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Soil Salinity under deficit drip irrigation of potato and millet in an arid environment

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Abstract: The influence of deficit irrigation (DI) with saline water on soil salinity in a drip-irrigated potato and millet fields was investigated. We had compared proportional soil salinity developed under Full and DI under drip irrigation. For both experiments, the treatments were (1) Full, control treatment where rooting zone soil water content was increased to field capacity at each irrigation; (2) DI80; (3) DI60 and DI40; 20, 40 and 60% deficit irrigation compared to Full treatment were applied, respectively. Soil salinity was assessed using the isosalinity maps constructed with grid soil sampling of plant root zone at harvest. Results show that high spatial variability was observed in salinity along soil profiles when applying saline water with drip irrigation for potato. For the DI60 and DI40 treatments, high soil salinity was recorded in the upper soil layer close to the emitter. Increase of soil salinity within soil depths of 30 cm or below was also observed under DI60 and DI40 treatments. The lowest increase was noted under the full treatment. Surface soil salinity was somewhat higher under DI60 and DI40 compared with that of Full and DI80 irrigation treatments. The distribution of salts around the dripper changes during the crop season according to applied irrigation treatments, with overall higher concentrations between the drippers and towards the margin of wetted band. Iso-salinity maps at harvest of potato showed that the surface layer of 30 cm depth had the lowest salinity which gradually increased at deeper zones irrespective of the treatment. Salt accumulation essentially occurred at wetting front between the drippers and the plant row. Although salt accumulation was relatively highest along the row under DI treatments, the area of accumulation was relatively shifted toward the center between the rows and the drip line. The results also show the importance of the potato cropping season to benefit from the leaching of soluble salts with the received rainfall. For millet experiments, salinity was lowest under emitters and highest midway to the margin of wetted bands and higher soil salinity was maintained in the root zone with deficit irrigation treatments than full irrigation. Millet and potato yields were highest under Full treatment. Yields decreased almost linearly when applied water was reduced. However, reduction in quality was significantly important for DI60 and DI40. The analysis outcome of the crops sensitivity to salt indicated respectively for autumn, winter and spring potato and millet crops that thresholds are close to the value calculated from published salt tolerance data (1.9, 1.55, 1.85 vs. 1.7 dS/m for potato and 3.46 vs. 3.65 dS/m for millet) but the slopes are considerably steeper (34, 54, 47 vs. 12%; 17 vs. 6.7%), apparently because of the combined effect of salinity and water stresses. The results provide information's to farmers for formulating improved planning regarding irrigation management practices. The results support the practicality of using the full irrigation (100% of ETc) methodology to optimize irrigation with saline water for potato and millet production and to control soil salinity. Under situations of water shortage, the deficit irrigation strategy (DI80 and DI60) is recommended as a tool to schedule irrigation of potato and millet crops in arid regions of Tunisia.

Key words: *arid, soil salinity, deficit irrigation, drip irrigation, potato, millet, yield*

Introduction

Limited supply of good quality water is the most important factor limiting crop production in arid Tunisia. However, there are considerable resources of saline water that has been included as an important substitutable resource for fresh water for agricultural irrigation through suitable irrigation management. The salinity of these resources of saline water varies in the range of electrical conductivities (ECi) between 3 and 9 dS/m. This water was considered not suitable for agricultural irrigation since its uses at long term could induce soil degradation. Therefore the inefficient use of these low quality waters results in the abandonment of some farms in these regions (El Mokh, 2016). However, the current water scarcity, primarily in the arid regions, has forced farmers to extensively explore the possibility of including saline water in the irrigation regimes of agricultural crops. Whereas, if management is not properly practiced, irrigation with low quality water can compound existing problems with soil salinity.

In arid regions of Tunisia, irrigation with waters having an ECi more than 3 dS/m is commonly practiced on a routine basis without scheduling and provision drainage and it carries the danger of a rapid soil salinization because of increased salt input (Nagaz *et al.*, 2013). It is well established that, applying saline water continuously for irrigation might result in salt accumulation close to the soil surface (DeMalach and Pasternak, 1993; Oron *et al.*, 1995).

The problems mentioned above can be overcome by applying saline water through a drip-irrigation system. It is anticipated that under drip irrigation, the salt front is partially driven down into the deeper soil bulk media and to the periphery of the root zone, thus minimizing the risk of damaging the main roots of the plants. Moreover, the improved moisture conditions in the vicinity of the emitter offsets the inhibiting effects of the presence of the salts in the saline water (Michelakis *et al.*, 1993). Additionally, it can result in water saving if the correct management procedures are applied. To further address the issue of water shortage and soil salinization, new irrigation scheduling techniques such as deficit irrigation (DI), which are not necessarily based on full crop water requirement can be investiated. Deficit irrigation, widely reported as a valuable strategy for dry regions (English, 1990; Pereira *et al.*, 2002; Fereres and Soriano, 2007), is particularly important for crops which are frequently subject to chronic water shortages.

