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IRRIGATION SCHEDULING CALENDARS DEVELOPMENT AND VALIDATION UNDER ACTUAL FARMERS' CONDITIONS IN ARID REGIONS OF TUNISIA

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SUMMARY - This paper presents a prototype of irrigation calendars that can help farmers in their irrigation scheduling under the arid conditions of southern Tunisia. The potato crop cultivated under drip irrigation on private wells is used as a case study. The methodology considers commonly available climatic data, crop and soil characteristics, and information on local irrigation practices. It calculates daily soil water balance by means of a spreadsheet program for Excel, developed according to the methodology formulated by Allen *et al.* (1998). Calendars are developed for three cropping seasons of potato and guide the user in the irrigation scheduling throughout the growing season. Their simplicity makes them useful tools for a better utilization of the saline water for irrigation in arid Tunisia.

The validation of developed irrigation scheduling calendars in commercial farms was an integrated part of this paper. Three farmers of the Médenine area were provided by the calendars and asked to use them for irrigation scheduling on a portion of the cropped land while continuing to use their traditional irrigation practices. For comparison, drip irrigation, Spunta variety, sandy soils and standard cultivation practices were used in all field plots. Irrigation waters come from wells having an ECi of 3.25, 3.60 and 4.80 dS/m respectively for the three farms. Yield, water supply and soil salinity were monitored in each experimental plot over two cropping seasons, spring and autumn. Results show that the proposed calendar have improved yield by 21-33% and 31-36% respectively for spring and autumn crops and allowed an important water savings. Water use efficiency (WUE) was also dramatically improved. Under the proposed scheduling, the WUE varied between 8.9 and 11.7 kg/m^3 against 4.6 and 7.1Kg/ m^3 obtained by farmers for spring production and 7.2 and 9.1 kg/m^3 against 3.7 and 4.9 Kg/ m^3 for farmers in autumn. The use of irrigation calendars not only allowed substantial improvements in yield, water savings and WUE but also a better control of soil salinization. The yield and irrigation water gains should incite farmers to adopt the suggested irrigation calendars in their usual production practices for potato cultivated under drip irrigation on private wells for a better utilization of saline irrigation water.

Key words: arid, potato, yield, water use efficiency, irrigation scheduling calendar, water management, salinity.

INTRODUCTION

The most important factor limiting agricultural expansion in Tunisia as in many Mediterranean regions is the restricted supply of good quality water. Presently, there is an increasing pressure to use saline water to intensify agriculture, particularly in the arid part of the country where for more income and employment is high among the rural population. Irrigation of a wide range of relatively new crops such as potato is expanding around shallow wells having a salinity ranging from 2 to 6 dS/m. Potato is considered relatively susceptible to salinity (Maas and Hoffman, 1977) and normally is not suited for stressful conditions. However, irrigation is typically applied on a routine basis without scheduling. Surveys carried out on potato cultivation in the area of Médenine (Nagaz and Ben Mechlia, 2003) show that production varies between 10 and 24 t.ha^{-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 farmers generally lack knowledge on aspects of soil-water-plant relationships and they apply water to the crop regardless of the plant needs. They seem to relate irrigation occurrences to days after planting with fixed intervals and water amounts rather than to crop growth stages progress.

A range of irrigation scheduling methods has been developed to assist farmers and irrigators to apply water more efficiently taking into account crop evapotranspiration and rainfall (Jensen, 1980). However at small farmers' level, such methods cannot be applied in a practical manner, as they require sophisticated monitoring equipment, and data processing. Past research and practical experience (Hill and Choudhary, 1990) has shown that irrigation management practices on the farm must be simplistic, useable and understandable by farmers in order for to be adopted. Simple means for communicating the best irrigation timing and supply is needed to assist farmers' in their decision-making process. Therefore, in the arid regions of Tunisia, farmers would benefit from simple water management rules. Indicative irrigation calendars have proved useful for smallholder farmers using climatic data and standardized crop and soil data. Fixed irrigation intervals and fixed application depths could be recommended to farmers with or without some empirical adjustments to actual weather conditions (Raes et al, 1998, 2002). However, fixed calendars are less reliable in conditions of variable rainfall. The corresponding irrigation applications are often characterized by periods of over and under irrigation. Excess watering in saline conditions may cause water logging, loss of valuable nutrients out of the root zone and soil salinization. Withholding irrigation, especially during crop sensitive periods, will result in limited growth and reduction in crop yield (Raes et al, 2002).

