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Evaluation of On-Farm Irrigation Scheduling: Case Study of Drip Irrigated Potatoes in Southern Tunisia

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Abstract: Effective irrigation scheduling and the use of modern irrigation systems are two possible options to improve water use efficiency in arid regions. Drip irrigation is highly efficient, but is not always used properly. Over irrigation seems to be a common problem encountered with this system, due to inadequate scheduling. The potential of irrigation scheduling to improve yield and to save water is investigated in this study. A case study of drip irrigated potato grown on sandy soil in field trials is used. The growers method consisting of supplying a fixed amount of water is compared to the method of a daily compensation of calculated crop consumption ($ETc = Kc*ET_0$) and the method of the Soil Water Balance (SWB) by compensating cumulated ETc. Well water with an ECi of 3.25 dSm^{-1} was used for irrigation over two cropping seasons. Yield, water supply and soil salinity were measured. Results show that in both seasons, fresh tuber yield was highest for the SWB scheduling technique, (40 and 30 tha^{-1}) although no significant differences were observed with the daily irrigation method. The producer method not only caused significant reductions in yield but also resulted in using 20 to 25% more water and increased soil salinity. The highest water use efficiency was obtained with SWB: 11.77 and 9.13 kgm^{-3} of fresh potato, respectively for spring and autumn seasons i.e. about 64 and 86% more than that of the grower. The SWB method is recommended as a tool to use saline water for irrigation in arid Tunisia.

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

INTRODUCTION

Restricted supply of good quality water is the most important factor limiting crop production in arid regions of southern Tunisia where water available for irrigation is frequently saline. These saline waters must be used with more care in this region, where supplemental water is needed to intensify agriculture. One way to address the issue of water shortage is through proper irrigation management by means of irrigation scheduling (Al-Jamal *et al*., 1999; Mermoud *et al*., 2005). Another way is to change to more efficient irrigation methods, such as drip irrigation (Bernstein and Francois, 1963; Sammis, 1980).

Potato species is considered relatively susceptible to salinity (Maas and Hoffman, 1977) and normally is not suited for stressful conditions. 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 dSm^{-1}. The reason of this new development is an easy access to subsidized drip irrigation equipment made possible recently because temperature conditions allow to produce potato over the autumn and spring seasons.

Drip irrigation is one of the most effective methods to supply water to crops (Hartz, 1993; Sermet *et al*., 2005). It can result in water saving if the correct management procedures are applied (Hillel, 1987; Shalhevet *et al*., 1983; Du Plessis *et al*., 1998; Ünlü *et al*., 2006). However, the most common problem encountered with this system amongst growers is that irrigation is applied in excess of crop requirements. In regions with serious water shortage, such a waste cannot be tolerated. However, Surveys carried out on potato cultivation in the area of Médenine (Nagaz and Ben Mechlia, 2003) show that usually production varies between 10 to 24 tha^{-1}. Inadequate management of irrigation has been identified as an important limiting factor to potato production, including areas where this crop is cultivated under drip irrigation on private wells. The advantage of water savings by drip is forfeited with over irrigated.

Following requests received from potato growers regarding best management of irrigation waters, field trials were conducted with the objective to evaluate the applicability of representative irrigation scheduling methods for drip system. Basically, the investigation had to compare yield, water use efficiency and soil salinity for

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various irrigation scheduling methods under the farmers' conditions. As a reference we used the prevailing common practices, with the expectation to enable potato growers to incorporate irrigation scheduling in their usual production practices.

MATERIALS AND METHODS

Experimental site and climate: Experiments were carried out during the spring 2000 and autumn 2002 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 low organic matter content and an ECe of 1.35 and 3.45 dSm^{-1} (0-60 cm depth of soil) for spring and autumn seasons, respectively. Total rainfall during the growing seasons is reported in Table 1. The total soil available water calculated between field capacity and wilting point for an assumed potato root extracting depth of 0.60 m, was 75 mm.

Crop management and experimental design: Planting took place on 5 February 2000 and 1 September 2002 for the spring and autumn seasons, respectively in 70 cm rows with tubers spaced 40 cm apart, in a randomized complete block design with four replicates and three irrigation scheduling methods. The same experimental area was used for both seasons and divided into four blocks with three 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 dSm^{-1}. Each dripper had a 4 lh^{-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 tha^{-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.