Due to chronic water shortage and soil degradation hazards in irrigated areas, there is a need to develop strategies that may help to save water and control salinity. In the absence of drainage systems and under conditions of high evaporative demand and chronic shortages of water, techniques based on irrigation restrictions during the whole growing period without substantially affecting yields seem to be reasonably appropriate. One consequence of reducing irrigation water use by DI is the greater risk of increased soil salinity due to reduced leaching, and its impact on the sustainability of the irrigation (Schoups et al., 2005). The evaluation of soil salinity developed under drip irrigation with DI practice should be investigated. Therefore, various deficit irrigation strategies have been applied to pearl millet and potato crops considered as moderately tolerant and relatively sensitive to water stress caused by deficit irrigation or salinity (Hajor *et al.*, 1996; Maas and Hoffman, 1977). The purpose of this study is to verify the effect of DI with drip irrigation on the salinity distribution in the soil profile and eventually the crop yield in order to develop an irrigation strategy that save water in irrigated millets and potatoes, and reduce salt input. The possibility of using saline water through DI for vegetable and cereal crops irrigation is being examined in the field experiments.

Materials and methods

Field experiments were carried out during the autumn, winter and spring for potato (2001/2002) and summer millet (2005/2006) growing seasons at farmers' sites situated in the Southern East of Tunisia. The climate is typical of arid areas and the rainfall received during the winter, spring and fall potato growing seasons was 59, 26 and 72 mm, respectively. No rainfall was received during the cropping period of millet over the two years. Reference evapotranspiration (ETo-PM) was, respectively, 342, 390 and 397 mm for winter, spring and autumn potatoes in 2001-2002, and 502 and 510 mm for millet growing season in 2005 and 2006.

Potato (*Solanum tuberosum* L. cv. Spunta) and millet (*Pennisetum glaucum* (L.) R. Br.), native of the region, were planted on sandy soils with low organic matter content, and an ECe of 1.35, 2.01 and 3.45 dS m-1 for spring, winter and autumn potatoes, respectively, and 2.50 and 1.74 dS m-1 for first and second year of millet crop, respectively. The total available soil water, calculated between field capacity and witling point for an assumed potato and millet root extracting depth of 0.60 and 0.70 m, was 75 and 62 mm, respectively.

Planting took place on 5 February 2000, 1 November 2001 and 1 September 2002 for the spring, winter and autumn potatoes respectively, in 70 cm rows with tubers spaced 40 cm apart, and on 25 May 2005 and 1 June 2006, with plant and row spacing 0.5 m x 0.40 m in a randomized complete block design with four replicates and four irrigation treatments. Both experimental areas were divided into four blocks with four elementary plots per block. Each elementary plot had four and ten rows with 4 and 12 m width and 26 and 30 m length, respectively, for potato and millet crops.

Potato and millet crops were drip irrigated with water from a shallow well having an ECi of 3.25 and of 7.6 dS m-1, respectively. Each dripper had a 4 l/h flow rate. Water for each block passed through a water meter, gate valve, before passing through laterals placed in every millet and 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; before planting of potato and millet crops, soil was spread with 17 and 15 t ha-1 of organic manure. Nutrient supply included N, P and K at rates of 300, 300 and 200 kg ha-1 for potato crops and 300, 200 and 150 kg ha-1 for millet crop, 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.

The experiments consisted of four distinct irrigation treatments: Full 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 Full treatment, but with quantities equal to 40, 60 and 80% of accumulated ETc (DI40, DI60 and DI80). These treatments were identified as deficit irrigation treatments.

The crop evapotranspiration (ETc) was estimated for daily time step by using reference evapotranspiration (ETo) combined with millet and potato crop coefficient (Kc). The ETo was estimated from daily climatic data collected from the Institute meteorological station (data not presented) by means of the FAO-56 Penman-Monteith method given in Allen et al. (1998). The potato and millet 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. 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 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 and 60% of TAW for potato and millet crops.

The program integrates the effects of climatic and crop data, soil characteristics, irrigation system and management to simulate and output the daily values of soil evaporation, transpiration, crop evapotranspiration, drainage and soil water depletion. Simulation starts with a soil water content at field capacity at planting. The water depletion from root zone is considered as the net water requirement. The amounts of irrigation water applied for the potato and millet crops from planting to harvest are given in Table 1.

Table 1 - Irrigation water supply under different irrigation treatments during the growing periods of potato and millet.

Crops	Periods	Irrigation (mm)			
		Full	DI80	DI60	DI40
Potato	Autumn	261	208	157	104
	Winter	215	172	129	86
	Spring	311	249	187	124
Millet	2005	431	345	260	172
	2006	415	332	249	166

At physiological maturity potato and millet yields were obtained. Twenty and ten plants per row within each plot were harvested by hand, respectively for millet and potato, to determine millet and potato yields and yield components.

