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Assessment of Actual Irrigation Management in Kalâat El Andalous District (Tunisia): Impact on Soil Salinity and Water Table Level and Salinity

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Abstract: The objective of this work is a monitoring of water and salt in the irrigated area of Kalâat El Andalous. Soil salinity, crops yield, water table level and drainage water flow were monitored during the period May 2008-June 2010. The results show that during irrigation season (May-September 2008), the supplied water amounts for drip irrigated crops (tomato, melon and squash) were higher than crop water requirements. In fact, the soil water content was always equal or higher than the field capacity. Average root zone (0-60 cm) electrical conductivity was 2.3 dS m^{-1}, 2.8 dS m^{-1} and 3 dS m^{-1} in May 2008, May 2009 and May 2010 respectively. But it isn't the case when we analyze an irrigation season where highest electrical conductivity value equal to 8.4 dS m^{-1} was recorded in the upper layer (0-30 cm). Following the rains fall particularly during the winter season there has been a decrease of the soil salinity when the average minimum value of electrical conductivity reached 2 dS m^{-1}. As an adaptation to soil salinization, farmers use crop rotation including rainfed crops and bare soil in order to decrease the soil salinity after irrigation season. During the irrigation season, the highest discharge rate of drainage measured (3.2 l/mn) was recorded on July 2008 when the maximum irrigation water amount was diverted. Water table level shows a sustained rise when irrigation is relatively frequent during summer.

Key words: Drip irrigation · Soil salinity · Soil water content · Drainage · Water table · Crop yield

INTRODUCTION

In arid and semi arid areas, irrigation is used to maximize crop yields by minimizing water stress in the root zone. However, this is often done an ad-hoc manner. Excess of water supplies may cause rising of ground water table which may carry salts from subsurface to surface layers through capillary rise and evaporation [1]. Soil salinization induced by capillary rise of shallow groundwater into the rooting zone plays a major role, nullifying pre-season salt leaching efforts, entailing yield decrease and seriously threatening economic growth and development [2, 3, 4, 5]. Such evapo-concentration phenomenon associated with saline irrigation water is the main cause of soil salinization in irrigated districts [6]. The salt accumulation in the soil profile is a widespread problem that seriously affects crop productivity throughout the world. More than 50% of the salinized areas in the Mediterranean basin are located in Algeria, Morocco, Spain, Tunisia and Turkey [7].

The use of drip irrigation may bring about a potential threat of the secondary soil salinization because no salt can be discharged from soil profile and salt build-up on the soil surface may be on the rise after long-term application of drip irrigation [8]. Hence, it is essential that farmers have a clear understanding about irrigation practices' impact on the soil moisture content, on soil salinity and on crop yields. In fact, optimal irrigation management is supposed to maintain favorable soil water content, prevent salinity stress and save water resources as much as possible. In Tunisia, Kalâat El Andalous irrigated district is one of the most affected area by salinization due to shallow groundwater level. This study aims to assess water and soil salinity evolution under the

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main frequently irrigated crops (tomato, melon and squash), rainfed crop (wheat) and bare soil in Kalaât El Andalous district.

MATERIALS AND METHODS

Experimental Site: The irrigated area of Kalâat El Andalous (latitude: 6° 37' and 37°2' N; longitude: 10°5' and 10° 10' E) is located on the end part of the Medjerda watershed (Figure 1), with an average annual ETP of 1400 mm and an average annual rainfall of 490 mm. Irrigation area of Kalâat El Andalous was launched since 1992 on a flood area. It covers an area of 2905 ha and the effectively irrigated area changes from season to season and the maximum was observed in the summer (about 1000 ha). The irrigated area was divided into plots of 5 ha supplied by a flow rate of 3 l/s.