Table1: Monthly values of rainfall during the two seasons of experimentation

Spring season (2000)	Rainfall (mm)	Autumn season (2002)	Rainfall (mm)
January	-	August	-
February	1.7	September	29.5
March	-	October	29.5
April	5	November	-
May	20	December	13
Total	26.7	Total	72

The experiments consisted of three distinct irrigation scheduling methods:

- The producer method corresponding to irrigation practices traditionally implemented by the local farmers i.e., a fixed amount of water of about 17 mm is supplied to the crop every 5 days from planting till harvest.
- Use of reference crop evapotranspiration with FAO crop coefficients (Kc*ETo) for a daily irrigation scheduling with amounts equal to ETc of the previous day.
- Use of a spreadsheet calculation program (Soil Water Balance; SWB) for irrigation when Readily Available Water (RAW) in the root zone has been depleted. Plants in this treatment receive an amount equivalent to cumulated crop Evapotranspiration (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.

Measurements and water-use efficiency: Potato was harvested on May 29, 2000 for the spring 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.

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; Singh *et al.*, 1977).

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.

Statistical analysis: Analysis of variance was performed to evaluate the statistical effect of irrigation scheduling methods on potato yields, 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: 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 illustrates 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 season 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 and 2.62 mm, respectively for spring and autumn seasons. As the crop canopy grew, ETc increased

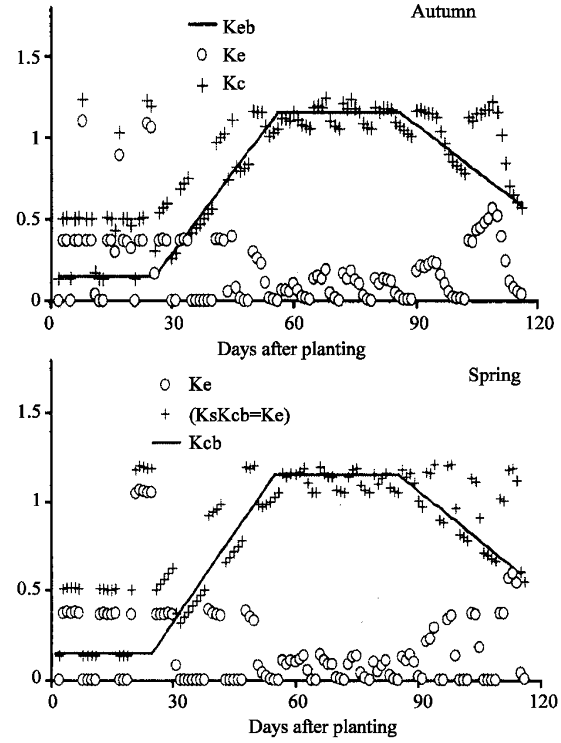

Fig. 1: FAO 56 crop coefficient curves for potato crop during the cropping seasons