Based on conclusions of farmers' interview it was hypothesized that simplified calendars for irrigation scheduling could have an important impact on improving agricultural productivity in the region. This paper is about the use of experimental findings (Nagaz and Ben Mechlia, 2004; Nagaz *et al.* 2004) to develop simple calendars for irrigation scheduling. The potential of developed irrigation scheduling calendars to improve yield and to save water is also investigated in this work. The irrigation calendars were distributed to three farmers for validation and also to test their applicability. Basically, the investigation had to compare yield, water use efficiency and soil salinity obtained by the proposed irrigation scheduling methods to those observed under commonly used techniques for two contrasting cropping seasons. The participatory approach was adopted in our work in order to enable potato growers to incorporate the proposed irrigation scheduling calendars in their usual production practices.

MATERIALS AND METHODS

Calendars development: Methodology used

The development of irrigation calendars is based on both FAO-56 guidelines and extensive experimental field work (Nagaz and Ben Mechlia, 2004; Nagaz *et al.* 2004). The soil water balance method was adopted for simulation of soil water depletion using the methodology formulated by Allen *et al.* (1998). To this end a spreadsheet program was developed in order to estimates the number of days to evaporate the readily available water (RAW) starting with a soil at 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, TAW). The root depth starts with a value of 0.15 m at planting and increases linearly with the increase of potato crop coefficient up to 0.60 m.

The crop evapotranspiration (ETc) was estimated using reference evapotranspiration (ETo) and crop coefficient (Kc) of potato as specified by FAO-56 (Allen *et al.* (1998). The dual crop coefficient approach is used to account for direct evaporation from soil. In this approach Kc is the sum of soil evaporation (Ke) and basal crop coefficient (Kcb) reduced by any occurrence of soil water stress (Ks), (Kc= Kcb Ks + Ke).

The spreadsheet 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. Irrigation is supposed to occur daily or when cumulative water depletion drops under a threshold value corresponding to the RAW, suggested amounts of irrigation is intended to replenish root zone to field capacity.

Calendars validation

Field work validation was carried out during the spring and autumn seasons in the Southern East of Tunisia in three commercial farms situated in Saadane, El-Hezma and Lassifer. Total rainfall during the cropping seasons is reported in *Table 1*. The soil is of a sandy type with low organic matter content. 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, 76 and 72 mm, respectively, in Saadane, El-Hezma and Lassifer. The electrical conductivity (ECe) values measured before planting were, respectively, 1.35 and 3.45; 1.90 and 3.90; and 2.12 and 5.10 dS/m for spring and autumn seasons.

The potato cultivar "Spunta" was used in both seasons; in 70 cm rows with tubers spaced 40 cm apart, in a randomized complete block design with four replicates and three irrigation-scheduling methods.

Table 1. Monthly values of rainfall during experimentation at the three selected farms.

Spring	Rainfall (mm)			Autumn	Rainfall (mm)		
season	Saadane	El-Hezma	Lassifer	Season	Saadane	El-Hezma	Lassifer
February	1.7	23.5	16.5	September	29.5	20	29
March	-	9	10	October	29.5	5	9
April	5	12	7	November	-	11.5	6
May	20	8.5	3	December	13	21	20.5
Total	26.7	53	36.5	Total	72	57.5	64.5

The experimental area was divided into four blocks with three elementary plots per block. All plots were drip irrigated by 16 mm polyethylene with inline emitters. Each 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 potato row. A control mini-valve in the lateral permits use or non-use of the dripper line. The water for the experiments was obtained from wells with conductivity of 3.25, 3.60 and 4.80 dS/m, respectively, for Saadane, El-Hezma and Lassifer farms. Before planting, soils were spread with 17 t/ha of organic manure. Nutrient supply included N, P and K at rates of 300, 300 and 200 kg/ha, respectively, which were adopted from 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 of potassium nitrate was applied.

Three irrigation-scheduling methods were investigated i) the producer method corresponding to irrigation practices traditionally implemented by local farmers i.e. fixed amounts of water of about 17, 21.5 and 24 mm are supplied to the crop every 5 days from planting till harvest ii) the method of a daily compensation of crop consumption: daily scheduling with amounts equal to ETc (daily scheduling) and iii) The method of scheduling consisting in replacement of 100 % of crop water requirement (scheduling100-CWR).

