 February 2002 for the winter crop and on December 24, 2002 for the autumn one. Ten plants per row within each plot were harvested by hand to determine potato yield, tuber number/m^2 and tuber weight.

Water Use Efficiency (WUE) is defined as the yield obtained per unit of water consumed, whether from irrigation or total received, therefore including the precipitation. The WUE was calculated as follow: WUE (kg/ha/mm) = 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.

Soil samples were collected after harvest and analyzed for ECe. The soil was sampled 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).

Analysis of variance was performed to evaluate the statistical effect of irrigation treatments on potato yields, WUE and soil salinity using the STATGRAPHICS Plus 5.1 (www.statgraphics.com). LSD test was used to find any significant difference between treatment means.

RESULTS AND DISCUSSION

Figure 1 shows computed Kc (KsKcb+Ke) during the cropping periods. The potential Kc values were about 1.2-1.3 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. 2). 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.

Figure 2 shows the course of daily ETc relative to ETo for the potato crop. During the first 25 days after plantation, in comparison with spring season, high ETc values in autumn and winter seasons where observed when the wetting of the soil surface by irrigation or precipitation coincides with high evaporative demand. 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 1.12, 2.85 and 2.62 mm, respectively for spring, winter and autumn seasons. As the crop canopy grew, ETc increased and reached its highest mean value at mid-season stage (4.20, 2.67 and 3.40 mm day^{-1}). The mean ETc values at the late stage were about 4.60, 2.50 and 1.96 mm day^{-1}, respectively for spring, winter and autumn seasons. At the late stage, where the canopy senescence began, the high ETc values in spring season were principally attributed to the important soil evaporation induced by the frequency of irrigation or precipitation and to the high evaporative demand.

Figure 3 shows soil water depletion, estimated by the spreadsheet program, under 100 L treatment during the three cropping periods. The spreadsheet program develops a water balance and supplies information on the timing and amounts of irrigation events. This Fig. 3 also shows the effect of an increasing root zone on the readily available water. Because irrigation is not applied in the spreadsheet 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.

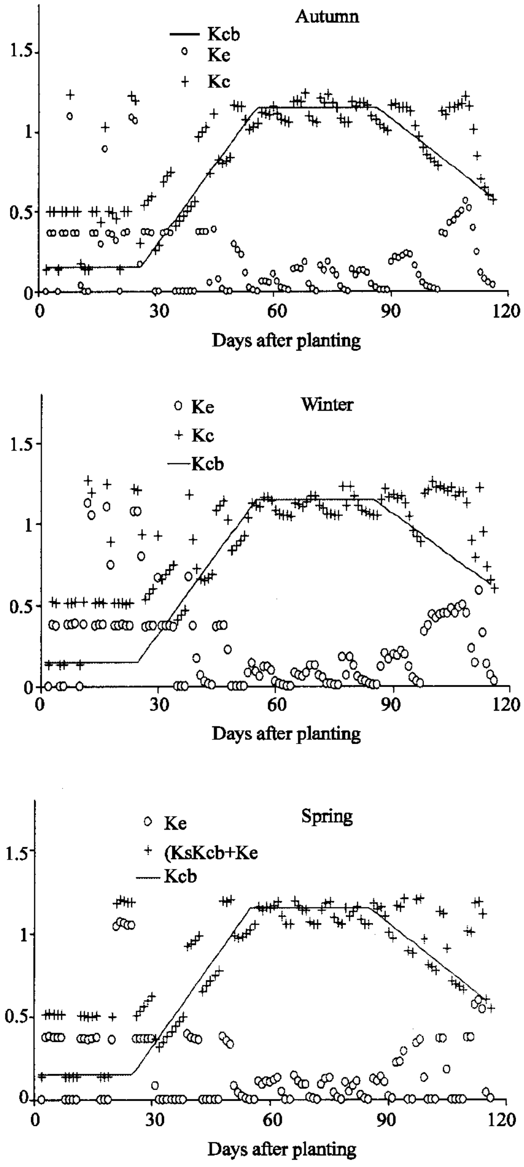

Fig. 1: FAO 56 crop coefficient curves for potato crop during the cropping seasons

The final ECe values under the different irrigation treatments are presented in Fig. 4. On the row, the highest ECe values were found to have occurred at a distance of 7 and 15 cm from the emitter when 40 L treatment was