Soil samples were collected after harvest of potato and millet crops and analyzed for ECe. The soil was sampled every 15 cm to a depth of 60 and 70 cm, at four sites perpendicular to the drip line and at four sites between the emitters. Conceptually, these should be areas representing the range of salt accumulations (Bresler, 1975; Singh *et al.***,** 1977).

Results and discussion

Soil salinity

Figures 1, 2 and 3 demonstrate the salinity distributions, ECe, in the soil in the autumn, winter and spring potatoes along the row and across row for each treatment. High spatial variability was observed in salinity along soil profiles when applying saline water with drip irrigation. The trends of salinity distribution in the soil as expressed by the ECe were similar for the three cropping seasons. For the DI40 and DI60 treatment, high soil salinity was recorded in the upper soil layer close to the emitter. Increase of soil salinity within soil depths of 30 cm or below was also observed under DI60 and DI40 treatments. Extra leaching is thus required to shift the salt front into deeper soil layers. For a new cultivated area, probably an intense leaching will be required prior to planting. As expected, the lowest increase was noted under the Full treatment because of leaching that occurred. Note that surface soil salinity was somewhat higher under DI60 and DI40 compared with that of DI80 (Figures 1, 2 & 3). In the immediate vicinity of the emitter for full and DI80 irrigation treatments, the soil salinity was relatively low. This finding is important, since it means that for full drip irrigation, the soil salinity for potatoes in the active root zone remains quite low and full drip irrigation maintains continuous soil leaching not only downwards, but also radially. The full and DI80 drip irrigation treatments facilitated sufficient leaching below the area wetted by emitter and do not contribute to extra accumulation of salts in the active root zone of the plant.

The distribution of salts around the dripper changes during the crop season according to applied irrigation treatments, with overall higher concentrations between the drippers and towards the margin of wetted band, and this for the three cropping periods. Iso-salinity maps at harvest showed also that the surface layer of 30 cm depth had the lowest salinity which gradually increased at deeper zones irrespective of the treatment. Salt accumulation essentially occurred at wetting front between the drippers and the plant row. Salinity below 30 cm depth proportionally was higher compared to surface layers. Although salt accumulation was relatively highest along the row under DI treatments, the area of accumulation was relatively shifted toward the center between the rows and the drip line. For potato experiments, the results also show the importance of the cropping season to benefit from the leaching of soluble salts with the received rainfall. For the spring crop, a clear increase in the salinity of the root zone of 60 cm was observed, the ECe increased from 1.35 at the plantation in February to approximately 2 dS/m after harvest in May. For the winter crop which takes place from November to February, the soil salinity remains in levels comparable with an ECe of about 1.5 dS/m. However, for the autumn crop the ECe decreased from 3.45 dS/m in September to about 2 dS/m after harvesting in January.

The application of deficit irrigation with reductions of 20, 40 and 60% of the water supplies causes salts accumulation increasing with the level of water reduction. ECe passes from approximately 2 dS/m for the full irrigation to 3.2 dS/m for the DI60. The increase in the soil salinity for the autumn and winter crops seems however less important than that of spring season. A deficit of 20% seems to constitute a good compromise to maintain low soil salinity values with limited impact on the yield. More important reductions do not make it possible to create favorable conditions to evacuate salts apart from the root zone, regardless, the cropping period. The reduction of irrigation water beyond 20% reduces the salts quantity brought on the soil, but it does not contribute to an effective soil leaching. Our results showed that risks of salt accumulation under the deficit irrigation treatment DI80 would not be much different than under Full irrigation. Therefore, in regions with limited irrigation water, DI80 could be preferred.

For millet experiments, the final ECe values at different distances from emitter and drip line under the different irrigation treatments are presented in Figure 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 DI40 treatment was used. Values of 6.10 and 4.92 dS/m were recorded below the emitter respectively in the first and second year. With DI60 treatment, ECe values of 4.03 and 3.33 dS/m were recorded below the emitter respectively for 2005 and 2006, 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 15 and 25 cm from drip line with DI40 treatment. With Full and DI80, ECe values decreased to 2.75 and 3.14 dS/m respectively beneath the emitter in 2005 and to 1.95 and 2.38 dS/m in 2006. The zone of highest ECe was moved out to 20 cm from the emitter. Soil salinity was highest midway between the emitters and towards the margin of wetted band. Nagaz *et al.*, (2007) and Singh *et al.* (1977) reported similar result.