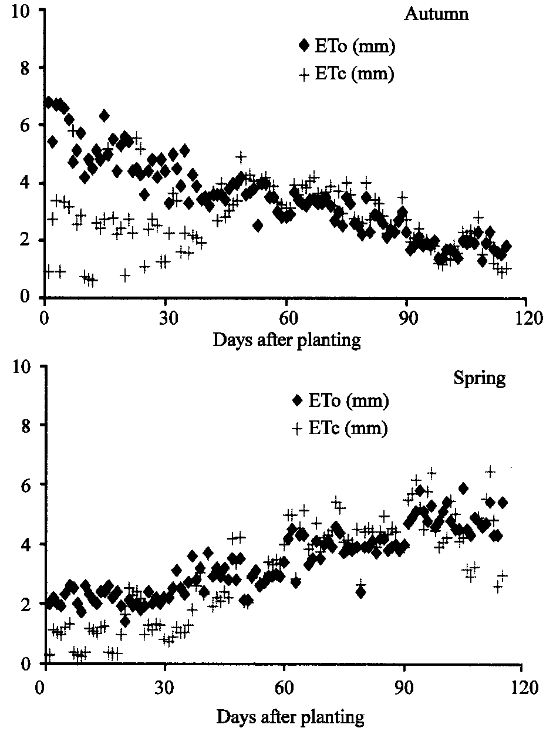

Fig. 2: Estimated daily Etc for the potto crop during the cropping seasons

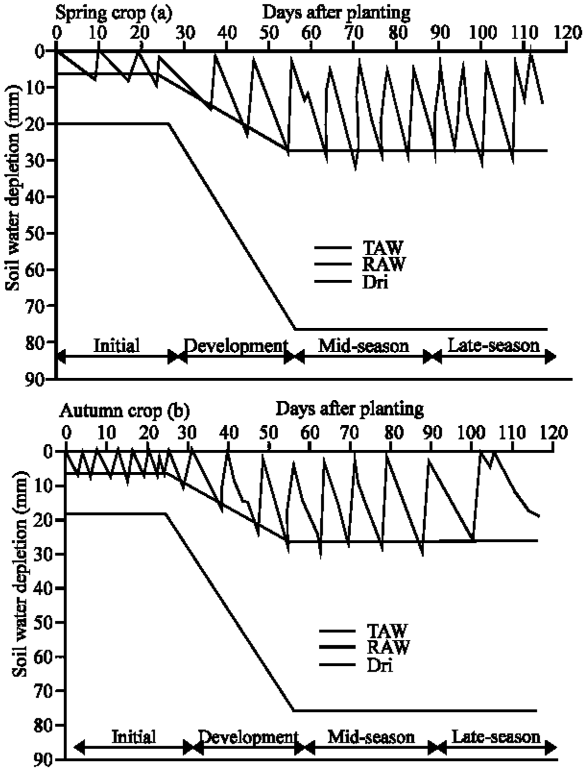

Fig. 3: Estimated root zone water depletion for the SWB irrigation scheduling with replacementof cumulated ETc in (a) spring and (b) autumn seasons

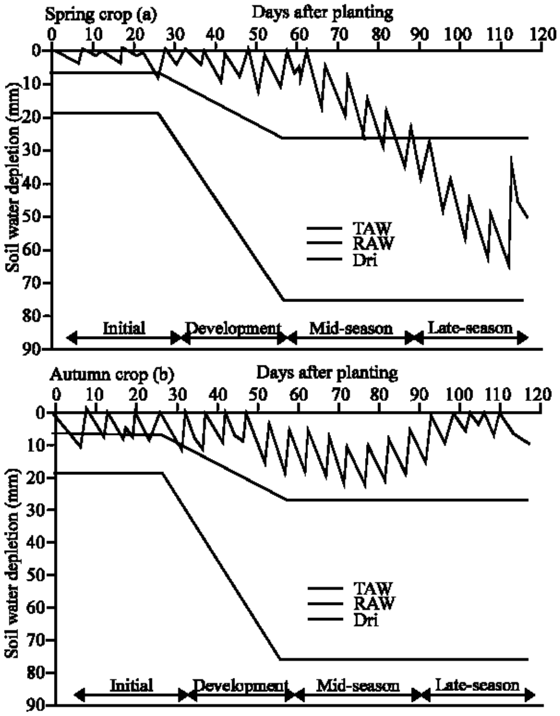

Fig. 4: Estimated root zone water depletion for the producer irrigation scheduling method in (a) spring and (b) autumn seasons

and reached its highest mean value at mid-season stage (4.20 and 3.40 mm.day^{-1}). The mean ETc values at the late stage were about 4.60 and 1.96 mm day^{-1}, respectively for spring 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.

Soil water balance: Figure 3 illustrates the root zone water depletion, estimated by the spreadsheet program, under SWB irrigation scheduling during the two cropping periods. 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 increasing root zone on the readily available water (threshold value). 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.

Generally, irrigations are frequent, in the spring season, during the mid and late-season stages when the crop water demand is high and less frequent at the beginning of the season. For the autumn season, applications are frequent during the initial stage due to high evaporative water demands. During the late-season stage when ETc is relatively small, irrigation is less frequent. The SWB irrigation scheduling method keeps the root zone water depletion between the threshold value and field capacity. Because irrigation is not applied until soil water depletion is greater than or equal to the readily available water, small stress prior to irrigation is expected.