Potato was harvested, respectively, in the fourth week of May and December for spring and autumn crops. Ten plants per row within each plot were harvested by hand to determine potato yield, tuber number/m² and tuber weight.

Water use efficiency (WUE) is defined as the ratio between yield and the quantity of water used from planting to harvest, whether from irrigation or rainfall:

$$\text{WUE (kg/m}^3\text{)} = \text{Yield (kg/ha) / total water supply (m}^3\text{/ha)} \qquad (1)$$

Soil samples were collected after harvest and analyzed for ECe. They were taken on every layer of 15 cm to a depth of 60 cm, at distances of 0, 10, 20 and 30 cm from the line, and at four sites on the line at 0, 7, 15 and 20 cm from the emitter. Conceptually, these should be areas representing a range of salt accumulations (Bresler, 1975; Singh *et al.*, 1977).

An ANOVA was carried out to evaluate the statistical effect of irrigation scheduling methods on yield and its components and soil salinity using the Statistical Graphics System. LSD test at 5 % level was used to find any significant difference between treatment means.

RESULTS AND DISCUSSION

Irrigation calendars

Based on the produced information on timing and amounts of irrigation events and the experimental findings (Nagaz and Ben Mechlia, 2004; Nagaz *et al.* 2004), the following tables have been developed for periodic replenishment of the root zone to field capacity (*Table 2*) and for daily replacement of estimated ETc (*Table 3*).

The need for irrigation is expressed by indicative values of water requirement: irrigation number and intervals for the three cropping seasons. The tables are specific to drip irrigated potato with saline waters, grown on sandy soil under arid environments. Irrigation water requirements are converted into minutes of drip irrigation to facilitate their application by farmers. Information about the crop sensitivity to water stress at various growth stages is presented at the bottom of *Table 2*. In case of water shortage, these references are useful to adjust irrigation scheduling. By adjusting irrigation supply during periods of low to moderate sensitivity to water stress, water can be saved. A slight to moderate adjustment of irrigation parameters will not strongly affect crop yield. Adjusting irrigation scheduling during periods when the crop is sensitive to very sensitive to water stress should be avoided.

Table 2. Irrigation chart for drip irrigated potato with saline water, cultivated in southern Tunisia on sandy soil. The procedure is for periodic replenishment of the root zone to field capacity using 4l/h drippers on plants at 40cm x 70cm density.

Cropping season	Growing stage				Total
	Initial	Development	Mid-season	Late-season	
		SPRING			
Irrigation Intervals	6 - 9	9 - 12	6 - 9	5 - 7	-
Irrigation number	3	3	4	4	14
Application time (min)	28 - 35	63 - 112	116 -127	111- 122	-
Water supply (mm)	22	64	114	111	311
		WINTER			
Irrigation intervals	3-5	4 -14	10-12	11	-
Irrigation number	6	4	3	1	14
Application time (min)	27 - 32	32 -108	115 -117	116	-
Water supply (mm)	43	61	83	28	215
		AUTUMN			
Irrigation intervals	3 - 5	5 - 9	7-8	11 - 12	-
Irrigation number	6	4	3	2	15
Application time (min)	28 - 35	42 -115	112 -120	112 -120	
Water supply (mm)	44	78	84	55	
Growing stage	Installation (1)	Development (2) (2a) ▲ (2b)	Yield formation (3)	Maturity (4)	
Sensitivity to water stress	++	+ +++	++++	+	

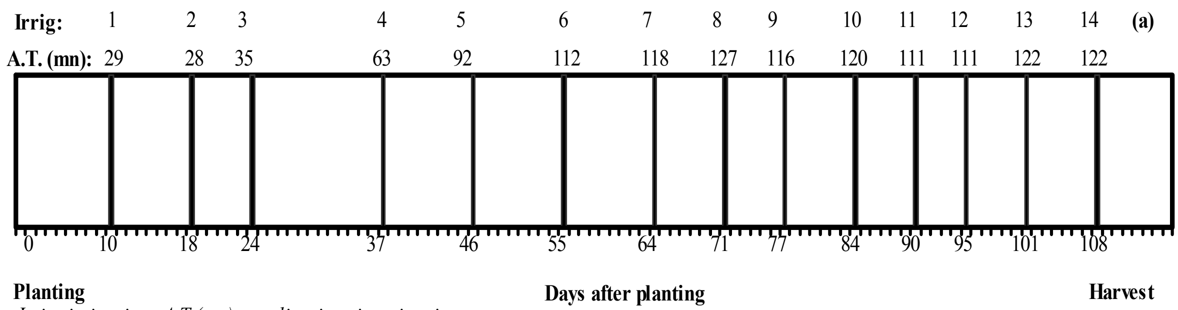
2a- early vegetative; 2b- stolonization and tuberisation; (1) The crop is moderate sensitive to water stress during the crop installation.
(2) This stage includes three phases: early vegetative (2a) where the crop is less sensitive; during stolonization and tuberisation (2b) the crop is sensitive to water stress and sufficient water should be applied to avoid a decrease in yield; (3) The crop is sensitive to water stress and water shortage should be avoided; (4) during maturity the crop is less sensitive to water stress.

