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Monitoring of Soil Salinization under Different Irrigation Water Amounts: Case of Tomato Crop Drip Irrigated within Kalaat El Andalous Irrigated District (North-East of Tunisia)

Ahmed SAIDI
National Agronomic Institute of Tunisia
43 Avenue Charles Nicolle, Cité Mahrajène, 1082 Tunis, Tunisia
Email: saidiahmed44@gmail.com
Tel.: + 216 97 88 77 36; Fax: (+216) 71 79 93 91

Moncef HAMMAMI
Higher Agronomic Institue of Mateur,
Road of Tabarka -7030 Mateur, Tunisia

Hedi DAGHARI
National Agronomic Institute of Tunisia,
43 Avenue Charles Nicolle, Cité Mahrajène, 1082 Tunis, Tunisia

Hedi BEN ALI
Agence de Promotion des Investissements Agricoles,
6000 Gabès -Tunisie

***Abstract* – This work was conducted in a tomato plot, within the irrigated district of Kalaat El Andalous, of 0.3 ha and managed with drip irrigation system. The main objectives of this study are to assess and to monitor the evolution of soil salinization during an irrigation season under different water irrigation supplies generated by emitters delivering flow rates of 1.5 l/h, 2 l/h, 2.5 l/h and 3 l/h respectively in order to determine one salts soil pattern representative to the whole plot. Throughout the irrigation season, flow water variation didn't exceed +/-3% and the average uniformity coefficient was about 71%. Such heterogeneous water distribution has led either to an excessive water amounts either to a deficient water amountscompared to theoretical irrigation requirements estimated at 890.5 mm. In terms of soil salinity, the heterogeneity of water distribution has resulted, either in salts leaching either in salts accumulation in the soil. Indeed, starting with an initial stock of salts of 5.23 dS/m in the layer (0-80 cm), an excess supply of water of about 6% was resulting in a decrease of salts stock of about 5.5 %. On the other hand, deficit supplies of water of 12.3%, 29.5% and 47.7% as recorded under emitters debiting 2.5 l/h, 2 l/h and 1.5 l/h respectively have resulted in an increase of salts stocks of 40.9 % 53.3 % and 75.4 % respectively. The average stock of salts in the layer (0-80 cm) was about 7.58 dS/m.**

***Keywords* – Drip Irrigation, Uniformity Coefficient, Soil Salinity, Electrical Conductivity, Salts Stocks.**

I. Introduction

In Tunisia, the irrigated agriculture is the largest consumer of water (more than 80% [6]-[8]. Given the scarcity of water and the increasing of water demand of irrigated agriculture, the government is expected to rationalize its exploitation in agriculture by the adoption of water-saving irrigation techniques. Particularly, drip irrigation has experienced a remarkable expansion given its considerable promising in conditions of water scarcity [13]. This technique has been introduced since 1974 in order to establish a water-saving agriculture [15]. In Tunisian irrigated agriculture, waters with salinity ranging between 2 and 3.5 g/l are the most used. Then, waters of 3.5 to 4.5 g/l come in second rank but some wells with salinity exceeding 7 g/l are also used [2]. The unavoidable use of brakich waters for irrigation is causing accumulation of salts in the root zone and consequential damages of soil fertility [7].Reference [4]reported that nearly 20 to 30 million hectares worldwide are severely affected by salinity and about 60 to 80 million hectares are affected by other forms of degradation such as waterlogging [9]. In Tunisia, the salt affected soils cover about 1.5 million hectares, which represents respectively 10% of the total territory of Tunisia and 25% of the total area of arable land. This work has been recorded within a tomato plot belonging to the irrigated district of Kalaat El Andalous. The main objective is to assess and monitor the evolution of soil salinization allover the irrigation season under different water supplies in order to determine one average salts soil profile that could be representative to the whole plot.

