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Comparative Effects of Drip and Furrow Irrigation with Saline Water on the Yield and Water Use Efficiency of Potato (*Solanum tuberosum L.*) in Arid Conditions of Tunisia

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Abstract: Field experiment was conducted on a sandy soil during spring of 2005 in southern Tunisia for evaluating the effects of drip and furrow irrigation methods on soil salinity, yield and water use efficiency of potato (*Solanum tuberosum L.*). For both irrigation methods, irrigations were scheduled when readily available water in the root zone (35% of the total available water) was depleted. Well water with an ECi of 3.25 dS m^{-1} was used for irrigation. Growth, yield, yield components, water supply and soil salinity were measured. Results show that higher soil salinity was maintained in the root zone with furrow than drip irrigation. The growth and yield of potato irrigated through furrows were significantly lower when compared with drip irrigation. Potato yield was increased 11% relative to that for furrow irrigated potato. Under drip irrigation, 20.8% of the irrigation water was saved in comparison with furrow irrigated potato; and irrigation water use efficiency increased by 29% compared with that of furrow irrigation. Drip irrigation method provides significant advantage on yield and WUE, compared to furrow irrigation in potato production under experimental conditions. Therefore, the drip irrigation method is recommended to optimize the use of saline water in potato production under the arid mediterranean conditions of southern Tunisia.

Key words: Arid, potato, yield, water use efficiency, drip irrigation, furrow irrigation, salinity

INTRODUCTION

Efficient use of water by irrigation systems is becoming increasingly important in arid regions of Tunisia with limited water resources and where potato has been expanding rapidly during the last few years around shallow wells having a salinity of 2-6 dS m^{-1}. Furrow irrigation is widely used in potato production in arid cropping system of Tunisia and is characterized by low efficiencies. Drip irrigation has not been widely used in potato production in this region, because of the higher cost of the drip line installation. In recent years, cost of installation has relatively decreased with the easy access to subsidized drip irrigation equipment made possible recently. Therefore, the drip irrigation practices will possibly be increased in potato production to attain the twin objectives of higher productivity and optimum use of water.

Earlier reports by Ayers *et al*. (1986), Saggu and Kaushal (1991), Goldberg and Shamueli (1970), Bernstein and Francois (1973) and Fereres *et al*. (1985) show that saline water can be efficiently used through drip irrigation even on saline soils. Moreover, it results in considerable saving in irrigation water (Tan, 1995; Yohannes and Tadesse, 1998; Cetin and Bilgel, 2002) thus reducing the risks of salinisation. Drip irrigation provides more efficient water use for crops than furrow irrigation because drip method applies frequent irrigation and localized water application to only part of the crop's potential root zone and reduces adverse effects of over-irrigated and water stress commonly caused by furrow irrigation. Many studies and reports have addressed that yield and quality of potato (*Solanum tuberosum*) tuber, onion, lettuce, tomato, cotton and cantaloupe could 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 Tadesse, 1998; Al-Jamal *et al*., 2001; Daleshwar Rajak *et al*., 2006; Erdem *et al*., 2006).

These potentials of drip irrigation are not yet fully known by farmers in arid regions of Tunisia with the exception of few commercial farmers who grow vegetables and fruits. Since little information is available about the water use efficiency, growth and yield of potato crop with on farm drip and furrow irrigation in arid conditions of Tunisia, An evaluation of the drip irrigation system was,

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therefore, necessary to confirm and demonstrate to local farmers the improved crop response and water savings as compared to conventional irrigation.

The objective of this study was to evaluate the comparative effect of drip and furrow irrigation on soil salinity, yield and water use efficiency of potato under the arid Mediterranean conditions of southern Tunisia.

MATERIALS AND METHODS

Experimental site and climate: Experiment was carried out during spring season of 2005 in the Southern East of Tunisia in a commercial farm located near the Institut des Regions Arides de Medenine. Potato (*Solanum tuberosum L.* cv. Spunta) was planted on sandy soil with low organic matter content and an ECe of 1.4 dS m^{-1}. The rainfall received during the cropping period was 42 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.

Crop management and experimental design: Planting took place on 15 February 2005 in flat beds for drip irrigation and on ridges for furrow irrigation keeping spacing of 0.70 × 0.40 m, in a randomized complete block design with 3 replicates and 2 irrigation methods i.e. drip and furrow methods for comparison. The experimental area was divided into 3 blocks with 2 elementary plots per block. Each elementary plot consisted of 10 rows. All plots were irrigated with water from a well having an ECi of 3.25 dS m^{-1}. For drip irrigation system, each dripper had a 4 L h^{-1} flow rate. Water for each drip-irrigated treatment 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. Irrigation water quantity applied through drip irrigation was measured by water meter. For furrow irrigation, each plot was made to small basins, which was furrowed and each furrow was feed individually. Measured amounts of water were delivered to the furrows using a hosepipe and water meters.