Table 3. Irrigation chart for drip irrigated potato with saline water, cultivated in southern Tunisia on sandy soil. The procedure is for daily replacement of estimated ETc capacity using 4l/h drippers on plants at 40cm x 70cm density.

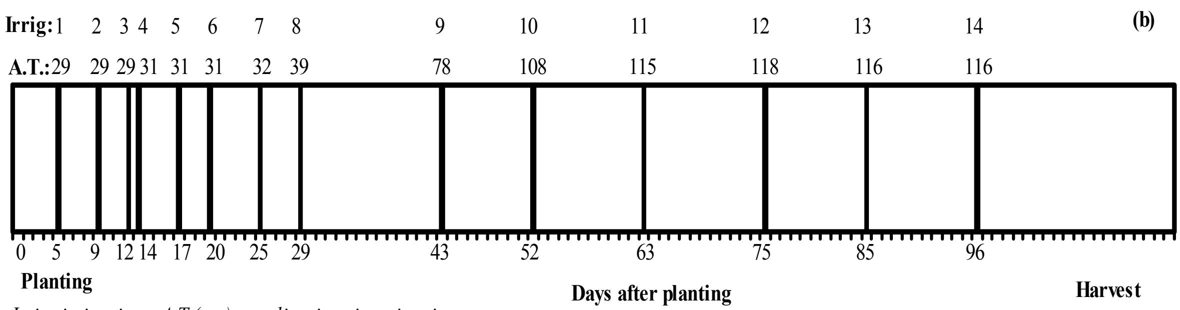
Cropping season	Growing stages				Total
	Initial	Development	Mid-season	Late-season	
SPRING					
Dose (mm)	0.23 - 2.53	0.70 - 4.21	2.65 - 5.42	2.60 - 6.44	
Application time (min)	1 - 11	3 - 18	11 - 23	11 - 27	-
Water supply (mm)	26	61	123	139	349
WINTER					
Dose (mm)	0.57 - 7.29	1.27 - 4.19	1.72 - 4.29	1.14 - 3.57	
Application time (min)	3 - 31	5 - 18	7 - 18	5 - 15	
Water supply (mm)	68	69	79	78	294
AUTUMN					
Dose (mm)	0.62 - 5.81	1.24 - 4.90	2.26 - 4.22	0.91 - 3.50	
Application time (min)	3 - 24	5 - 21	10 - 18	4 - 15	
Water supply (mm)	64	85	105	59	313

With the described technique, irrigation water supplies and intervals have been determined for the three cropping seasons of potato. The developed irrigation guidelines presented in irrigation *Table 2* are presented graphically in Fig. 1. Recommended irrigation occurrences of drip irrigated potato expressed in days after planting are very easy to apply by farmers.

In these irrigation calendars, irrigation intervals and water supplies were determined in function of soil and crop parameters, climatic data and irrigation system. Adjusting irrigation doses when significant rainfall occurs between two water applications is needed. The amount of recorded rainfall is accounted for by subtracting from the total amount of water required for the particular day of irrigation.