II. Materials and Methods

A. Study Site Presentation

This work was performed in a private farm within the irrigated district of Kalaat El Andalous on a plot of 0.3 ha planted with tomatoes (1.5m x 0.3 m). The irrigation technique used is trickle irrigation using integrated emitters delivering a nominal flow rate of 4 l/h.

The main source of irrigation water is the Mejerda River whose average salinity is of 3.73 dS/m. The study plot is managed with plugged drainage system placed at a depth of 1.8 m with spacing between drainage lines of 40 m.

B. Experiments

- *Soil characterization*

In order to characterize the study site, we proceeded with a particle size analysis of three soil samples collected at three points well distributed in the plot. These soil samples were also used in order to determine an initial average soil salts profile before the beginning of irrigation cycles (03/05/2007) by the method of saturated paste extract. It was also proceeded to determine the specific soil water contents by gravimetric method and the saturated permeability by the method of double rings.

• *Flow water measurement, monitoring of irrigation uniformity and analysis of irrigation management*

To determine the homogeneity of water distribution at the scale of an irrigated plot, it was used to measure the flow rates of 16 emitters well distributed in the plot [1].Allover the irrigation season, four sets of measurements were performed respectively in 03/05/2007 (before irrigation), 11/07/2007, 02/08/2007 and 04/10/2007). The uniformity coefficient was calculated using the formula of Keller and Karmeli[5]:

$$CU(\%) = 100 \times \frac{q_{1/4}}{\bar{q}} \quad (1)$$

$\bar{q}$: Average emitter's flow and $q_{1/4}$: minimum average emitter's flow (1 /h).

To analyze the efficiency of irrigation management, applied water volumes were compared to theoretical irrigation water requirements which correspond to the sum of crops water requirements and leaching water requirements.

- Crops water requirements are calculated by the following expression:

$$ET_{Crops} = K_C \times ET0 - P \quad (2)$$

With: ETc: Crop evapotranspiration (mm/month); ET0: Potential evapotranspiration (mm/month) estimated by Penman Monteith expression which is adopted by the FAO[3]-[10], Kc: Crop coefficient determined from the FAO-56 paper and P: the amount of rainfall (mm/month).

- Leaching water requirements $\left(B_{Leaching}\right)$ are estimated by the expression:

$$B_{Leaching} = LR \times ET_{Crops} \quad (3)$$

The leaching fraction LR is calculated by the formula of Rhoades [11] and Rhoades and Merrill [12]:

$$LR = \frac{EC_w}{5EC_e - EC_w} \quad (4)$$

With: LR: Minimum leaching requirement, ECw: Salinity of irrigation water (dS/m) and ECe: Average soil salinity tolerated by the considered crop.

- Volumes of applied water (V_a) during each irrigation are determined by the following formula:

$$V_a = N \times T_a \times \bar{Q} \quad (5)$$

With : V_a (l), N , T_a and $\bar{Q}$ denote respectively the amount of water (liters), the number of emitters per ha, the irrigation duration (hours) and the average emitter flow rate (l/h).

• *Monitoring of soil salinity*

The monitoring of spatiotemporal salinity evolution within a soil layer of 80 cm was recorded under twelve emitters well distributed in the plot and delivering flow rates ranging between 1.5 l/h and 3 l/h. In order to cover any possible flow variation, the selected emitters' flows represent those which are the most frequented during these trials according to the uniformity concept (Fig.1).

In this experimentation, three sets of soil sampling with auger were performed respectively on 11/07/2007, 02/08/2007 and 04/10/2007. Each sample involved a soil layer of 80 cm depth's at a rate of one sample every 20 cm. An averaged salt profile was also determined on 03/05/2007 before the beginning of irrigation season. The soil salinity was determined by the method of the extract of saturated paste which was established by the United States Salinity Laboratory researcher's in Riverside[14].