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 applied in all treatments during early vegetative growth. After tubers initiation stage, 120 kg ha^{-1} of potassium nitrate was applied.

The experiments consisted of 2 irrigation methods. For both methods, 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.

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 drip and furrow methods 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 June 9, 2005. 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: W.U.E (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.

Soil samples were collected after harvest. The soil was sampled with a 4 cm auger every 15 cm to a depth of 60 cm. Samples were air-dried and ground to pass a mesh of 2 mm size and were analyzed for ECe.

Statistical analysis: Analysis of variance was performed to evaluate the statistical effect of irrigation treatments on potato yield, yield components, 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

Evapotranspiration estimates and soil water balance: Figure 1 shows computed Kc (KsKcb+Ke) during the cropping period under drip and furrow irrigation methods. The potential Kc values were about 1.1-1.2 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 0.9-1.1 following wetting by rainfall. Some of the evaporation spikes were lower during this period under drip irrigation since only fraction of the soil surface (fw=0.3) was wetted only by irrigation. However, the relatively high Ke values under furrow irrigation during the initial stage were principally attributed to the high fraction of the soil surface wetted by irrigation from which most evaporation occurs (fw=0.8). 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 illustrates the course of daily ETc relative to ETo for the drip and furrow-irrigated potato. During the first 25 days after plantation, in comparison with drip irrigation, high ETc values under furrow irrigation were observed because of the important soil evaporation values. 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 1.54 and 2.65 mm, respectively for drip and furrow irrigation systems. As the crop canopy grew, ETc increased and reached its highest mean value at mid-season stage (4.12 and 4.43 mm.day^{-1}). The mean ETc values at the late stage were about 4.07 and 4.91 mm day^{-1}, respectively for drip and furrow methods. At the late 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.

Figure 3 illustrates soil water depletion, estimated by the spreadsheet program, under drip and furrow-irrigated potato during the cropping period. The spreadsheet program develops a water balance and supplies information on the timing and amounts of irrigation events. This figure illustrates also, the effect of an

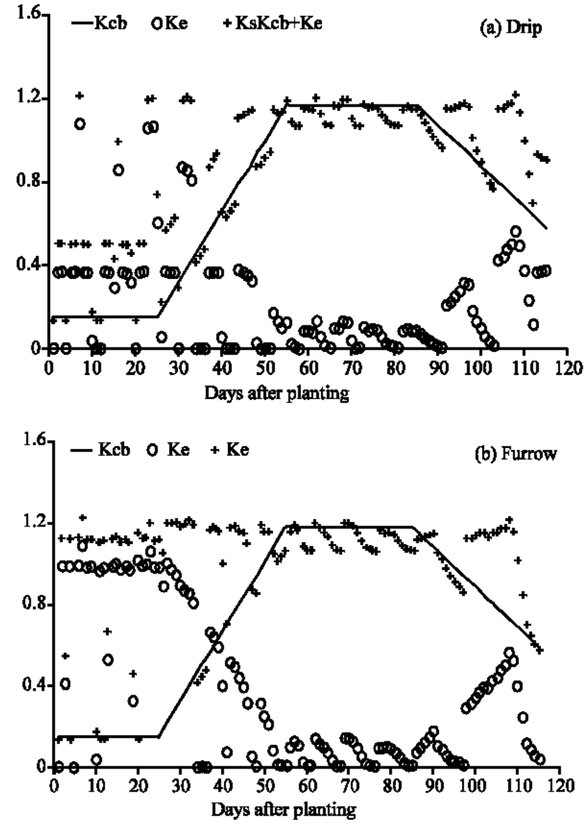

Fig. 1: FAO 56 crop coefficient curves for potato crop during the cropping season

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 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.

Soil salinity: The initial and final average Ece values (0-60 cm soil depth) under drip and furrow methods are presented in Fig. 4. Initial soil salinity determined at the time of planting was 1.4 dS m^{-1}. After the crop harvest, higher soil salinity was observed in case of furrow irrigation than drip irrigation (Fig. 4). The reason for the higher soil salinity obtained for furrow method may be attributed to evaporation of ridge soil during the periods between the respective irrigations and since irrigation was applied through furrows, little leaching of the ridge soil is expected. However, the application of water in the vicinity of root through drippers provides better soil moisture in