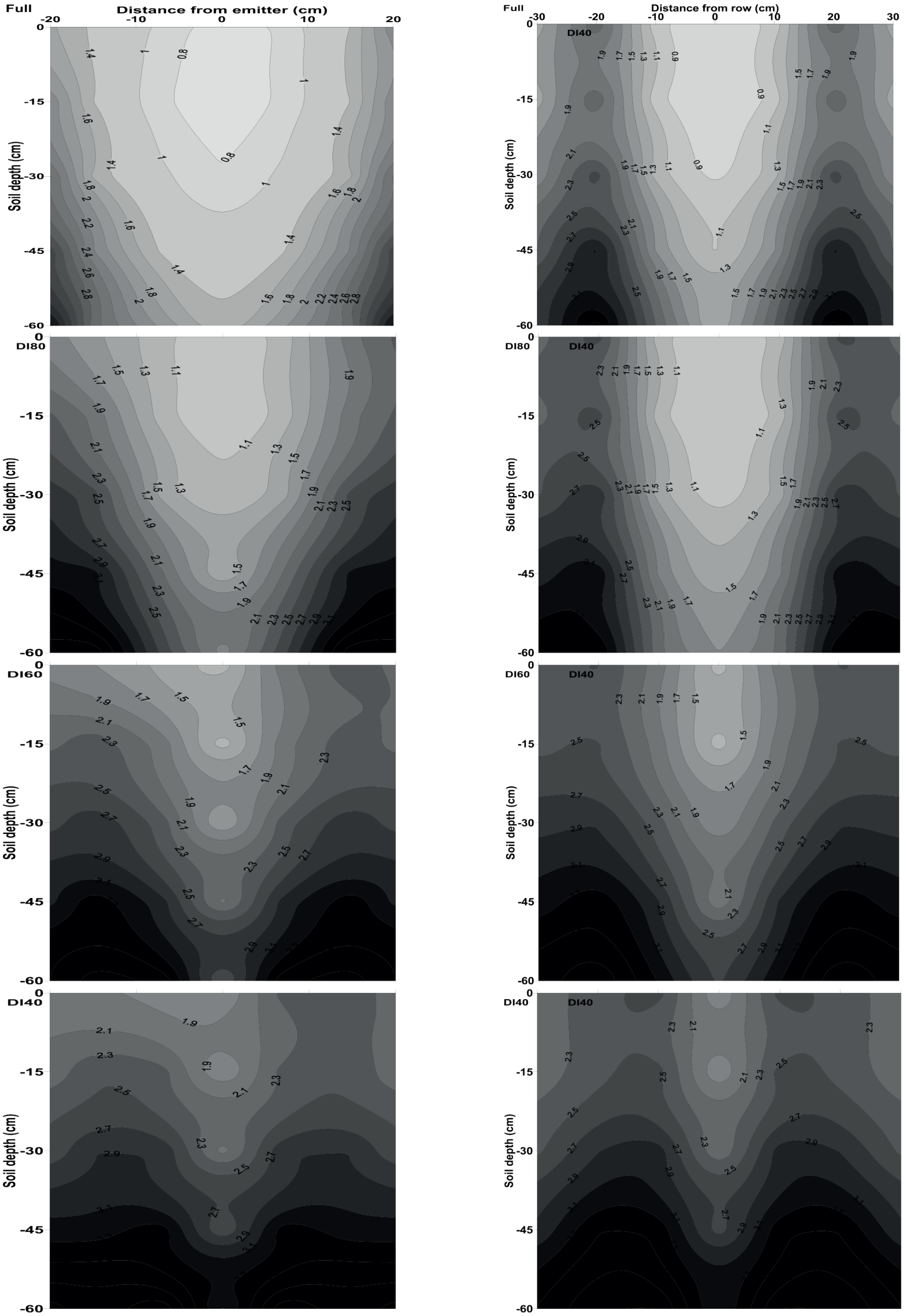


Figure 1 - Soil salinity (ECe, dS/m) under different irrigation treatments along the row and across row: Autumn potato