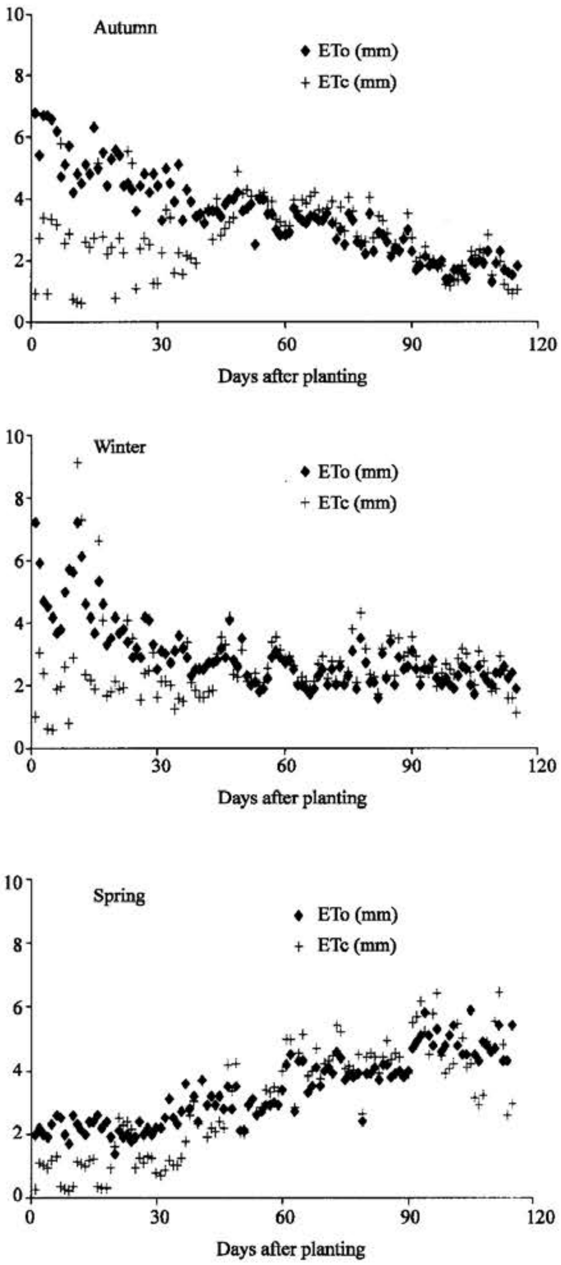

Fig. 2: Estimated daily ETc for the potato crop during the cropping seasons

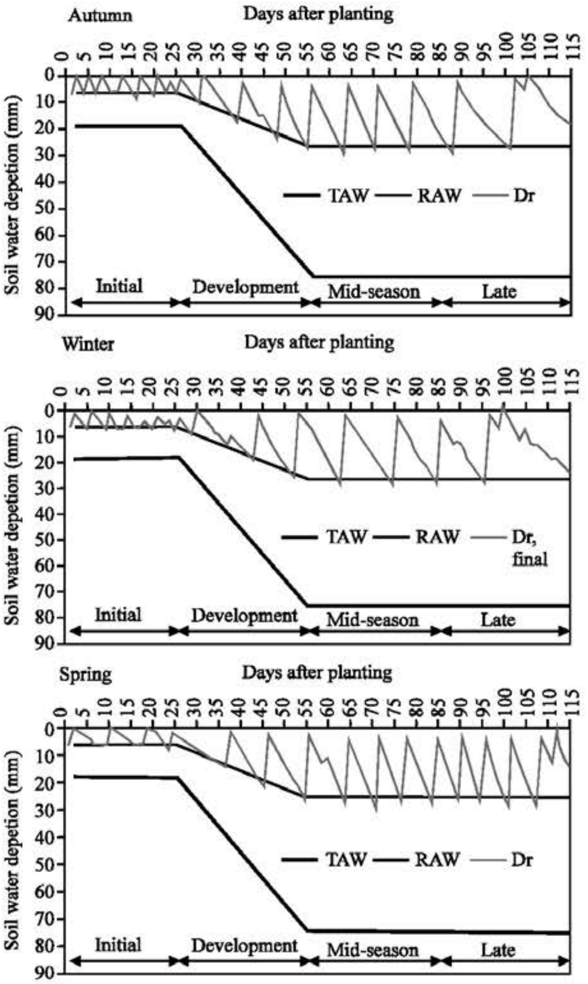

Fig. 3: Estimated daily soil water depletion for potato under 100 L irrigation treatment during the cropping seasons