All the irrigated area was equipped by a pressurized irrigation network and a subsurface drainage system with a length of 180 m and a depth of 1.5 m and spaced at intervals of 40 m. The drainage outlet is below sea level and the drainage waters are discharged to the Mediterranean Sea through a pumping station (SP4). The soils are alluvial with 43% loam, 33% sandy and 22% clay. Soil pH ranged from 7.3 to 8.9. The average bulk density of the soil is about 1.5 g/cm^3. Some physical and chemical characteristics of the soil of the experimental site were determined (Table 1). The irrigation water is coming from Medjerda River. Irrigation water salinity ranges between 3.1 g/l and 2.5 g/l in winter and between 2.3 g/l and 2.4 g/l in summer. The general characteristics of the irrigation district [7] were presented in Table 2.

This study was carried out during May 2008-Juin 2010 in a farm plot of 2.38 ha (170 m x 140 m) equipped by four subsurface drainage pipes D_1, D_2 and D_3 and by drip irrigation system. Table 3 and Table 4 indicated the variations of cropping pattern and irrigation characteristics system respectively.

Measurements: In the field, measurements included irrigation water volume and salinity, pipe drainage discharge and salinity, water table level and salinity, soil water content and salinity. The water supplied volumes V (m^3) are determined as:

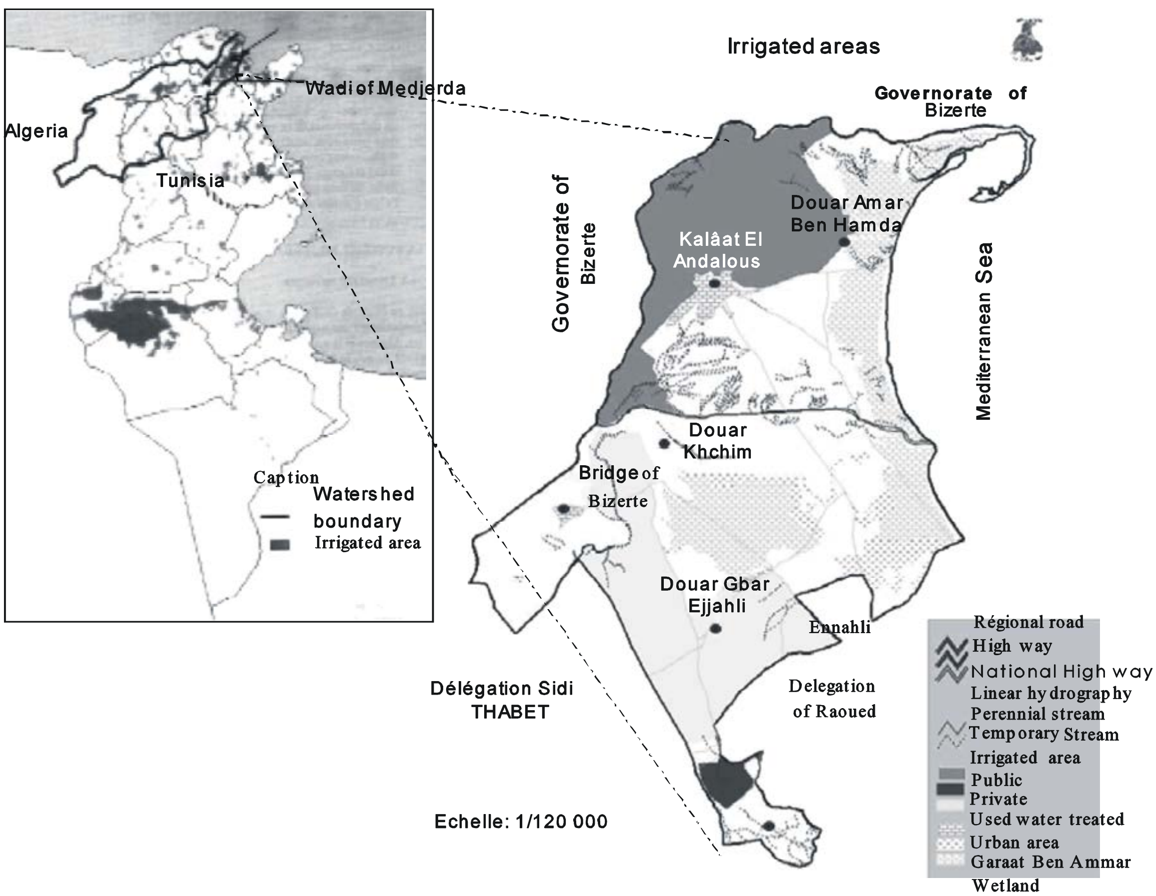

Fig. 1: Irrigated area of Kalâat El Andalous

Table 1: Field soils characteristics of Kalâat El Andalous area

		Volumetric water content (%)				
Soil profile depth (cm)	SP (%)	WP	FC	% OM	% $CaCO_3$	pH
0-30	50	20	35	4.6	42.2	8.9
30-60	52	15	32	1.8	43.5	8.8
60-90	57	26	42	1.3	44	8.6
90-120	67	26	44	1.9	46.2	7.3
120-150	55	27	44	1.3	36.8	8.5
150-180	60	27	45	2.9	48	8.5

Table 2: Water budgets in the irrigation district of Kalâat EL Andalous during the hydrological year (2007/2008).

Parameter	Value
Irrigation (I, mm)	1187
Precipitation (P, mm)	676
Reference ET(ET0)	1412
Crop ET (ETc, mm)	975
Surface drainage (Q, mm)	411

Table 3: Variation of cropping patterns during studied period (May 2008-Juin 2010).

Period	Soil occupation
May 2008-September 2008	Irrigated crops: tomato (1.08 ha), melon (1 ha) and squash (0.3 ha)
October 2008-November 2008	Bare soil
December 2008-June 2009	Rainfed crop (wheat)
July 2009-November 2009	Bare soil