Irrig: irrigation; A.T.(mn): application times in minutes



Irrig: irrigation ; A.T.(mn): application times in minutes

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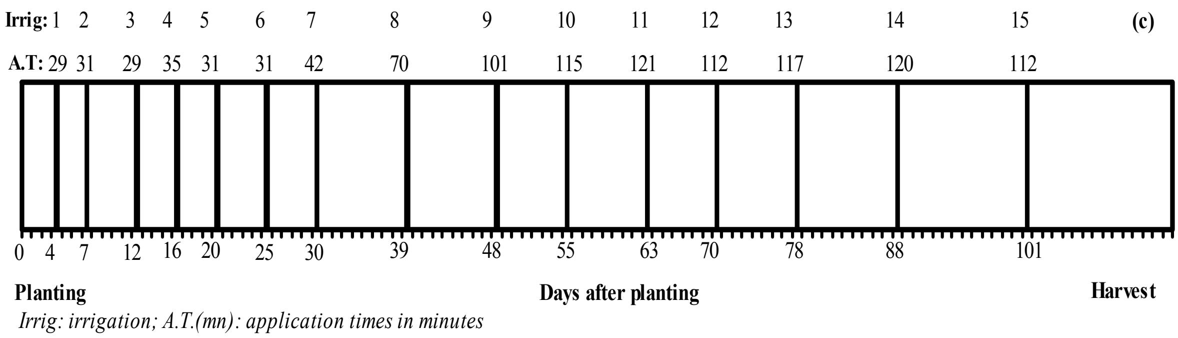

Fig. 1. Irrigation calendars for drip irrigated potato with saline water, cultivated on sandy soil in: (a) Spring, (b) winter and (c) Autumn seasons. The procedure is for periodic replenishment of the root zone to field capacity using 4l/h drippers on plants at 40cm x 70cm density.

Calendars validation

Soil salinity

Final averages of ECe values (0 - 60 cm soil depth) at different distances from emitter and drip line are presented in Figs. 2, 3 and 4. In both seasons the highest ECe values were found to have occurred when producers' method was used. Relatively high values of soil salinity were observed below the emitter. 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. The irrigation scheduling100-CWR method decreased the soil salinity beneath the emitter in both seasons.

The zone of highest ECe was moved out to 20 cm from the emitter. Daily irrigation method 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 irrigation scheduling100-CWR. In both seasons soil salinity was highest midway between the emitters and towards the margin of wetted band (20 to 30 cm) (Figs 2, 3 and 4).

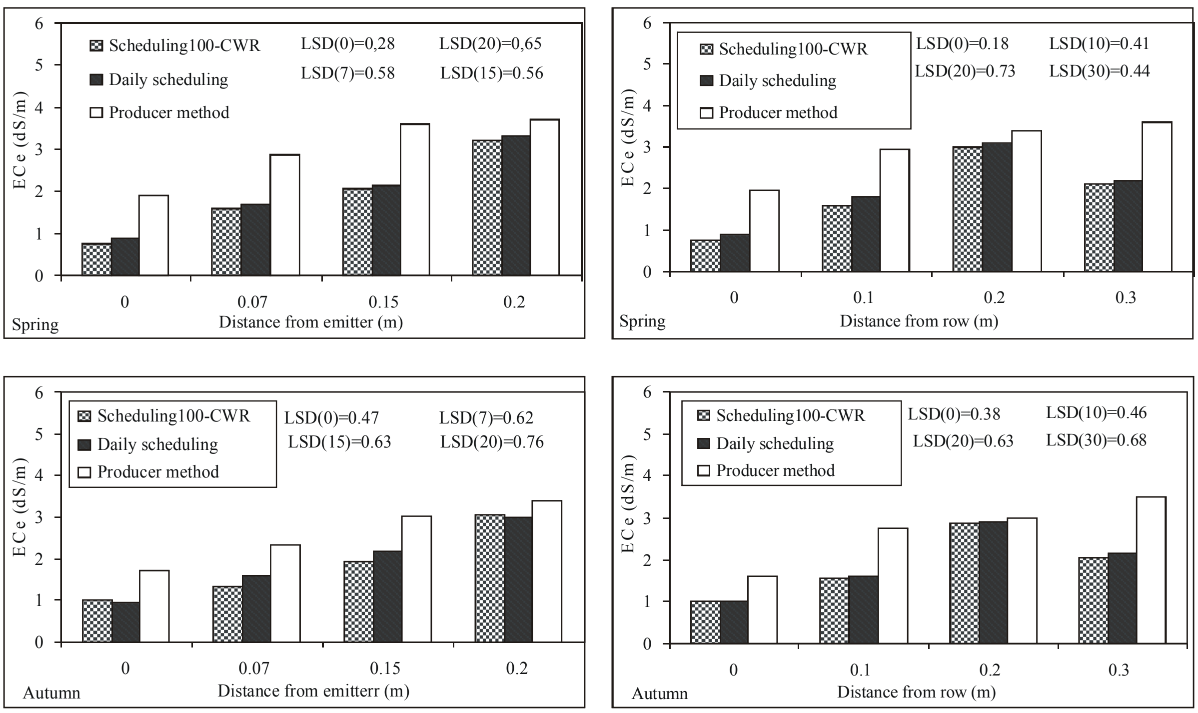

Fig. 2. Soil salinity (ECe, dS/m) under the different irrigation scheduling methods along the row and across rows in both seasons: Case of Saadane farmer