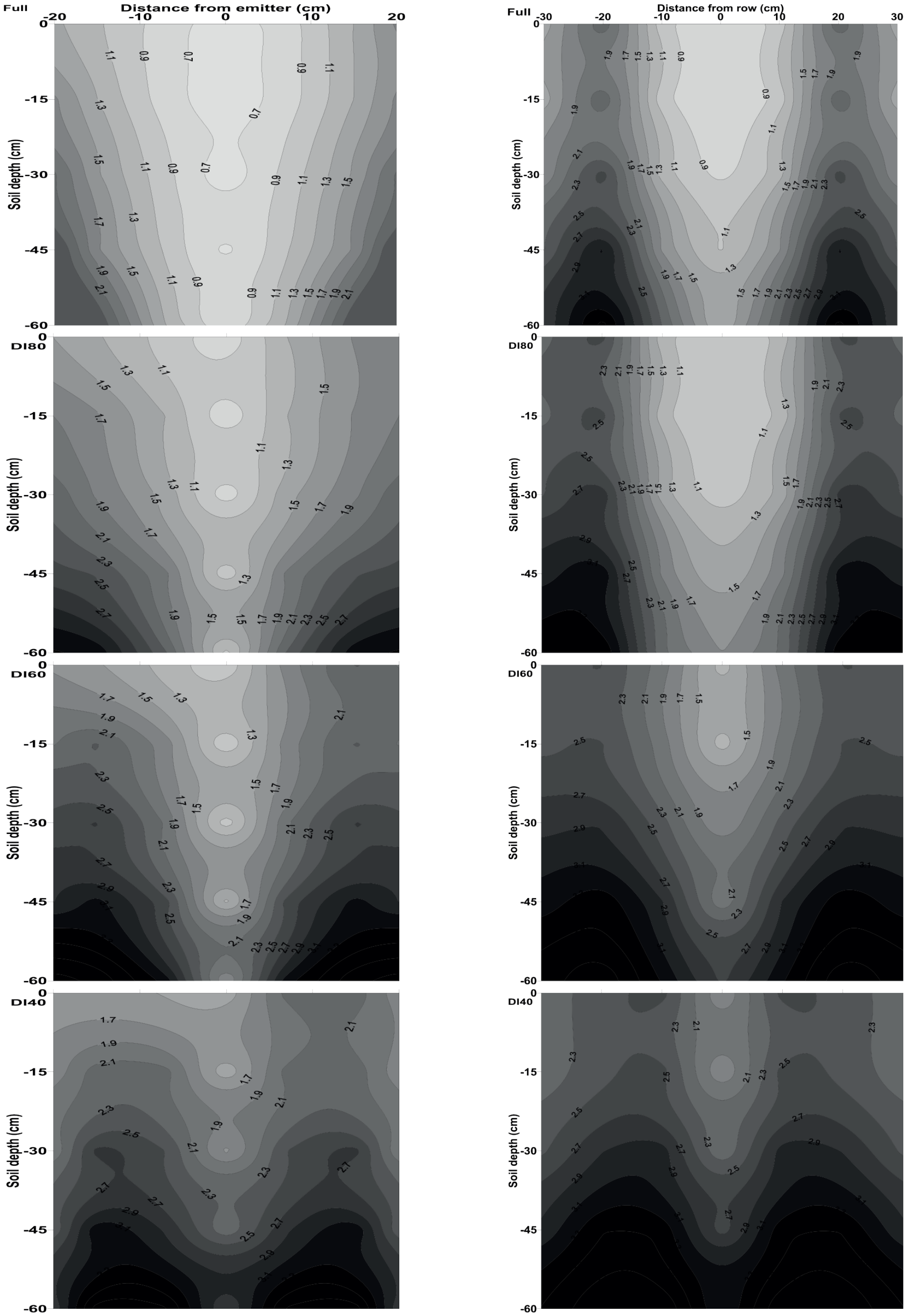


Figure 2 - Soil salinity (ECe, dS/m) under different irrigation treatments along the row and across row: Winter potato