December 2009-June 2010	Rainfed crop (wheat)

Table 4: Fields and irrigation characteristics system during irrigation season (May 2008 - September 2008)

Crops	Scientific Name	Field size (ha)	Date of plantation	Row spacing (m)	Emitter spacing (m)
Tomato	*Lycopersicum esculentum*	1.08	3 May 2008	1.5	0.4
Melon	*Cucumis mela* L. CV. *Sancha*	1	17 April 2008	1.5	0.8
Squash	-	0.3	25 May 2008	1.5	0.8

$$V = N\ q\ T.10^3 \qquad (1)$$

where: N is the number of emitters per hectare, q the average emitter discharge (l/h) and T irrigation duration. The discharge of emitters was measured weekly. The duration of irrigation was estimated according to farmer declaration. The CROPWAT model [9] was used to compare the crop water requirement and amounts of irrigation water delivered to crops. Daily climatic data were collected by a Campbel meteorological station located near the site. The water table levels were measured monthly using a piezometer localized in the plot. Also, samples were monthly taken to measure the Electrical Conductivity (EC) of the groundwater. To assess the amount of salts removed from the study area, drain discharge was measured at the end of subsurface drainage pipes D_1, D_2 and D_3. Furthermore, soil sampling were carried out to monitor soil salinity under irrigated crops (tomato, melon and squash), under rainfed crops (wheat) and bare soil. Sampling was done on three spots at 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm and 150-180 cm depths every two weeks during the irrigation season and about once a month for the other periods. Soil water content (SWC) was determined gravimetrically before and after irrigation under two mains crops (tomato and melon) for two dates (14/06/2008 and 12/07/2008). Sample depths were 0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm and 70-90 cm on three spots. Soil, drainage water and groundwater samples were analysed to determine electrical conductivity and pH. The millimolar concentrations, C, of calcium, magnesium and sodium were determined on saturated soil extracts [10] and the sodium adsorption ratio (SAR) was calculated according to the relationship:

$$SAR = \frac{C_{Na}}{(C_{Ca} + C_{Mg})^{0.5}} \qquad (1)$$

In this study, data were analyzed by using descriptive statistics (average, minimum, maximum, coefficient of variation and standard deviation).