Estimated root zone water depletion related to the producer method in both seasons is presented in Fig. 4. It shows an over irrigation during the initial development and vegetation growth, when crop ETc is low. During the mid and late seasons, when demand is highest, an under irrigation is observed. This method leads to unavoidable losses in periods of low requirements and water shortage in periods of high water demand. In periods of low ET demand, in early season, over irrigation bring the full root zone to field capacity. During the periods of high evaporation, irrigation does not cover totally ETc and the crop makes use of stored soil moisture. This situation is

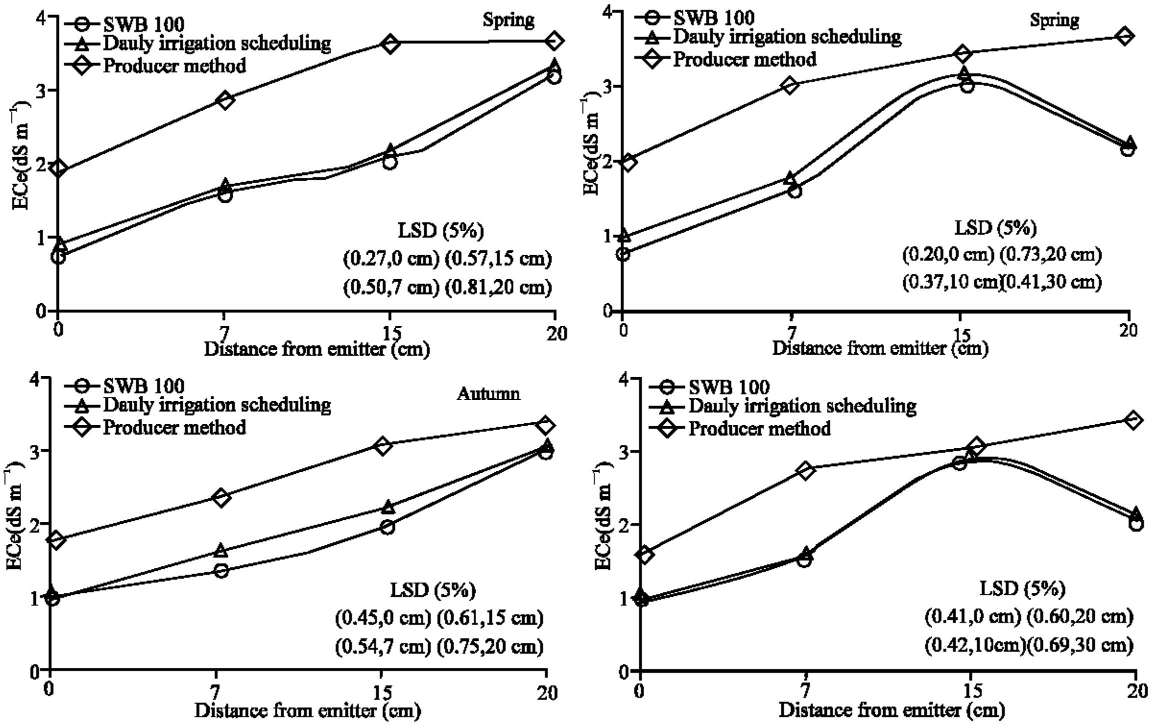

Fig. 5: Soil salinity (ECe, dS m^{-1}) under the different irrigation scheduling methods along the row and across rows

typical to late stage of the spring season when water stored in the soil is gradually depleted by ETc (Fig. 4a).

Soil salinity: The final average ECe values (0-60 cm soil depth) at different distances from emitter and drip line are presented in Fig. 5. For both seasons, the highest ECe values were found to have occurred when producer method was used. Values of 1.9 and 1.7 dSm^{-1} were recorded below the emitter, respectively in the spring and autumn seasons. The greatest values of ECe were also recorded at distances of 7, 15 and 20 cm from the emitter and of 10, 20 and 30 cm from the drip line (Fig. 5).

With SWB irrigation scheduling, the average ECe value was equal to 1 dS.m^{-1}, beneath the emitter in autumn and to 0.75 dS.m^{-1} in spring season. The zone of highest ECe was moved out to 20 cm from the emitter. Daily irrigation resulted also in low ECe value beneath the emitter. At a distance of 20 cm from the emitter, the ECe value is similar to the ECe for SWB. In both seasons soil salinity was highest midway between the emitters and towards the margin of wetted band (20 to 30 cm) (Fig. 5). Singh *et al.* (1977) and Laosheng (2000) reported similar result.

ECe values under the different irrigation scheduling methods in both seasons 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 (Table 1).

Yield and its components: For analyzing the effect of irrigation scheduling methods 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 scheduling methods, are presented in Table 2. The data shows that yields obtained in both seasons are slightly higher under SWB than under daily irrigation, but with no significant differences. On the other hand producer method decreased significantly the fresh tuber yield. SWB and Daily scheduling have resulted in consistent increases in yield, over the two seasons; they gave 27-21% and 36-32% more production than the producer's, respectively, in spring and autumn.