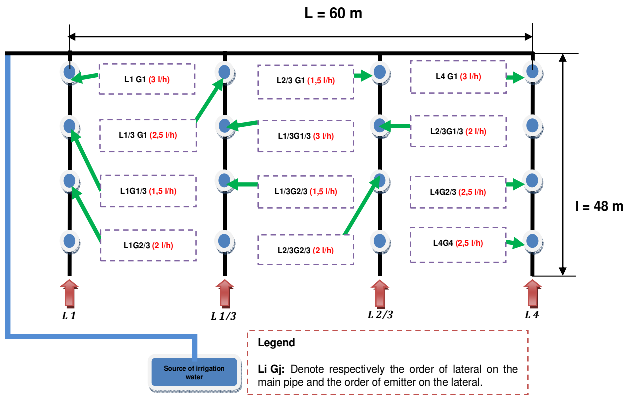

Fig.1. Location of selected emitters

III. Results and Discussion

A. Soilcharacterization

Particles size analysis recorded at different points well distributed in the test plot showed that soils are deep and with fine texture (clay loam texture to clay loam texture) and bulk density is averaging 1.35 g/cm3 and 1.20 g/cm3 respectively in soil layers (0-40 cm) and (40-80 cm).

Table 1: Soilcharacterization

	Soillayer (cm)			
	0-20	**20-40**	**40-60**	**60-80**
Clay (%)	22	17	20	23
Loam (%)	41	33	48	43
Sand (%)	37	49	31	33
Da (g/cm^3)	1.35	1.35	1.2	1.2
Water content at saturation status θs (%)	45	45	46	-
Water content at wilting point θwp (%)	19.5	15	25.5	25.5
Water content at field capacity θfc (%)	34.5	31.5	42	43.5
Permeability at saturation Ks (cm/h)	2.4	0.15	1.2	-

B. Assessment of irrigation uniformity and analysis of current irrigation management efficiency

Allover the irrigation season, the average irrigation uniformity coefficient, determined based on Keller and Karmeliformula[5], is about 71%. The comparison of measured flows during each campaign to those measured just at the beginning of the irrigation season showed a slight variation of all emitter's flows that didn't exceed +/- 3%.

Table 2: Evaluation of average flows under selected emitters

Most Frequented Flows	Emitters (LiGi)	Average measured flows (l/h)			
		03/05/2007	11/07/2007	02/08/2007	04/10/2007
3 l/h	L1G1; L1/3G1/3; L4G1	3.00	3.08	2.98	3.08
2.5 l/h	L1/3G1; L4G2/3; L4G4	2.50	2.53	2.53	2.54
2 l/h	L1G2/3; L2/3G1/3; L2/3G2/3	2.00	2.05	2.01	1.99
1.5 l/h	L1G1/3; L1/3G2/3; L2/3G1	1.50	1.50	1.54	1.52

Allover irrigation season, the farmer has adopted variable irrigation durations ranging from 1 hour to 3 hours 30 minutes with one irrigation during every two days throughout the irrigation season (May to September).

Table 3: Monthly and total irrigation duration

Month	May	June	July	August	September
Irrigation duration (Hours)	1.00	2.50	3.50	2.00	1.00
Total irrigation duration (Hours)	15.00	38.00	52.00	30.00	4.00

The amounts of water volumes recorded underneath twelve emitters well distributed in the plot are highly variable and range from 466.17 mm to 942.03 mm with an average amount of 704.28 mm. However, theoretical irrigation water requirements of tomato crop are about 688 mm and the leaching requirements calculated based on Rhoades [11]and Rhoades and Merrill [12]formula are about 27% which is equal to a water amount of 202.50 mm. Therefore, the total irrigation water requirements are about 890.50 mm. Comparison of applied water amounts to the total irrigation water requirements showed that only the volume of water generated by emitters delivering 3 l/h is able to meet both crop water requirements and leaching water requirements. However, volumes of water generated by emitters delivering 2.5 l/h, 2 l/h and 1.5 l/h didn't ensure the satisfaction of the total irrigation water requirements. Deficits irrigation water are respectively of 12.3%, 29.5% and 47.7%.