RESULTS AND DISCUSSION

Water Irrigation Volume, Salt Amount and Soil Water Content: The applied water during the irrigation season, ranged from 4 to 16 mm/day for tomato, from 3 to 9 mm/day for melon and from 4 to 5.5 mm/day for squash. For tomato and squash, the maximum irrigation water volume was given in July about 4143 m^3/ha and 1130 m^3/ha respectively. The amount of water applied in August decreased, mainly because the crop water requirement decreased. The amounts of irrigation water delivered to crops are higher compared to the total net crop water requirements (Table 5).

These results were in accordance with some studies conducted in the same area. In fact, Slama *et al*. [11] found a similar value of amounts of water diverted to tomato (10000 m^3/ha) with drip irrigation. The rain fall reached 472 mm, 651 mm and 485 mm in 2008, 2009 and 2010. During the irrigation season (May-September 2008), rainfall was only 17 mm. The mass of salt induced by irrigation water reached 24 tons, 12 tons and 7 tons for tomato, melon and squash respectively (Table 5). Hence, salt soil accumulation may affect seriously crop productivity as manifested in reduced yield.

During the irrigation season, the water content was always more or near the field capacity (34%) (Figure 2). In fact, for the two dates (14/06/2008 and 12/07/2008) the average soil profile water content before irrigation was more than 30% for tomato and 33% for melon. The most important changes in soil moisture content were observed between 0 and 10 cm when the soil water content jumps from 34 % to 39% under the emitter, from 32% to 36% at 10 cm far from the emitter and from 32% to 35% at 20 cm far from the emitter on 12/07/2008. In the deep layer the water content distribution was nearly constant throughout the soil profile. It reaches an average of 37% in the layer 70-90 cm. Rawlins and Rotas [12] and Guohua *et al*. [13] reported that compared with the border-irrigation, frequent irrigations in drip and sprinkler-irrigated field help to maintain higher average soil water content.

Soil Profile Salinity Variation: Table 6 lists the descriptive statistics of the electrical conductivity at 31 measurement points, including minimum, maximum, mean, standard deviation and coefficient of variation (CV) during the period May 2008-June 2010. The variation of electrical conductivity is more pronounced in the upper layer (0-30 cm, CV = 45%) than in the dipper layer (150-180 cm, CV = 8%). When we consider a cycle of two years, the soil profile salinity was stable. In fact, in May 2008, May 2009 and May 2010 average salinity in the root zone (0-60 cm) was 2.3 dS m^{-1}, 2.8 dS m^{-1} and 3 dS m^{-1} respectively (Figure 3) but it isn't the case when we analyze an irrigation season. Changes in electrical conductivity of soil samples, taken on various dates during the growing season of tomato, melon and squash are shown in Table 7.

For irrigated crops, the salinity distribution throughout the soil profile was found to have changed. With crop growth and irrigation, an increase of the electrical conductivity of the soil was observed. In fact, the electrical conductivity increased from 2 dS m^{-1} as an average value of salinity at the beginning of the irrigation season in the root zone (0-60 cm) to 5.3 dS m^{-1}, 3.3 dS m^{-1} and 6.8 dS m^{-1} for tomato, melon and squash respectively at the end of the irrigation season. Applying irrigation water causes an increase of soil salinity which was higher in the upper layer (0-30 cm) than in the deep layer (150-180 cm). During the irrigation season, salt accumulation occurred specially in the top layer (0-30 cm) for all irrigated crops. In fact, highest electrical conductivity values equal to 8.4 dS m^{-1} was recorded on 19/07/2008 under melon and values of 7 dS m^{-1} and 7.7 dS m^{-1} were recorded under tomato and squash respectively on 16/09/2008.