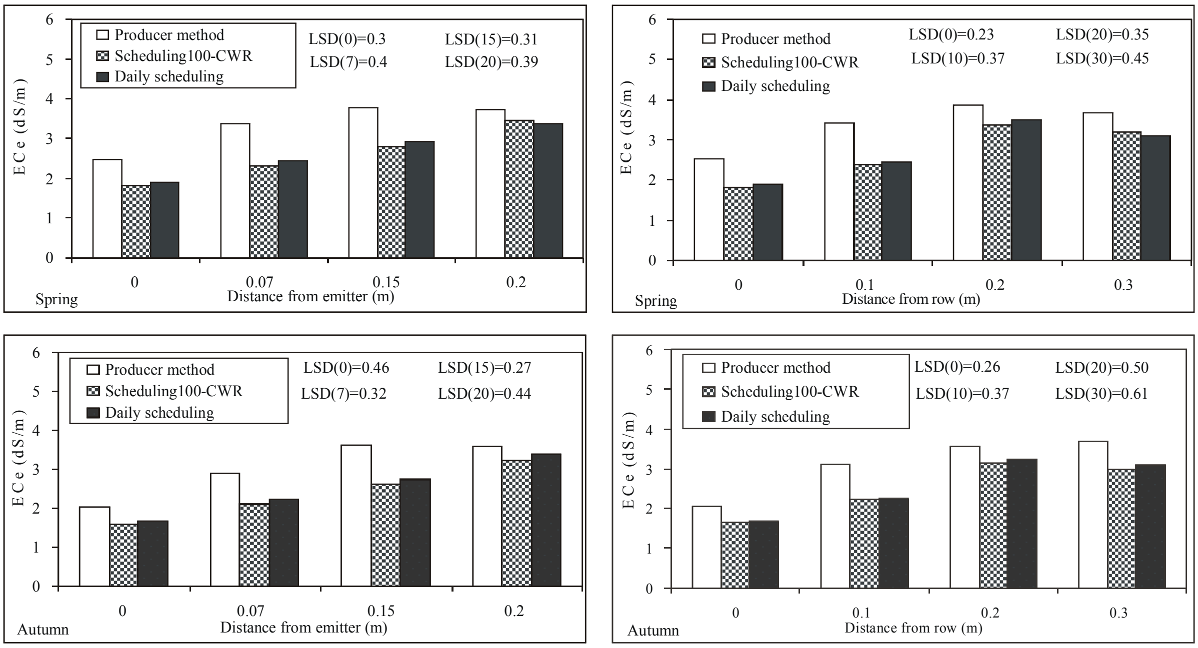

Fig. 3. Soil salinity (ECe, dS/m) under the different irrigation scheduling methods along the row and across rows in both seasons: Case of El-Hezma farmer

ECe values under the different irrigation scheduling methods in both seasons were generally lower than ECi of the irrigation waters 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 those of ECiw.

A Lower ECe values under the prevailing climatic conditions were due to leaching of soluble salts with rainfall (*Table 1*). Leaching by rain occurred mainly during September, October and December in autumn, and in February, April and May in the spring season.