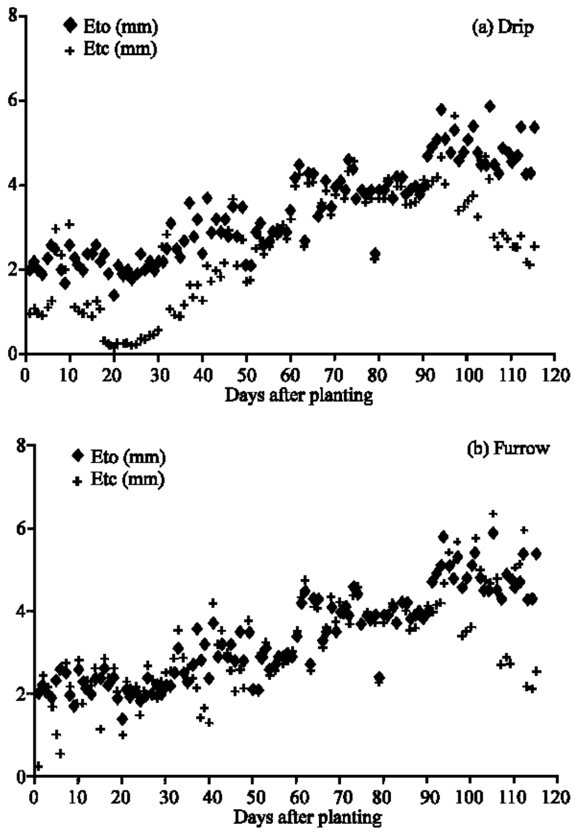

Fig. 2: Estimated daily ETc for the potato crop during the cropping season

the root zone and thus lowering the salinity under drip irrigation. Later results agree with earlier reports of Saggu and Kaushal (1991), who reported that the salinity in the root zone of potato was lower for drip irrigation than for furrow irrigation.

Ece values under the different irrigation methods were generally lower than ECi 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.

Yield and its components: For analyzing the effect of irrigation methods on the final yield, 3 criteria were retained: tuber yield, tuber number m^{-2} and tuber weight. The data concerning the 3 parameters considered, observed for all irrigation scheduling methods, are presented in Table 1.

The overall growth monitored in terms of parameters like plant height, leaf area and dry matter per plant was better under drip irrigation as compared with furrow irrigation (data not presented). Better growth ultimately resulted in higher potato yield from drip-irrigated crop (Table 1). Yield for drip irrigated treatment was significantly greater than that for treatment by furrow irrigation ($p<0.05$), it gave 11% more production than the furrow irrigation treatment. Cetin and Bilgel (2002) have earlier reported that application of irrigation water in the vicinity of root through drippers provides better soil moisture in root zone and thus resulting in higher yield.

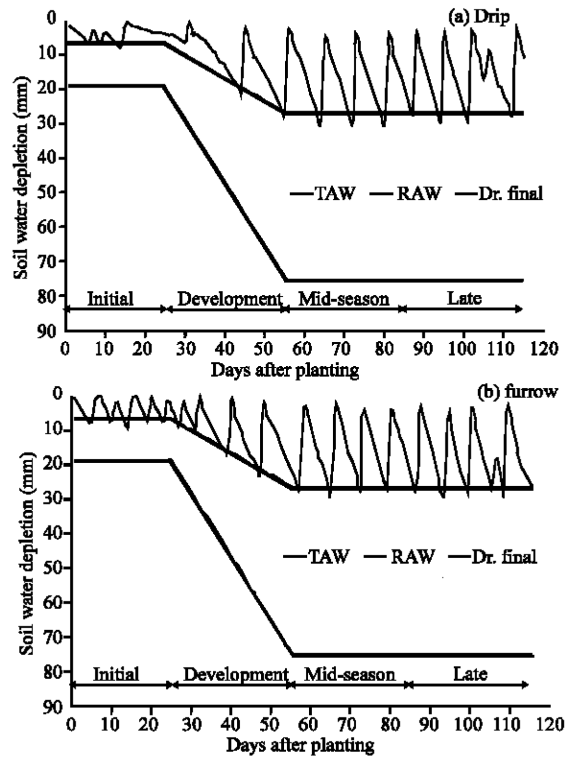

Fig. 3: Estimated daily soil water depletion for potato under drip and furrow irrigation methods during the cropping season

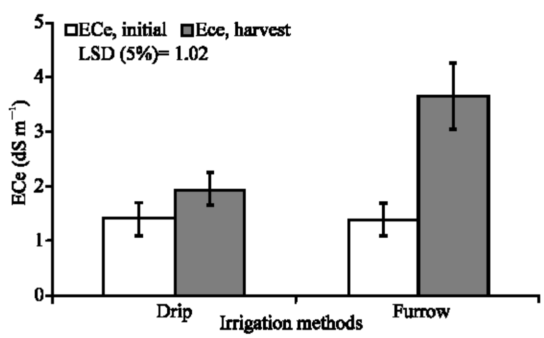

Fig. 4: Soil salinity (ECe, dS m^{-1}) under the different irrigation methods. Vertical bar indicates the standard deviation