Following the rainfall, there has been a decline in soil electrical conductivity. Values of 4.6 dS m^{-1}, 3.8 dS m^{-1}, 3.4 dS m^{-1}, 3.5 dS m^{-1} and 3.9 dS m^{-1}, were measured respectively in 06/11/2008, 4/01/2009, 6/02/2009, 29/11/2009 and 30/01/2010. The smallest EC (1.6 dS m^{-1}) was recorded under rainfed conditions. Soil salinity in the root zone (0-60 cm) in case of irrigated crops ranged generally between 2.7 dS m^{-1} and 6 dS m^{-1} while for the rainfed wheat growing season the EC of the soil in the root zone ranged between 1.6 dS m^{-1} and 4.1 dS m^{-1} and ranged between 2.9 dS m^{-1} and 4 dS m^{-1} without crops. The soil salinity in the root area increased considerably due to the influence of irrigation. Hence, inadequate management of irrigation water has lead to considerable salinization of the soil. The maximum value of the SAR reached in the root zone (0-60 cm) were 16.1, 15.1, 10.7, 4.5 and 6.2 under irrigated squash, under irrigated tomato, under irrigated melon, under rainfed wheat and under fallow soil respectively.

Crop Yield: Measured yields of the different crops are shown in Table 8. In summer 2008, harvests began at 1st August for melon, at mid August for tomato and at 1st of September for squash. In Tunisia, the national average

Table 5: Amounts of irrigation water diverted to crops and mass of salts induced by irrigation water

Crops	Beginning of irrigation	End of irrigation	ET_c (mm)	Water amounts diverted (mm)	Mass of salts induced by irrigation water (tons/ha)
Tomato	5 May 2008	15 September 2008	449	1030	24
Melon	15 May 2008	16 August 2008	332	503	12
Squash	1st June 2008	15 September 2008	285	299	7

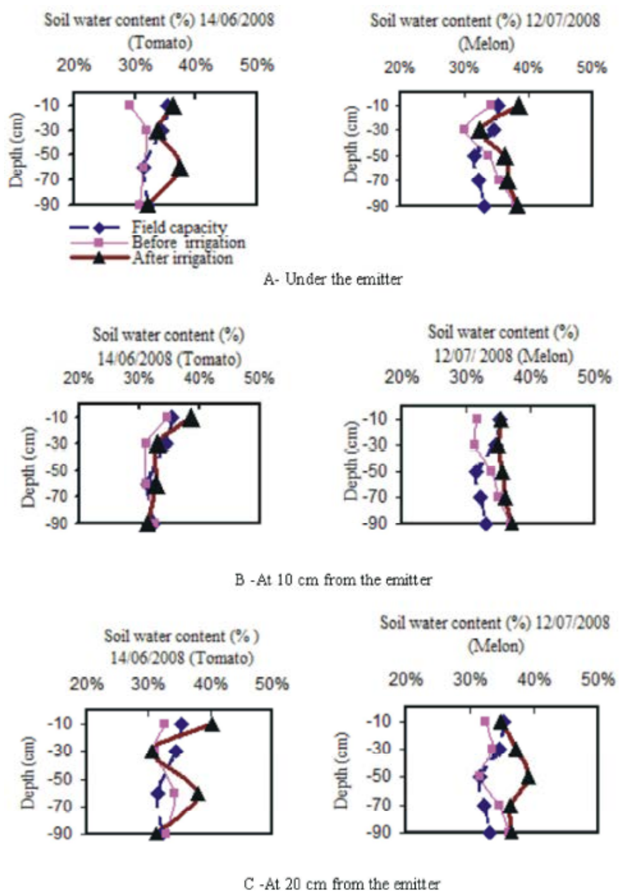

Fig. 2: Volumetric water content profiles before and after irrigation: A: under the emitter; B: at 10 cm from the emitter and C: at 20 cm from the emitter on 14 June 2008 and 12 July 2008. All data are averaged values of three soil samples