used. Value of 2.30, 1.97 and 2.55 dS m^{-1} were recorded below the emitter respectively in autumn, winter and spring seasons. With 60 L treatment, ECe values of 1.80, 1.22 and 1.77 dS m^{-1} were recorded below the emitter respectively for autumn, winter and spring seasons and reached the maximum at a distance of 15 cm from the emitter. Between rows, the greatest values of ECe were recorded at distances of 10 and 20 cm from drip line with 40 L treatment. With 100 and 80 L, ECe values decreased to 1 and 1.3 dS m^{-1}, respectively beneath the emitter in autumn season, to 0.65 and 0.9 dS m^{-1} in winter crop and to 0.75 and 1.1 dS m^{-1} in spring one. The zone of highest ECe was moved out to 20 cm from the emitter. Daily irrigation treatment (100 D) resulted in lower ECe value beneath the emitter. At a distance of 20 cm from the emitter, the ECe value is similar to the ECe for the 100 L treatment. Soil salinity was highest midway between the emitters (20 cm) and towards the margin of wetted band (20 to 30 cm). Singh *et al*. (1977) and Laosheng (2000) reported similar result.

The ECe values under the different irrigation treatments were lower than the EC 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

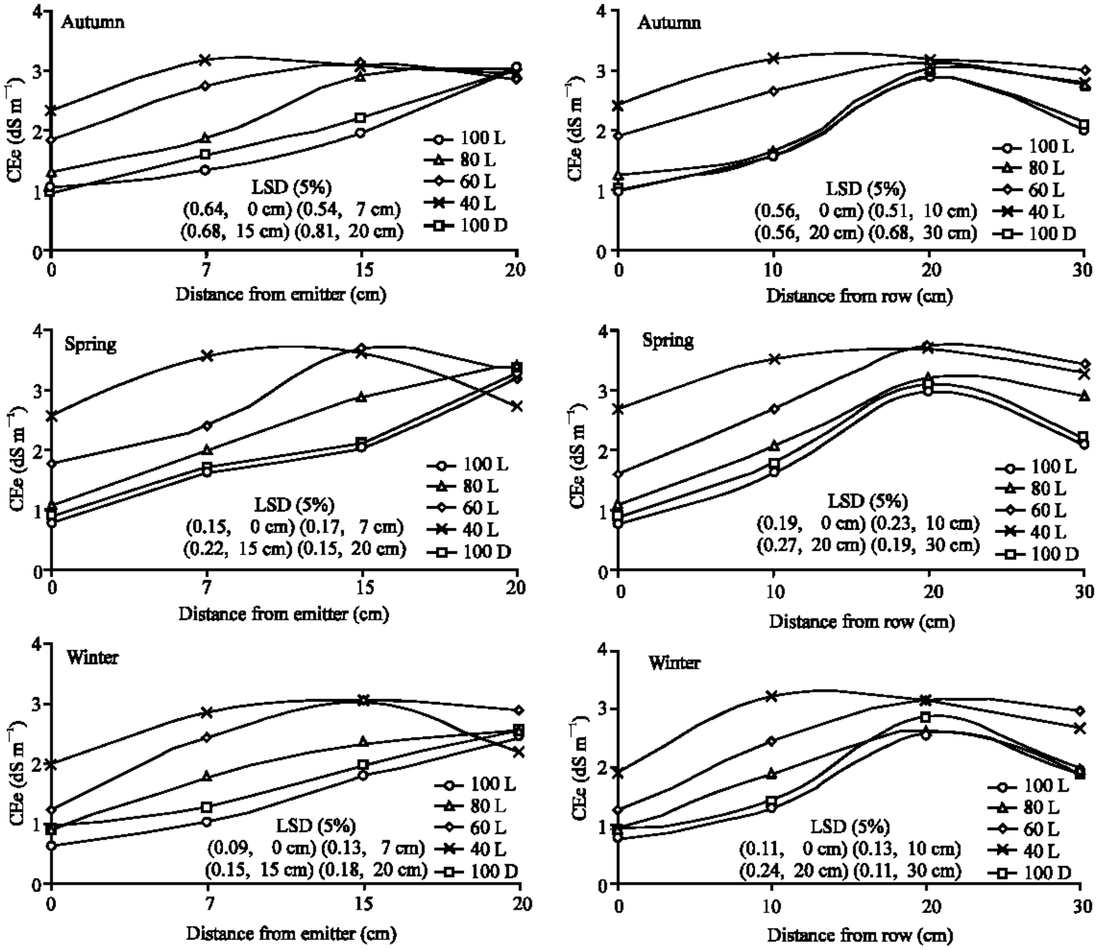

Fig. 4: Soil salinity (ECe, dS/m) under different irrigation treatments along the row and across row

Table 1: Yield and yield components under 100 L and 100 D irrigation treatments during the three seasons

	Spring		Autumn		Winter	
Criteria	100 L	100 D	100 L	100 D	100 L	100 D
Yield (t ha^{-1})	39.6	36.5	30.4	28.9	22.7	20.5
Tubers (m^{-2})	36.0	34.0	32.2	29.7	25.0	23.5
Tuber weight (g)	110.3	107.2	100.6	97.2	90.6	87.3

under the prevailing climatic conditions were due to the leaching of soluble salts with the received rainfall.

For analyzing the effect of irrigation treatments on the final yield, three criteria were retained: tuber yield, tuber number m^{-2} and tuber weight. The data concerning the three parameters considered, observed for all irrigation treatments, are presented in Table 1 and Fig. 5. The data shows that for three seasons the maximum tuber yield occurred in the 100 L