Table 1: Yield and its components for different irrigation methods

Yield components	Drip	Furrow	LSD (5%)
Fresh tubers yield (t ha^{-1})	36.432	32.596	3.40
Tubers number m^{-1}	35.00	33.70	2.04
Tubers weight (g)	105.70	96.40	8.21

Table 2: Total water supply (mm) and water use efficiency (WUE, kg m^{-3}) for different irrigation methods

Components	Drip	Furrow	LSD (5%)
Irrigation (I)*	326	412	-
Saving of irrigation water over furrow irrigation (%)	20.8	-	-
Precipitation (P)	42	42	-
Total water received (I+P)	368	454	-
IW.U.E	11.17	7.91	1.51
TWUE	9.9	7.18	1.09

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

Tubers number m^{-2} and weight (Table 1) were affected by the irrigation methods although, no significant difference in tubers number m^{-2} was observed between the 2 methods. Similarly, Singh *et al*. (1977) and Onder *et al*. (2005) reported that the number of tuber per m^2 was not significantly affected by irrigation methods. However, the tuber weight for furrow irrigation was significantly lower than that obtained with drip irrigation ($p<0.05$). The reduction in tuber yield was mainly attributed to reduction in tubers number and weight. Note that the furrow irrigation treatment results in higher salinity in the rooting zone than the drip irrigation treatment (Fig. 4). A higher salinity associated with furrow irrigation caused important reductions in tuber yield and its components.

Water use efficiency: Data on the amounts of applied irrigation water under drip and furrow irrigation methods during the growing period are presented in Table 2. Total water supply was 368 and 454 mm for drip and furrow irrigation, respectively. As expected, the drip-irrigated treatment required less water than the furrow-irrigated treatment. Surplus was 86 mm. The amounts of irrigation water were similar to those reported by Singh *et al*. (1977), Fabeiro *et al*. (2001), Panigrahi *et al*. (2001), Onder *et al*. (2005) and Erdem *et al*. (2006). The net saving in irrigation water with drip irrigation was 20.8% when compared with furrow irrigation. Computations of water expressed as the ratio of potato yield to total water received from planting to harvest (Table 2) showed that it was highest (9.9 kg m^{-3}) with drip irrigation and was lowest (7.18 kg.m^{-3}) in case of furrow irrigation ($p<0.05$). IWUE of drip-irrigated treatment (11.17 kg m^{-3}) was higher and differed significantly from furrow-irrigated treatment (7.91 kg m^{-3}) ($p<0.05$). Kang *et al*. (2004), Onder *et al*. (2005) and Erdem *et al*. (2006) also registered similar WUE values for potato. Higher water use efficiency in case drip irrigation treatment was obviously due to higher yield accompanied by saving of irrigation water as compared to furrow method of irrigation. These results corroborated the earlier findings of Onder *et al*. (2005), Erdem *et al*. (2006), Tiwari *et al*. (1998, 2003), Manjunatha *et al*. (2001) and Cetin and Bilgel (2002).

CONCLUSION

Results of this study indicate that the irrigation methods had significant effects on growth and yield of potato. The higher potato yield and water use efficiency were obtained with drip irrigation as compared with furrow irrigation. The effect of drip irrigation on growth parameters of potato such as plant height leaf area and dry matter per plant were also significant. Higher soil salinity was maintained in the root zone with furrow than drip irrigation. As the salinity increased, there was a considerable reduction in crop yield under furrow irrigation than drip irrigation. Irrigation WUE for drip irrigation was increased by 29% compared with that of furrow irrigation following the same irrigation scheduling rule for both. The tuber yield under drip irrigation was increased by 11% relative to that for furrow irrigated potato. Drip irrigation treatment resulted in saving 20.8% of the irrigation water in comparison with furrow irrigated potato.

Based on results, it can be concluded that the drip irrigation method offers significant advantage for both yield and WUE compared to the furrow irrigation in potato production under arid conditions. The irrigation facilities and the results of the drip irrigation field experiment were demonstrated to the local farmers where the yield increase and savings in irrigation water was fully understood. As a result of this research, drip irrigation method is recommended for irrigation of potato cultivation. Also, the yield improvement associated with conversion to drip irrigation was substantial and further economic analysis should be done to establish the economic feasibility of converting large areas of potato production from furrow to drip irrigation.

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