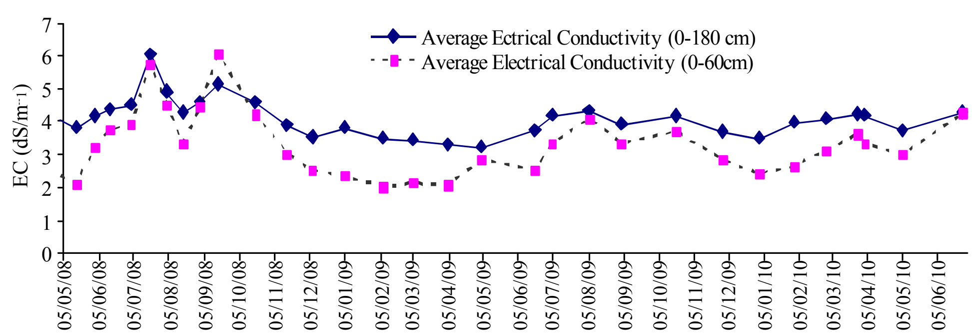

Fig. 3: Average soil profile electrical conductivity during (May 2008-June 2010)

tomato yield is more than 80 tons/ha whereas yield recorded in this study area is low and it's about only 50 tons/ha. According to Reina-Sanchez *et al*. [14], tomato fruit is the most sensitive organ to the salinity and it shows significant yield reduction under irrigation water with salinity equal to 2.5-7.3 dS m^{-1}. Ayers [15] reported

Table 6: Summary statistics of the electrical conductivity of the saturated paste extract of soil during the studied period (May 2008-June 2010)

	Electrical conductivity ($dS\ m^{-1}$) Depth (cm)					
	-30	-60	-90	-120	-150	-180
Number	31.0	31.0	31.0	31.0	31.0	31.0
Average	3.3	3.3	3.3	4.0	5.1	5.6
Min.	1.6	2.1	1.9	2.0	3.6	5.0
Max.	8.4	4.9	5.1	6.3	6.5	6.9
Standard deviation	1.5	0.8	0.7	0.8	0.7	0.4
Coefficient of variation	45%	23%	20%	19%	15%	8%

Table 7: Electrical conductivity variations of the saturation past extract during the irrigation season

		Electrical conductivity ($dS\ m^{-1}$) Depth (cm)					
Crops	Date	-30	-60	-90	-120	-150	-180
Tomato	02/05/2008	1.9	2.8	3.9	3.6	6.2	6.2
	16/05/2008	2.0	2.2	2.8	3.8	6.1	6.0
	01/06/2008	3.1	3.3	2.9	4.0	5.9	5.8
	14/06/2008	4.0	3.5	3.2	4.5	5.5	5.5
	02/07/2008	4.1	3.7	4.0	4.2	5.2	5.9
	19/07/2008	6.5	4.9	5.1	6.3	6.5	6.9
	02/08/2008	5.1	3.9	4.1	4.2	6.1	6.0
	16/08/2008	4.1	2.6	2.6	5.6	6.0	5.0
	01/09/2008	5.0	3.9	3.0	4.0	5.9	5.8
	16/09/2008	7.0	3.7	4.3	3.4	5.5	5.7
Melon	02/05/2008	1.6	2.3	2.0	3.8	5.2	5.9
	16/05/2008	1.8	2.5	2.3	3.9	5.7	6.0
	01/06/2008	1.9	2.1	2.3	3.9	5.6	5.7
	14/06/2008	3.0	2.1	2.4	4.0	5.9	6.2
	02/07/2008	5.1	3.3	3.9	3.9	5.9	6.1
	19/07/2008	8.4	3.8	3.5	4.9	6.5	6.8
	02/08/2008	5.3	3.8	3.2	4.5	6.1	6.3
	16/08/2008	4.1	2.6	2.6	5.6	7.7	6.9
Squash	02/05/2008	2.9	2.7	4.1	4.5	5.1	5.2
	16/05/2008	2.7	2.6	4.1	4.9	5.4	5.3
	01/06/2008	2.8	2.5	4.0	5.0	5.3	5.5
	14/06/2008	3.7	3.5	3.3	4.5	5.3	6.1
	02/07/2008	3.8	3.6	3.4	5.2	5.4	6.0
	19/07/2008	3.9	3.7	3.5	5.9	6.3	6.5
	02/08/2008	3.7	3.8	3.5	5.1	6.1	6.2
	16/08/2008	3.8	4.1	3.9	5.5	5.4	5.7
	01/09/2008	4.0	4.3	4.2	5.2	5.3	5.8
	16/09/2008	7.7	6.1	4.4	4.4	4.7	5.6