treatment. The yields in the 100 D treatment were not statistically different from those obtained with 100 L treatment (Table 1). However, the decrease in water applied from 100 to 80% of ETc decreased the tuber yields. A significant reduction in fresh tuber yields occurred with the 60 L and 40 L treatments (Fig. 5). The reduction in tuber yield was mainly attributed to reduction in tubers number and

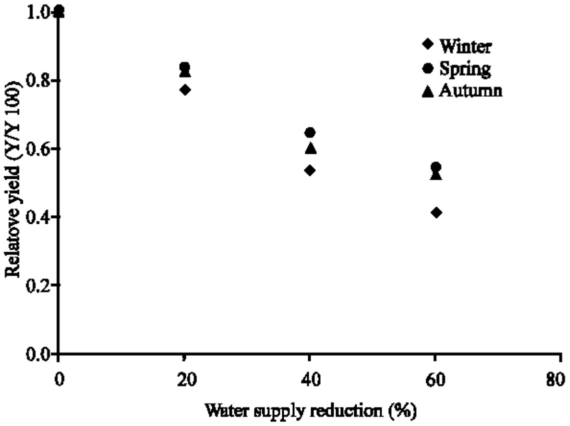

Fig. 5: Relative yield (Y/Y100 L) decrease in relation to relative water supply deficit

Table 2: Coefficients for the salt tolerance of potato

Criteria	Slope (B) % per dS m^{-1} Value	95% confidence limits	Threshold (A) dS m^{-1} Value	95% confidence limits
Relative tuber yield Yr = 100-B (ECe-A)				
Autumn	47	±8.77	1.85	±0.13
Winter	54	±8.60	1.55	±0.11
Spring	34	±12.50	1.90	±0.26

Table 3: Total water supply from planting to harvest and Water Use Efficiency (WUE) under irrigation treatments during the cropping seasons

	Autumn			Winter			Spring		
Irrigation treatments	Irrigation *(mm)	Rainfall (mm)	WUE (kg/ha/mm)	Irrigation *(mm)	Rainfall (mm)	WUE (kg/ha/mm)	Irrigation *(mm)	Rainfall (mm)	WUE (kg/ha/mm)
100 D	313	72	75.1	294	59	58.10	349	26.7	97.30
100 L	261	72	91.3	215	59	82.50	311	26.7	117.50
80 L	208	72	89.4	172	59	74.90	249	26.7	119.50
60 L	157	72	79.8	129	59	63.80	187	26.7	119.10
40 L	104	72	89.7	86	59	63.60	124	26.7	141.70
LSD (5%)	-	-	8.32	-	-	10.10	-	-	15.38

* an irrigation of 75 mm supplied just before planting is not included in these totals

weight as a consequence of water supply shortage during tubers initiation and development. Previous studies have shown that adequate water supply before and during tubers initiation increases the number of tubers per plant (Cappaert *et al*., 1992; Shock *et al*., 1992); whereas, after tubers initiation, it increases their individual sizes (Stark and McCann, 1992; Shock *et al*., 1998). Note that the deficit irrigation treatments results in higher salinity in the rooting zone than the full irrigation treatments (100 L and 100 D) (Fig. 4). A higher salinity associated with deficit irrigation caused important reductions in tuber yield and its components.