Tubers number.m^{-2} and weight (Table 2) were influenced by the irrigation scheduling methods although in spring season, no significant differences in tubers number m^{-2} were observed between the three methods. However, the tuber weight for producer's method was lowest while Daily and SWB irrigation scheduling methods did not differ significantly from each other. Note that the producer method resulted in higher salinity in the rooting zone (Fig. 5). Higher salinity associated with water

Table 2: Yield and its components for different irrigation scheduling methods in both seasons

Irrigation scheduling	Spring season			Autumn season		
	Fresh tubers yield(t ha^{-1})	Tubers number /m^2	Tubers weight (g)	Fresh tubers yield (t/ha)	Tubers number /m^2	Tubers weight(g)
SWB	39.67	36.00	110.30	30.35	32.25	100.60
Daily irrigation scheduling	36.74	34.00	107.25	28.92	29.75	97.23
Producer method	28.79	32.75	86.34	19.40	25.00	77.60
LSD (5%)	4.86	3.87	14.82	3.04	2.23	8.09

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

Components	SWB	Daily irrigation	Producer method	LSD(5%)
	Spring			
Irrigation (I)*	311	349	374	-
Precipitation (P)	26	26	26	-
Total water received (I+P)	337	375	400	-
W.U.E	11.77	9.73	7.19	1.32
	Autumn			
Irrigation (I)*	261	313	323	-
Precipitation (P)	72	72	72	-
Total water received (I+P)	333	385	395	-
W.U.E	9.13	7.51	4.91	0.78

* An irrigation of 75mm supplied just before planting is not included in these to

deficits seems to have caused important decreases in yield, through a reduction in tubers number and weight (Table 2).

The yield is greatly influenced by timing, amount and frequency of irrigation applied (Carr, 1989; Roth, 1990; Trebejo and Midmore, 1990; Wetter and Schmidt, 1990). The reason for the lower yields obtained for producer method may be attributed to the fact that the farmer applies water to the crop regardless of the plant needs. The farmer seems to relate irrigation occurrences to days after planting rather than to crop growth stages progress.

The SWB irrigation scheduling based on crop water requirements and soil characteristics results in varying water application and intervals and then allows for applying irrigation water when needed during the growing season. Smith (1985) reported that accurate or optimal irrigation scheduling is only possible when water supply and irrigation amounts can be managed independently by farmer. For a single farm with an independent water source, as in arid regions of Tunisia where potatoes are cultivated primarily on perimeters irrigated with well waters, accurate scheduling is manageable and therefore there is high chances to optimize water supply to crops under the studied conditions.

Water use efficiency: Amounts of irrigation water and total water supply for each irrigation scheduling method during the two growing seasons are presented in Table 3. For all treatments, total water supply ranged from about 330 to 400 mm. With the producer method more water was used than the SWB and the Daily irrigation scheduling methods. Surplus was, respectively 63 and 25 mm in spring; 62 and 10 mm, in autumn.

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 both 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 scheduling methods. For both seasons, WUE values of SWB and the daily scheduling methods were considerably higher than those of the producer method. With SWB scheduling, 11.77 and 9.13 kg.m^{-3} were obtained, respectively in spring and autumn seasons. The low water use efficiency for the producer method during the two cropping periods can be attributed to reduced yields but also to higher water consumptive use. Combination of these 2 reasons explains also why WUEs obtained with SWB method were statistically higher than those obtained with Daily irrigation scheduling.

CONCLUSION

The study shows that with reference to traditional practices, water supply based on the SWB irrigation scheduling method helps reduce soil salinization, save water and produce higher fresh tuber yield, for potatoes cultivated in 2 contrasting seasons. Daily scheduling using crop coefficients and reference evapotranspiration seems to be a little less efficient than the SWB irrigation scheduling method, apparently because of a higher direct evaporation rates. The "fixed amount approach" used by the farmer was the least efficient and caused higher salinity in the rooting zone. This method gave the lowest fresh tuber yields i.e., 27 and 36% less with 20 and 25% more water applied, respectively in the spring and autumn seasons. These results, obtained under actual farming conditions, support the practicality of the optimal irrigation scheduling to facilitate the use of saline water for irrigation. In the considered climatic context, the SWB method (classical concept of readily available water) can be used favourably by farmers to schedule irrigation of potato in arid regions of Tunisia.

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