that the use of irrigation water with EC of 1.7, 2.3, 3.4 and 5 $dS\ m^{-1}$ reduce the tomato yield by 0, 10, 25 and 50 % respectively.

Cuartero and Fernandez-Munoz [16] summarized that the yields of tomato reduced when the plants were irrigated with nutrient solution having an electrical conductivity equal to 2.5 $dS\ m^{-1}$ or higher. They concluded that tomato yield can be reduced by the decrease of average fruit weight and/or the number of fruits produced per plant. Campos *et al*. [17] compared effects of five levels of salinity (1, 2, 3, 4 and 5 $dS\ m^{-1}$) of the irrigation water on industrial tomato and concluded that total yield reduced by 11% upon each unit increase in the salinity of the irrigation water while fruit quality increased with the increasing salinity. The low yield observed shows clearly the negative effect of salinization and of over irrigation.

Drainage Discharge: The average flow was measured at the end of subsurface drainage pipes, D_1 under tomato, D_2 under melon and D_3 under squash during the irrigation season on 05/05/2008, 31/05/2008, 14/06/2008, 12/07/2008, 30/07/2008, 16/08/2008, 04/09/2008 and 16/09/2008 (Table 9). The drainage flows have registered an evolution related to the occurrence of irrigation. The maximum value are observed (respectively during July month) when the maximum irrigation water was diverted. For all the fields, the highest discharge rates observed during the irrigation season were between 1.5 l/mn and 3.2 l/mn. Theses values were recorded on July 2008. After the irrigation season, discharge rate have recorded a remarkable decrease and nullify on 01/10/2008.

During the rainy season, the outlet drainage pipes were flooded. During the irrigation season, the EC of drainage water ranges between 4 $dS\ m^{-1}$and 8 $dS\ m^{-1}$. The salt mass leached by drains were 2.6 tons/ha, 1.9 tons/ha and 1.7 tons/ha respectively under D_1, D_2 and D_3. Tedeschi et *al*. [18] found that average flow rate of the drainage waters reaches 26.7 $l\ s^{-1}$ and 31.3 $l\ s^{-1}$ respectively during the non-irrigated season and irrigation season and concluded that the mass of salts exported with the drainage waters was linearly correlated ($p<0.001$) with the drainage volume and the drainage volume depended ($P<0.001$) on irrigation volumes.

Water Table Level and Salinity Variation: The groundwater level was 1.3 m on 2 May 2008. In spite of a lack of rain between May 2008 and July 2008, the water table came up to the surface and reached 1.2 m on 12 July 2008 due to over irrigation. At the end of the irrigation season (September 2008) the water level reached 1.3 m. With the end of irrigation, the water table decreases and the maximum deep values measured were 1.5 m reached on

Table 8: Crop yield

Crops	Average fruit number/plant	Number of plants	Average fruit weight (g)	Average calculated/ estimated yield (tons/ha)	Tunisian national average yield (tons/ha)
Tomato	24	16667	124	50	80
Melon	3	7200	2000	43	60
Squash	2	7000	4500	63	70
Wheat				1.6	2

Table 9: Irrigation water amounts and average drainage flow rate during the irrigation season