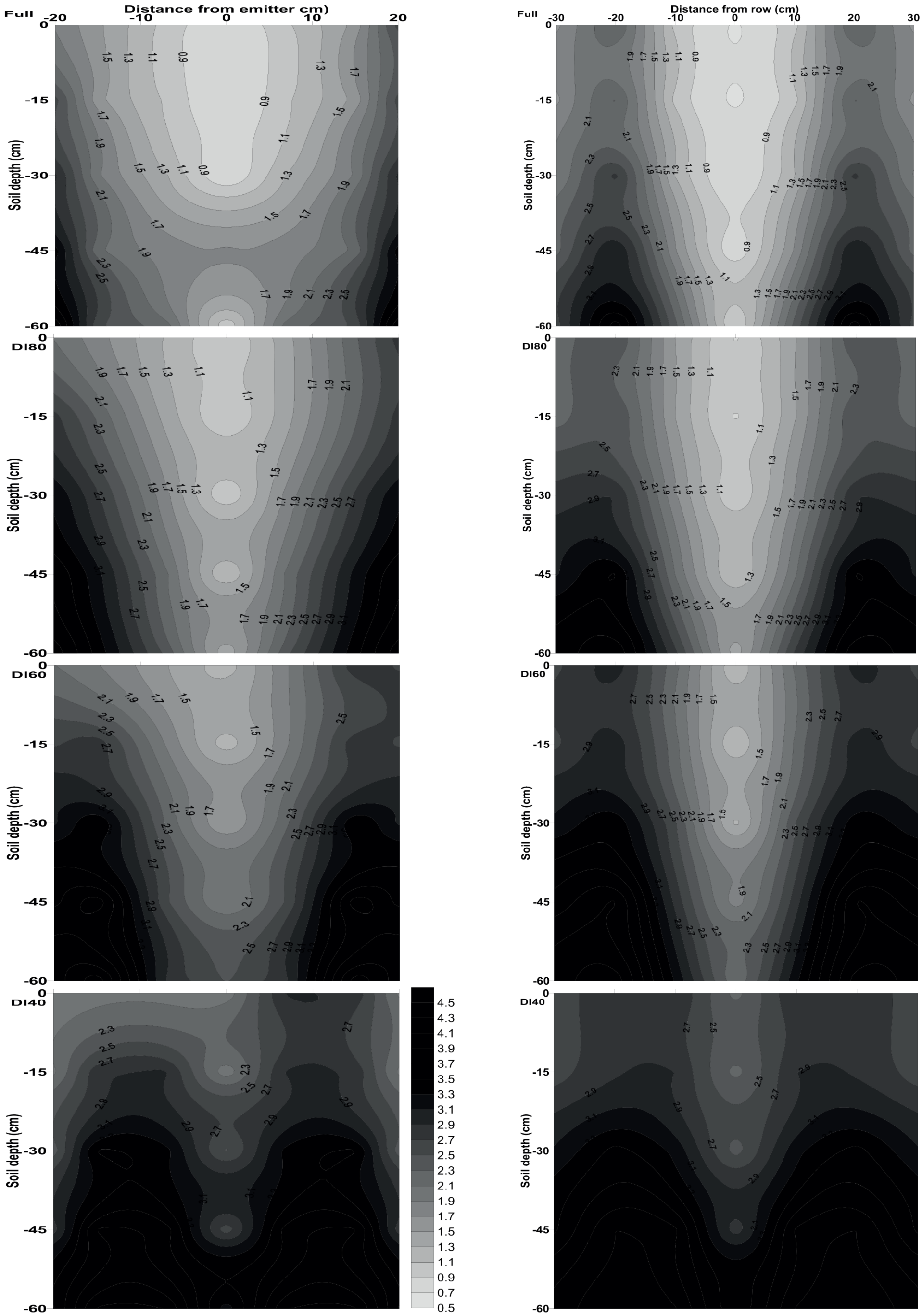


Figure 3 - Soil salinity (ECe, dS/m) under different irrigation treatments along the row and across row: Spring potato

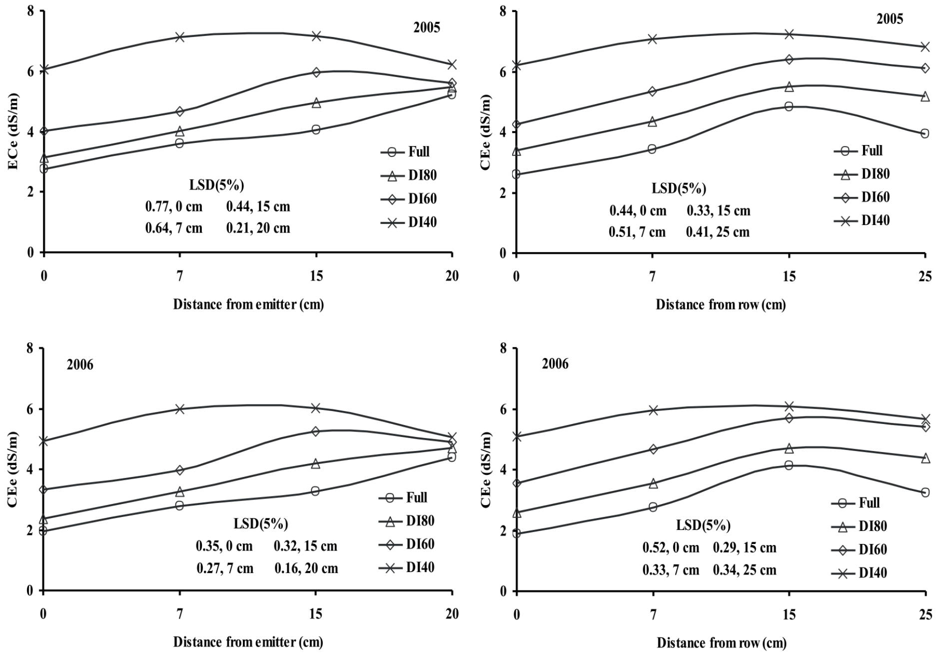


Figure 4 - Soil salinity (ECe) under different millet irrigation treatments along the row and across row.

The mean ECe values under the different irrigation treatments were lower than the EC of the irrigation waters used (Figure 5). Singh & 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 during winter, spring and fall potato seasons that are close to the historical average values (16 years) (59, 26 and 72 mm vs. 52, 21 and 80 mm), and to the low initial soil salinity at planting of millet crop in first and second year (2.50 and 1.74 dS/m). Thus, the impact of using saline water for irrigation on soil salinization seems to be limited for crops with short growing season particularly when cropping cycle coincide with the rainy season i.e. potato and can benefit from the leaching capacity of rainfall events.