Table 4: Monthly and total applied water volumes under emitters delivering 3 l/h, 2.5 l/h, 2 l/h and 1.5 l/h

Month	Applied water amounts (mm)				Average applied water amounts (mm)
	3 l/h	2.5 l/h	2 l/h	1.5 l/h	
May	100.00	83.33	66.67	50.00	**75.00**
June	260.09	213.64	173.11	126.67	**193.38**
July	355.91	292.35	236.89	173.33	**264.62**
August	198.67	168.67	134.00	102.67	**151.00**
September	27.38	22.58	17.69	13.51	**20.29**
TOTAL	**942.04**	**780.57**	**628.35**	**466.17**	**704.28**

C. Monitoring of soil salinity evolution and determination of an average salts stock profile

- *Analysis of soil salinity evolution*

At the beginning of the irrigation season (03/05/2007), an averaged soil profile was sampled at three locations within the field trials in order to determine the soil salinity (Electrical conductivity EC) profile at the initial status. Within the rooted layer (0-80 cm), the salts stock is about 5.23 dS/m.At the end of irrigation season, the average salinityvalues measured in a soil layer of 80 cm experienced a net increase under the different applied water volumes. Indeed, the average electrical conductivity (EC) increased from 5.23 dS/m to 9.72 dS/m, 12.92 dS/m, 13.44 dS/m and 14.68 dS/m respectively under emitters delivering 3 l/h, 2.5 l/h, 2 l/h and 1.5 l/h (Fig.2).

Hence, the calculation of averaged stocks of salts in the soil layer of 80 cm has allowed making the following observations:

- Under emitters delivering 3 l/h, the average stock of salts in the soil has shown a slight decrease from 5.23 dS/m to 4.49 dS/m
- Under emitters delivering 2.5 l/h, 2 l/h and 1.5 l/h, on the contrary, stocks of salts in the soil have respectively increased from 5.23 dS/m to 7.69 dS/m; 8.21 dS/m and 9.45 dS/m

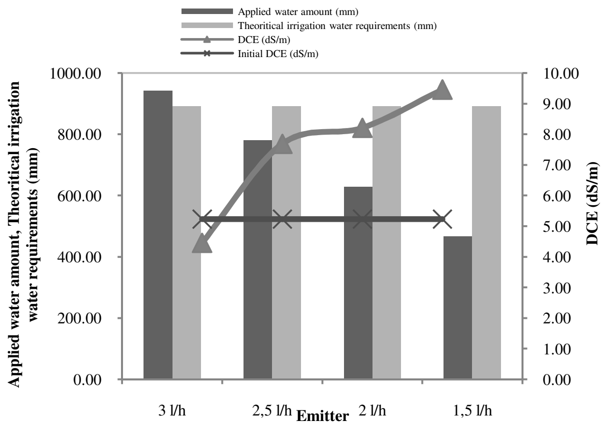

Fig.2. Average salts stocks evolution under emitters delivering 3 l/h, 2.5 l/h, 2 l/h and 1.5 l/h

Considering all tested flows together, we noticed that salts stock in the soil is as much important that the volume of water applied is lower and vice versa. Indeed, according to these trials, we remark that the volume of water applied

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by emitters delivering 3 l/h can largely supply either crop water requirements either those of leaching requirements. Thus, a slight decrease of soil salinity of -5,5% has been observed. However, deficits water amounts of 12.3%, 29.5% et 47.7% recorded respectively under emitters delivering 2.5 l/h, 2 l/h and 1.5 l/h have resulted in a considerable increase of salts stock in the soil with an increase rates over the initial measured salts stock of 40.9%, 53.3% and 75 4% respectively (Fig.3).