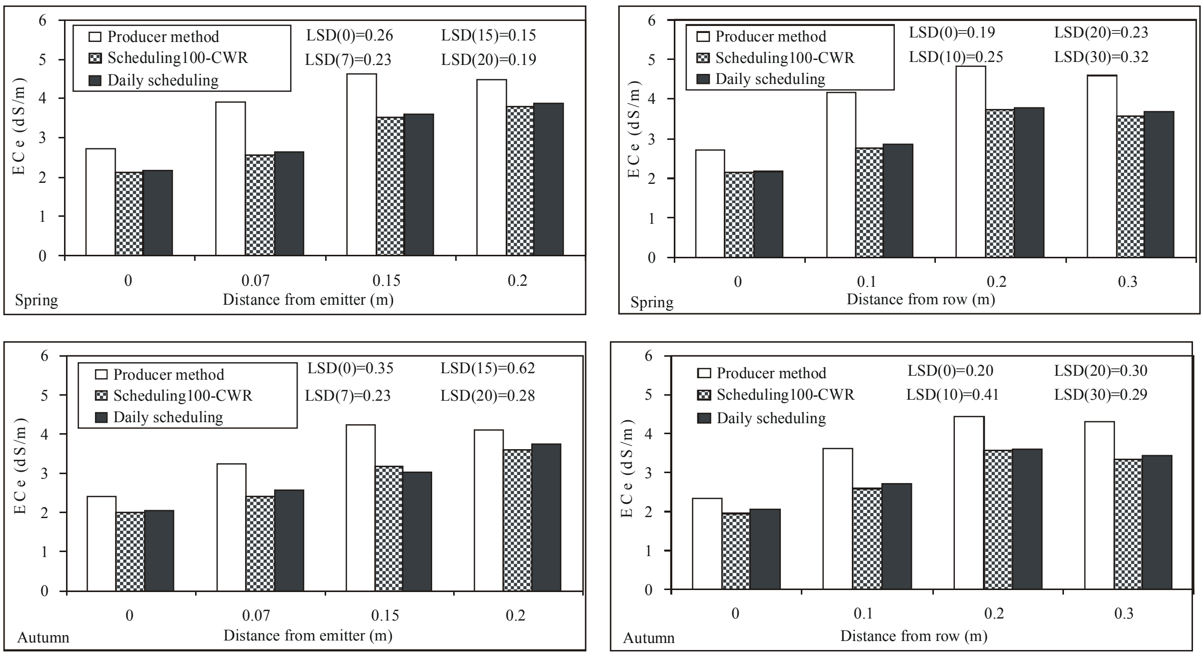

Fig. 4. Soil salinity (ECe, dS/m) under the different irrigation scheduling methods along the row and across rows in both seasons: Case of Lassifer farmer

Yield and its components

Yields obtained in both seasons are presented in *Table 4*. They are slightly higher under scheduling100-CWR than under daily scheduling, but with no significant differences. On the other hand producer method decreased significantly the fresh tuber yield. Scheduling100-CWR and daily scheduling have resulted in consistent increasing in yield over the two seasons; they gave 33 - 19 % and 36 - 29% more production than the producer, respectively, in spring and autumn (*Table 4*).

Tubers number/m² and weight (*Table 4*) were influenced by the irrigation scheduling methods although in spring season, no significant differences in tubers number/m² were observed between the three methods. However, the tuber weight for producer's method was lowest while daily and 100-CWR irrigation scheduling methods did not differ significantly from each other. Note that the producer method resulted in higher salinity in the rooting zone (Figs. 2, 3 and 4). Higher salinity levels associated with water deficits observed under the traditional irrigation scheduling method seems to affect yield mostly through a reduction in tubers number and weight (*Table 4*).

Table 4. Yield and its components for different irrigation scheduling methods in both seasons

Irrigation scheduling	Spring			Autumn		
	Fresh tubers yield (t/ha)	Tubers number/m²	Tubers weight (g)	Fresh tubers yield (t/ha)	Tubers number/m²	Tubers weight (g)
			Saadane			
Scheduling100-CWR	39.6	36.0	110.3	30.4	32.2	100.6
Daily scheduling	36.4	34.0	107.2	28.9	29.7	97.2
Producer method	28.8	32.7	86.3	19.4	25.0	77.5
LSD (5%)	4.88	3.87	7.28	3.05	2.23	8.09
			El-Hezma			
Scheduling100-CWR	32.1	31.0	103.4	26.9	27.5	97.9
Daily scheduling	31.2	30.7	101.4	25.7	26.7	96.1
Producer method	25.2	27.5	91.7	18.1	21.7	83.5
LSD (5%)	5.50	4.25	4.23	4.69	4.00	3.60
			Lassifer			
Scheduling100-CWR	30.3	30.2	100.0	24.5	25.7	95.3
Daily scheduling	29.2	29.5	99.0	23.6	25.0	94.5
Producer method	20.2	22.7	88.9	16.7	20.7	80.5
LSD (5%)	5.80	4.60	5.35	2.87	2.35	3.61