To assess its sensitivity to salt, yields data were statistically analyzed with a piecewise linear response model (van Genuchten, 1983). The model uses a non Linear least square regression to determine the slope and threshold for the salt tolerance equation. The equation coefficients are given in Table 2. Based on these data it can be stated that under our conditions Yr = 100-54 (ECe-1.55) for ECe greater than 1.55 dS m^{-1} and Yr = 100 for ECe less than 1.55 dS m^{-1} for the winter season. The salt tolerance of potato is Yr = 100- 47 (ECe-1.85) for ECe greater than 1.85 dS m^{-1} and Yr = 100 for ECe less than 1.85 dS m^{-1} for the autumn season and Yr = 100-34 (ECe-1.82) for ECe greater than 1.90 dS m^{-1} and Yr = 100 for ECe less than 1.9 dS m^{-1} for the spring season. The threshold is close to the value calculated from published salt tolerance data (1.55, 1.85 and 1.90 vs. 1.70 dS m^{-1}) but the slope is considerably steeper (54, 47 and 34 vs. 12%) (Maas and Hoffman, 1977), most likely because of the combined effect of salinity and water deficit for sandy soil in an arid climatic context characterized by a high evaporative demand. These results, obtained under actual farming conditions, support the practicality of using the 100 L methodology to implement an efficient use of saline water for potato production. Under severe shortage of water irrigation could be reduced voluntarily. There is a quantitative indication of the yield loss associated with deficit irrigation (Fig. 5).

The WUE expressed as the ratio of potato yield to total water received from planting to harvest is presented in Table 3. The WUEs values obtained for three seasons are comparable with those obtained in other field studies (Fabeiro *et al*., 2001; Ferreira *et al*., 1999; Singh *et al*., 1977) and were affected by irrigation treatments. In the autumn season, the WUE for fresh tuber yield was the lowest under 100 D treatment and the highest under 100 L treatment. The WUE with 100 L treatment was not significantly different from those obtained with 80 and 40 L treatments but statistically different from those obtained with 100 D and 60 L treatments. These two last did not show a statistical difference between them. In the spring season, the WUE with 40 L was significantly different from those obtained with 100, 80, 60 L and 100 D treatments. The difference was also significant between 100 D treatment and the 100, 80 and 60 L treatments. These three last did not show a statistical difference between them. For winter season, the WUE was the lowest under 100 D treatment and the highest under 100 L treatment. The WUEs with 100 L were not significantly different from those obtained with 80 L but statistically different from those obtained with 100 D, 60 and 40 L. These three last treatments did not show a statistical difference between them. The values of water-use efficiency with 100 D, 60 and 40 L were considerably lower than those obtained under the others treatments. The WUEs obtained with 80 L are statistically different from those obtained with 100 D, 60 and 40 L. The relatively high yields and water use efficiencies noted in 80 L treatments in three seasons indicate an acceptable response of potato to mild water deficit.

CONCLUSIONS

Results of this study indicate that the well irrigated treatments (100 D and 100 L) decreased the soil salinity beneath the emitter as the zone of salt accumulation moved from the emitter. Salts were concentrated midway between the emitters and towards the wetting front. Relatively high values of soil salinity were observed beneath the emitter for 40 and 60 L treatments; whereas, the highest soil salinity occurred at a distance of 7 and 15 cm from the emitter and 10 and 20 cm from the drip line. The 100% of ETc irrigation treatments (100 D and 100 L) produced the highest fresh tuber yields for the three seasons. Treatment 80 L gave also a good yield. Note that the deficit irrigation treatments gave lower yield and resulted in higher salinity in the rooting zone than the full irrigation (100 L and 100 D). The higher salinity associated with the deficit irrigation treatments were sufficient to cause reduction in potato fresh tuber yield. The WUE was significantly affected by irrigation treatments. According to the experimental data, it is clear that lower yields under 40 L and 60-treatments were due to a large reduction in tubers number and weight. From an economical point of view, the reduction in marketable tuber size (tuber weight) under 40 and 60 L may limit the use of these strategies for scheduling. In consequence, 100 L appears to be a promising irrigation strategy for potato crop under the arid climate of southern Tunisia. In case of situations where water supply is limited, irrigation of potato could be scheduled using 80% of ETc.