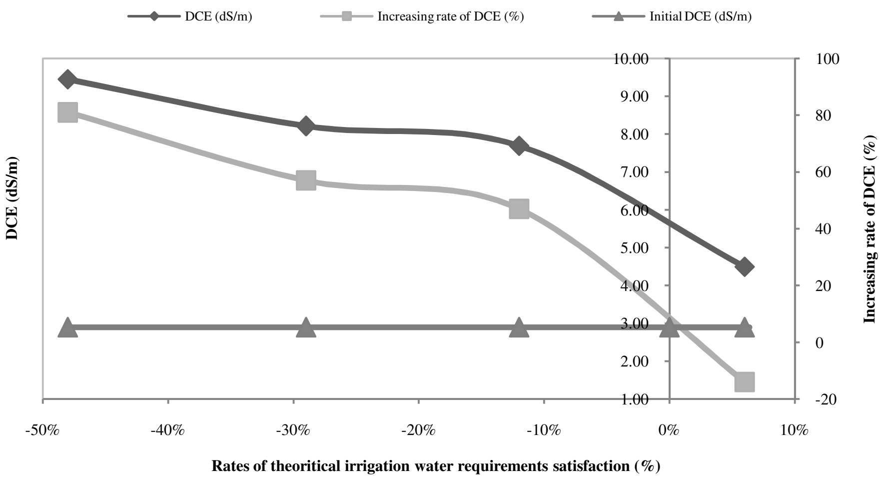

Fig.3. Evolution of salts stocks as a function of irrigation water requirements satisfaction

- *Evaluation of an average soil salt stock profile*

The local analysis of soil salinity evolution has allowed highlighting the complexity of soil profile salinity estimation at the field scale due to the great spatial and temporal variability of salinity. Indeed, poor water distribution within the plot involves a heterogeneous distribution of salinity which makes an accurate estimation of one representative soil saline profile so difficult. However, the test we performed contributes to the resolution of this problem through the adoption of a particular protocol to monitor the evolution of this parameter under twelve emitters with different flow rates and well distributed in the plot. Choice of emitters was based on their flows while relying on the protocol of Keller and Karmeli[5]. To have a representative saline profile to the whole plot, it is necessary to consider a weighted average salt profile and do not consider just a simple arithmetic average. So, the average stock of salts calculated in current study within the rooted layer (0-80 cm) is about 7.58 dS/m.

Table 5: Evaluation of an average salts stock

Flow (l/h)	N	Weighting factor (%)	Average DCE (dS/m)	
			Arithmetic value	Weighted value
3 l/h	3	18.75	4.49	0.84
2,5 l/h	5	31.25	7.69	2.40
2 l/h	5	31.25	8.21	2.57
1,5 l/h	3	18.75	9.45	1.77
Average Salts Stock In The Layer (0-80 cm)			7,46	7.58

Conclusion

Given the scarcity of water resources and increased competition for water of good quality among different users, farmers are forced to irrigate with poor quality waters. Therefore, drip irrigation is an efficient and water saving method of irrigation, but when brackish waters are used, a lot of care should be taken. These experimentations have been recorded in a private farm within the irrigated district of Kalaat El Andalous, aiming to monitor the evolution of soil salinity under tomato crop trickle irrigated in order to determine an average soil salinity profile. Throughout the irrigation season, emitters' flow variation didn't exceed +/-3% and the average uniformity coefficient was about 71%. The amount of water provided at the field scale were ranging between -47.7% to +6% of theoretical irrigation water requirements. Indeed, allover the irrigation season, stocks of salts were ranging between 4.49 dS/m and 9.45 dS/m. Thus, average salts stock of the whole plot is of 7.58 dS/m. However, such experiments need to be reconducted again under other crops and in other climatic contexts in order to assess the overall trend of salinization at the whole irrigated district scale.

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AUTHOR'S PROFILE

Dr. Ahmed SAIDI

Mr. Ahmed SAIDI is a native of Tunisia. He has obtained his Engineer degree from the Higher Agronomic Institute of Chott Mariem-Sousse and then his Master of Science and doctorate degrees from the National Agronomic Institute of Tunisia in the field of Rural Engineering, Water and Forests. Currently, he is working in the National Researches Institute of Rural Engineering, Water and Forests as an engineer specialized in hydraulic and irrigation.