Yields

The data concerning the yields of millet and potato crops, observed for all irrigation treatments, are presented in Figure 6. The data shows that for both crops the maximum yield occurred in the Full treatment. The decrease in water applied from

100 to 80% of ETc decreased the millet and potato yields. A considerable reduction in grain and fresh tuber yields occurred with the DI60 and DI40 treatments (Figure 6). The reduction in yields was mainly attributed to reduction in yield components (data not presented) as a consequence of water supply shortage during potato tubers initiation and development, and during panicle initiation, flowering and millet grain filling. Previous studies have shown that adequate irrigation water supply during panicle initiation, flowering and grain filling increases the panicle number and kernel number and weight (van Oosterom *et al.*, 2002; Bidinger *et al.*, 1987; Mahalakshmi and Bidinger, 1986). Adequate water supplies before and during tubers initiation increases the number of tubers per plant (Shock *et al.*, 1992); whereas, after tubers initiation, it increases their individual sizes (Shock *et al.*, 1998).

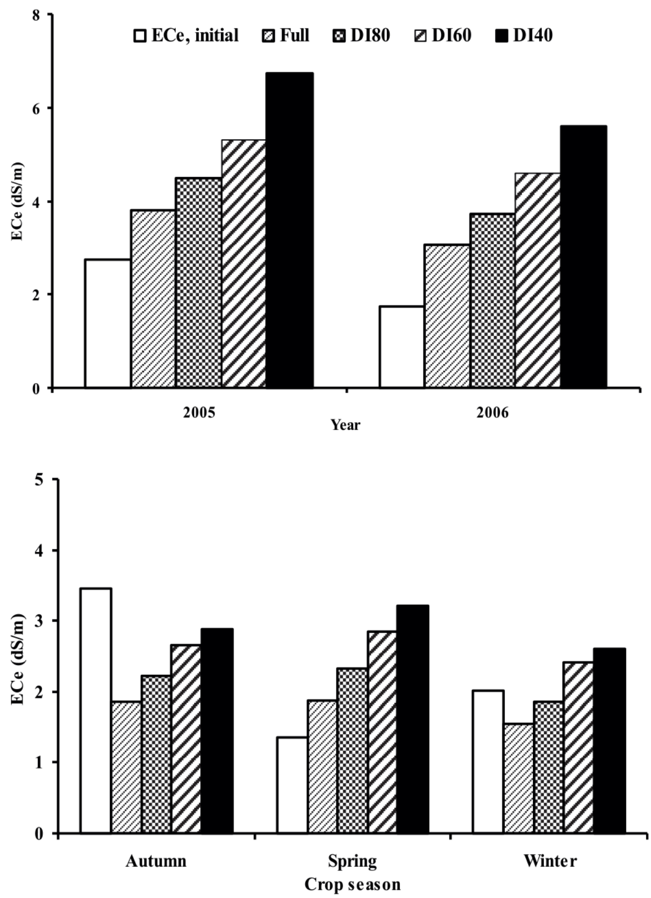
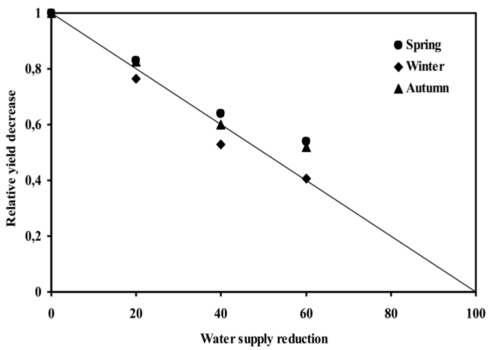


Figure 5 - Mean soil salinity values under different irrigation treatments.

Note that the deficit irrigation treatments results in higher salinity in the rooting zone than the full irrigation treatment (Figure 5). One consequence of reducing irrigation water use by deficit irrigation is the greater risk of increased soil salinity due to reduced leaching, (Schoups *et al.*, 2005). A higher salinity associated with deficit irrigation caused important reductions in yield and yield components of millet and potato. These results, obtained under actual farming conditions, support the practicality of using the Full methodology to implement an efficient use of saline water for millet and 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 (Figure 6).



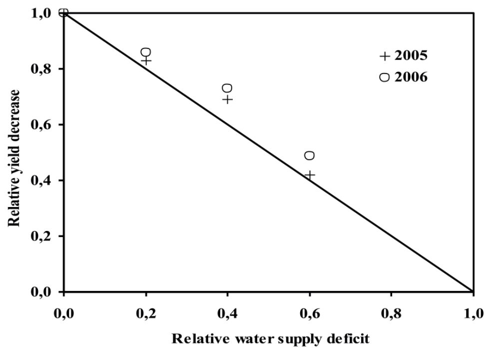


Figure 6 - Relative potato and millet yields (Y/YFull) decrease in relation to relative water supply deficit.