REFERENCES

Allen, R.G., L.S. Perreira, D. Raes and M. Smith, 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. Irrig. and Drain. Paper No. 56, FAO, Rome, Italy, pp: 300.

Bresler, E., 1975. Two Dimensional transport of solutes during nonsteady infiltration from trickle source. Soil Sci. Soc. Am. Proc., 39: 604-613.

Bustan, A., M. Sagi, Y. De Malach and D. Pasternak, 2004. Effect of saline irrigation water and heat waves on potato production in an arid environment. Field Crop Res., 90: 275-285.

Cappaert, M.R., M.L. Powelson, N.W. Christensen, W.R. Stevenson and F.J. Crowe, 1992. Influence of irrigation severity on potato early dying tuber yield. Phytopathology, 82: 1448-1453.

Fabeiro, C., F. Martin De Santa Ollala and J.A. De Juan, 2001. Yield and size of deficit irrigated potatoes. Agric. Water Manage., 48: 255-266.

Ferreira, T.C., A.N.C. Malheiro, F.A.M.F.P. Freixo, A.A.S. Bernardo and M.K.V. Carr, 1999. Variation in the response to water and nitrogen of potatoes (*Solanum tuberosum* L.) grown in the highlands of Northeast Portugal. In: Proceedings of 14th Triennial Conference of the European Association for Potato Research, 2-7 May 1999, Sorrento, Italy, pp: 410-411.

Katerji, N., J.W. van Hoorn, A. Hamdy and M. Mastrorilli, 2000. Salt tolerance classification of crops according to soil salinity and to water stress day index. Agric. Water Manage., 43: 99-109.

Laosheng, Wu., 2000. Drip irrigation using low-quality water. Irrig. J., 7: 18-20.

Maas, E.V. and G.J. Hoffman, 1977. Crop salt tolerance: Current assessment. J. Irrig. Drain. Div. Am. Soc. Civ. Eng., 103: 115-134.

Patel, R.M., S.O. Prasher, D. Donnelly and R.B. Bonnell, 2001. Effect of initial soil salinity and subirrigation water salinity on potato tuber yield and size. Agric. Water Manage., 46: 231-239.

Sermet, O., M.E. Caliskan, D. Onder and S. Caliskan, 2005. Different irrigation methods and water stress effects on potato yield components. Agric. Water Manage., 73: 73-86.

Shalhevet, J., 1994. Using water of marginal quality for crop production: Major issues. Agric. Water Manage., 25: 233-269.

Shock, C.C., J.C. Zalewski, T.D. Stieber and D.S. Burnett, 1992. Impact of early-season water deficits on Russet Burbank plant development, tuber yield and quality. Am. P.J., 69: 793-803.

Shock, C.C., E.B.G. Feibert and L.D. Saunders, 1998. Potato yield and quality response to deficit irrigation. HortScience, 33: 655-659.

Singh, B. and D.R. Bhumbla, 1968. Effect of quality of irrigation water on soil properties. J. Res. Punjab Agric. Univ., 5: 166-172.

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

Stark, J.C. and I.R. McCann, 1992. Optimal allocation of limited water supplies for Russet Burbank potatoes. Am. Potato J., 69: 413-421.

Van Genuchten, M.T., 1983. Analyzing Crop Salt Tolerance Data: Model Description and User's Manual. Research Report No. 120, pp: 50, USDA-ARS, U.S.S. Laboratory, Riverside, CA.

Waddel, J.T., S.C. Gupta, J.F. Moncrief, C.J. Rosen and D.D. Steel, 1999. Irrigation and nitrogen managemennt effects on potato yield, tuber quality and nitrogen uptake. Agron. J., 91: 991-997.