	Irrigation water amounts (m^3/ha)			Average drainage flow rate (l/mn)			
Irrigation period	Tomato	Pepper	Melon	Squash	Tomato (drain D_1)	Melon (drain D_2)	Squash (drain D3)
May	1567	630	400		0.6	0.2	0.3
June	3030	1910	2120	820	0.4	0.4	0.7
July	4143	2800	2170	1130	3.0	3.2	1.5
August	1260	780	340	680	0.6	0.6	0.8
September	300	260	-	360	0.1	0.0	0.2

Table 10: Water table level and salinity variation

Date	Level (m)	Salinity (dS m^{-1})	Date	Level (m)	Salinity (dS m^{-1})
02/05/2008	1.3	3.8	02/05/2009	1.3	4.8
14/06/2008	1.3	3.5	05/07/2009	1.8	5.5
12/07/2008	1.2	2.8	16/08/2009	1.8	5.7
16/08/2008	1.3	3.1	01/11/2009	1.6	5.3
16/09/2008	1.3	3.2	30/01/2010	1.4	4.9
01/11/2008	1.5	3.5	27/03/2010	1.5	5.4
06/12/2008	1.4	3.6	07/05/2010	1.4	5.5
06/02/2009	1.24	5.8	26/06/2010	1.7	5.3

01/11/2008, 1.8 m reached on 05/07/2009 and 1, 7 m reached on 26/06/ 2010. During the winter and due to rain, the groundwater level increases to 1.24 m and reached 1.3 m in May 2009, (Table 10) the same value observed in May 2008. Hence, groundwater at shallow depths contributes to salt build-up in the soil through the evaporation process. Feng *et al*. [19] report that after the autumn irrigation, the groundwater level rose remarkably from 2.92 to 1.32 m below soil surface.

At the beginning of the irrigation season (05/05/2008), the EC of water table was 5.5 dS m^{-1}. During the irrigation season, there has been a remarkable decrease in salinity and a minimum value of 2.8 dS m^{-1} was measured on 12/07/2008, equal to the irrigation water salinity. All salinities measured during the irrigation season were lower than 3.6 dS m^{-1}. This decrease is due to the important irrigation water amounts that reach the groundwater. Since the first of November 2008, salinity has increased and reached 5.8 dS m^{-1} on 06/02/2009. It should be noted that the rainfall recorded during all the year was 462 mm while the amount of irrigation water diverted to crops was 1030 mm for tomato, 503 mm for melon and 299 mm for squash. As previously discussed, the high amounts of irrigation water diverted to crops during the irrigation season are responsible for the remarkable rise of water table level which came to surface and the decrease of its salinity due to the dilution effect. Therefore, the groundwater exhibits seasonal variation in terms of quality and depth, being influenced by recharge from rainfall.

CONCLUSIONS

This study was carried out during May 2008-Juin 2010 in a farm plot of 2.38 ha under irrigated crops (tomato, melon and squash), rainfed crop (wheat) and bare soil. The amounts of irrigation water diverted to crops (tomato, melon and squash) are higher than the total crop water requirements. Hence, during the irrigation season, the soil water content was always more or near the field capacity. Therefore, water table level shows a sustained rise when irrigation is relatively frequent and drainage flow rates depended on the irrigation volumes. During a cycle of two years, the soil profile salinity was stable, but it isn't the case when we analyze an irrigation season. In fact, results show that irrigation increases the electrical conductivity of the soil profile. The monitoring of soil profile during the irrigation season indicates that the most important concern was an increase in EC in the top soil layer (0-30 cm). Following the rains fall, there has been a desalination of the soil profile.

As an adaptation to soil salinization, farmers use crop rotation including rainfed crops and bare soil in order to decrease the soil salinity after irrigation season. Even so, for fields irrigated with brackish or saline water it is essential to regularly monitor soil salinity to allow take necessary action to avoid salinity build up in the root zone of any crop. To control salinity in irrigation districts, the irrigation management could be substantially improved.

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