There were differences between experiments in millet and potato yields. To assess their respective sensitivity to salt, yields data for each experiment were statistically analyzed with a piecewise linear response model (van Genucthen, 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 figure 7. 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 and Yr= 100 for ECe less than 1.55 dS/m for the winter season. The salt tolerance of potato is Yr = 100- 47 (ECe-1.85) for ECe greater than 1.85 dS/m and Yr= 100 for ECe less than 1.85 dS/m for the autumn season, and Yr=100 - 34(ECe-1.82) for ECe greater than 1.90 dS/m and Yr=100 for ECe less than 1.9 dS/m for the spring season.

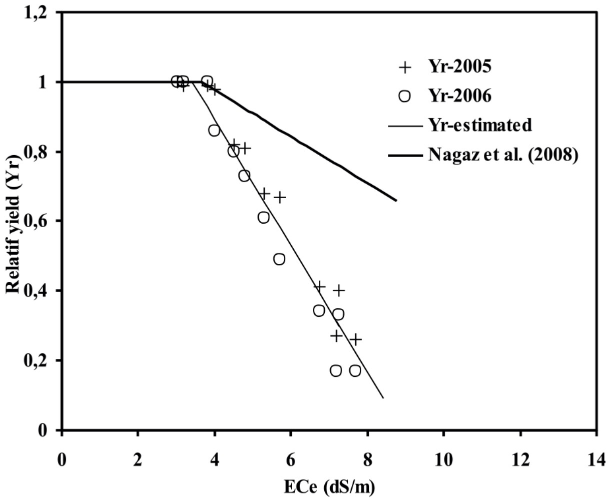


Figure 7 - Relative millet grain yield in relation to soil salinity (ECe, dS/m)

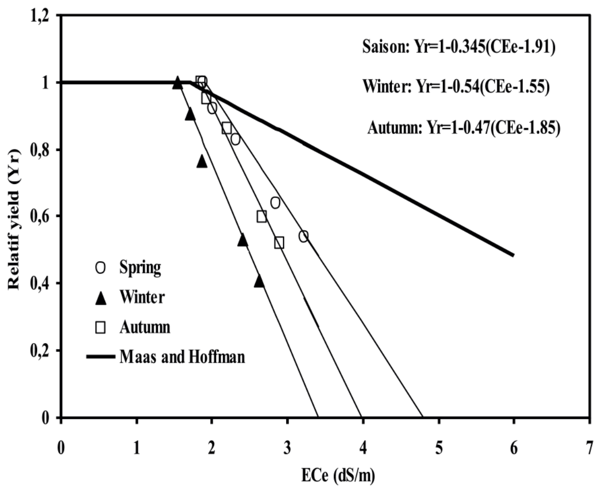


Figure 8 - Relative fresh tuber yields in relation to soil salinity (ECe, dS/m)

The analysis outcome indicated that thresholds were nearly the same for both millet experiments. Therefore, both yield sets were combined and analyzed (Figure 8). Based on these data it can be stated that under our conditions Yr = 100- 17 (ECe-3.46) for ECe greater than 3.46 dS/m and Yr= 100 for ECe less than 3.46 dS/m. The threshold is close to the value calculated from published salt tolerance data (3.46 vs.

3.65) but the slope is considerably steeper (17 vs. 6.7) (Nagaz *et al.*, 2008), 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.

Conclusion

Results of this study indicate that the full irrigation treatment (Full) decreased the soil salinity beneath the emitter as the zone of salt accumulation moved away 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 DI40 and DI60 treatments; whereas, the highest soil salinity occurred at a distance of 7 and 15 cm from the emitter, and 15 and 25 cm, 10 and 20 from the millet and potato drip line, respectively. Millet and potato yields were influenced by irrigation treatments. For both experiments, yields of deficit irrigated treatments (DI80, DI60 and DI40) were considerably lower than those in full irrigation treatment. The full irrigation treatment produced the highest grain and tuber yields. Treatment DI80 gave also good yields. Note that the deficit irrigation treatments gave lower yields and resulted in higher salinity in the rooting zone than the full irrigation. The higher salinity associated with the deficit irrigation treatments were sufficient to cause reduction in millet and potato yields.

The yield and quality obtained under these treatments do not allow opting for such important reductions. The relatively high yields noted under full irrigation in both experiments indicate the high potential of the potato and millet crops to valorize irrigation waters of limited quality, provided that good management is applied.

The results suggest that in the arid Mediterranean conditions of southern Tunisia, Full irrigation strategy is recommended for potato and millet cultivation. Deficit irrigation practices can be a feasible option for improving irrigation schedules and thereby to increase efficient use of restricted water resources. Thus, irrigation of millet could be scheduled using DI80 or DI60 irrigation strategy, but DI80 could be a promising irrigation strategy to potato when irrigation water is limited.

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