The yield is greatly influenced by timing, amount and frequency of irrigation applied (Carr, 1989; Roth, 1990; Trebejo and Midmore, 1990; Wetter and Schimdt, 1990). Lower yields obtained by producers may be attributed to the fact that they apply water to the crop regardless of the plant needs. Farmers seem to relate irrigation occurrences to days after planting rather than to crop growth stages progress. The 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 a farmer having a single farm with an independent water source can manage independently water supply and irrigation amounts. In arid regions of Tunisia potato is cultivated primarily on perimeters irrigated with well waters, accurate scheduling is manageable and therefore there is a high chance to optimize water supply to this crop under such conditions.

Water use efficiency

Amounts of irrigation water and total water supply for each irrigation scheduling method during the two cropping seasons are presented in *Table 5*. Total water supply ranged from about 330 to 460 mm depending on the irrigation scheduling methods and the crop season. With the producer method more water was used than the daily and 100-CWR irrigation scheduling methods. Surplus ranged respectively from 25 to 103 mm in spring; and from 10 to 108 mm, in autumn. The producer method not only caused significant reductions in yield but also resulted in using 20 to 39 % more irrigation water compared to the 100-CWR irrigation scheduling method.

Water use efficiencies (WUE) obtained under the different methods are presented in *Table 6*. For both seasons, WUE values of the daily and 100-CWR scheduling were considerably higher than that of the producer method. In the spring season, 11.7, 9.0 and 8.9 kg/m^3 were obtained, respectively, with scheduling100-CWR in Saadane, El-Hezma and Lassifer.

Low WUE values of the producers during both seasons are attributed to reduced yields but also to higher water consumptive use. Combination of these two reasons explains also why WUEs obtained with 100-CWR method were statistically higher than those obtained with daily scheduling.

Table 5. Total water supply, I+R (mm) for the irrigation scheduling methods in both seasons.

Irrigation scheduling	Spring season			Autumn season		
	Irrigation (I)	Rainfall (R)	I+R	Irrigation (I)	Rainfall (R)	I+R
Saadane						
Scheduling100-CWR	311	26	337	261	72	333
Daily scheduling	349	26	375	313	72	385
Producer method	374	26	400	323	72	395
El Hezma						
Scheduling100-CWR	304	53	357	279	57	336
Daily scheduling	349	53	402	313	57	370
Producer method	407	53	460	364	57	421
Lassifer						
Scheduling100-CWR	304	36	340	272	64	336
Daily scheduling	349	36	385	313	64	377
Producer method	404	36	440	380	64	444

Table 6. Water use efficiency (WUE, kg/m^3) obtained under the irrigation scheduling methods for the spring and autumn seasons.

Irrigation scheduling	Spring season	Autumn season
Saadane		
Scheduling100-CWR	11.7	9.1
Daily scheduling	9.6	7.5
Producer method	7.1	4.9
LSD (5%)	1.32	0.78
El Hezma		
Scheduling100-CWR	9.0	8.0
Daily scheduling	7.7	6.9
Producer method	5.4	4.3
LSD (5%)	1.41	1.29
Lassifer		
Scheduling100-CWR	8.9	7.2
Daily scheduling	7.5	6.2
Producer method	4.6	3.7
LSD (5%)	1.55	0.74

CONCLUSION

Irrigation charts, which can be distributed to farmers, are presented in this work. The proposed calendars are simple to read and provide farmers with important information to scheduling irrigation. They give quantitative information on irrigation intervals and number, water supply and irrigation doses for the three cropping seasons of potato. They are intended to be useful tools in decision-making concerning irrigation and the use of saline water for potato cultivation on private wells in Southern Tunisia.

This study concerns also the adoption of developed irrigation calendars for potato crop by farmers and the potential of this method in improving yield and WUE. Results shows that with reference to producer method, water supply based on the scheduling 100-CWR method helps reduce soil salinization, save water and produce higher fresh tuber yield for potatoes cultivated in two contrasting seasons. Daily scheduling using irrigation calendar seems to be a little less efficient than the scheduling100-CWR 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. 21 to 33 % and 31 to 36 % less with 20 to 34 % and 24 to 39 % 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 as proposed by irrigation calendar to facilitate the use of saline water for irrigation. In the considered climatic context, the schedling100-CWR method can be used favorably by farmers to schedule irrigation of potato in arid regions of Tunisia.

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