International Journal of Multidisciplinary and Current Research ISSN: 2321-3124
Research Article Available at: http://ijmcr.com

Diagnosis of the waterlogging and the soil salinity status in irrigated areas after several decades of irrigation: The case of Henchir Tobias in lower valley of Mejerda river (Tunisia)

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Received 01 Sept 2017, Accepted 02 Nov 2017, Available online 03 Nov 2017, **Vol.5 (Nov/Dec 2017 issue)**

Abstract

In semi-arid and arid countries, irrigation is an important requirement for crop production. The aim of this study was to characterize the current status and to develop statistical regression models and map spatial variations in soil salinity in the irrigated perimeter of Henchir Tobias. During the two control campaigns of autumn 2014 and spring 2015, this irrigated perimeter was characterized by higher salinity in the surface horizons. It remains highest in the underlying horizons. The spatial distribution of soil salinity (Electric Conductivity of paste extract: ECe) shows that it is generally higher in the eastern and northeastern parts of the irrigated perimeter, especially in autumn 2014. The underground water is more salty in the center and north-eastern part of the perimeter. High values of electrical conductivity of the ground water (EC≥12 mS/cm) were noted in autumn 2014. A significant linear and positive correlation (r = 0.477) between underground water salinity and underground water level were established for the spring campaign of 2015. However, there is not a significant correlation between the underground water level and soil salinity, but with correlation coefficients approaching the significance threshold. There is a relationship between the underground water salinity and soil salinity for the autumn campaign of 2014. There is also a positive correlation (r = 0.77) between the underground water salinity and the soil salinity only for the upper horizon (0-20 cm) in spring 2015. The investigation of the interaction between soil characteristics and plant production has shown that there is a significant but negative correlation between the average of soil salinity and yield of artichoke (Cynara scolymus L.). However, underground water levels and salinity have strong negative effect on the yield of artichoke crops.

Keywords*: waterlogging, salinization, soils, piezometers, yield, Tunisia.*

1. Introduction

The production increase in semi-arid and arid countries as Tunisia, needs a good water quality and soil management because these resources are limiting factors for agriculture production (Hachicha *et al*., 2013). In arid and semi-arid regions, irrigation is an important requirement for crop production. However, soil salinity development can be major threats to sustainable crop productivity under irrigated agriculture without proper water management (Hillel and Vlek, 2005; Ouji *et al*., 2015; Boudabous *et al*., 2016). It is a serious problem that hinders the development of agriculture (Li *et al*., 2014). Soil salinity is also a major limiting factor for crop yield in poorly drained soils (Çullu, 2003). In Tunisia, soils affected by salts cover about 1.5 million hectares, which represents around 10% of the total country area (Kahlaoui *et al*., 2011). About 36% of irrigated areas are affected by salts in different degrees (Bouksila *et al*., 2010). Soil salinity affects the soil permeability and the water retention negatively (Keren, 2000). There are various factors that cause salinization which include natural or inherent and human induced factors and these are generally categorized into primary and secondary salinization respectively (Shrestha, 2006).

Secondary salinization is a serious threat to sustainable irrigated agricultural production since estimates indicate that, globally, 20% of irrigated land suffers salinization induced by the build-up of salts caused by irrigation (Wood *et al*., 2000; Aragüés *et al*., 2011). Secondary salinization develops from mobilization of the stored salts in the soil profile, surface water or underground water, due to human activity such as urbanization, deforestation and agriculture (irrigated and dry land) (Ferjani *et al*., 2012). Globally, more than 770 000 km² of the lands are affected by secondary salinization, 20% of the irrigated areas and about 2% of the agricultural lands (FAO, 2000; Kahlaoui *et al*., 2011).

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The soil salinity is also affected by the water movement at the surface and depends on the irrigation method. In fact, the use of drip irrigation may bring about a salt build-up on the soil profile and the soil surface after long-term application of this irrigation fashion (Ferjani *et al*., 2013). Soil salinization constitutes a major problem for irrigated land sustainability (Bouksila *et al*., 2010). Salinity of water shallow aquifers is the cause of salinity development in irrigated soils. Perimeters which are subject to regimes of salt shallow aquifers are located either in low altitude depressions characterized by deficient internal drainage or around salted areas or near coasts (Ben Hassine, 2005; Ben Hassine *et al*., 2013). According to Bouksila *et al*. (2010), soil salinization over a shallow water table, depends on climatic conditions, soil properties, vegetation, soil management (irrigation, fertilization, tillage, etc.), depth and salinity of the underground water. The irrigated area of "Henchir Tobias", located in the alluvial plain, the Lower Valley of Medjerda (Tunisia), is exposed to several dynamics that contribute to salinization and waterlogging processes, such as low slope, fine soil texture and low saline water table.

The present study was realized in the irrigated perimeter of Henchir Tobias. It is situated in the area of Mejreda river basin (Tunisia). The measurements carried out in autumn 2014 and spring 2015 had for objective to assess the impact of the underground water on soil salinity of this irrigated perimeter. It essentially aims to the representation of the spatial distribution of the salinity and to establish its possible links with the shallow underground water and with the irrigation water used.

2. Materials and methods

2.1. Study Area

Depends on the delegation of Utica, governorate of Bizerte, the irrigated perimeter of Henchir Tobias is located at the left side of Mejerda river, between Kalâat Landalous and Utica. It is limited on the west side of the GP8 road linking Tunis to Bizerte (Figure 1). It covers 1450 hectares reclaimed, since the 1960-1970 period, under the Project of agricultural development of irrigated areas in the lowest part of Mejreda River basin. It is equipped with irrigation and drainage networks. The irrigation water is brought from the Mejreda River accumulated in El Aroussia dam.

The soils have a fine texture, ranging from clay to clay-silt. They are attached, mostly, at Entisols order (Soil Taxonomy). The altitude varies between 5 and 20 meters above sea level.The relief of Jebel Menzel Ghoul, delimiting the perimeter at the northwest side, rises to 175 meters and has a moderate slope that varies between 5% and 11%. Surface runoffs from Jebel Menzel Ghoul are so minor. The basin of Garâat El Mabtouh, southwest side, and plain of Utica on the northeast side are areas to temporary submergence where the water hardly evacuates because of the weakness of slopes (Mansouri, 1979).

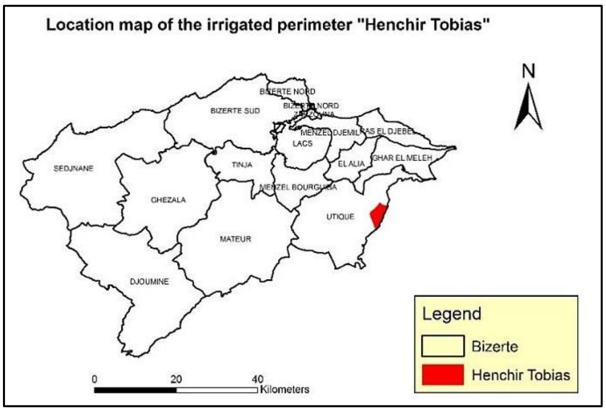

Figure 1: Location of the irrigated perimeter "Henchir Tobias" on an administrative map of Bizerte governorate

2.2. Soil sampling

The study of soil salinity is based on the sampling campaigns carried out in autumn 2014 (September – October) and in spring 2015, during the period March – April. The soil samples were collected with auger, in 9 points at depths of 0-20, 20-40, 40-60, 60-80, 80-100 and 100-120 cm.

2.3. Construction and implementation of a survey questionnaire

To identify the impact of salinity on crop production within the perimeter, an investigation was carried around thematic modules defined in terms of objectives. The investigation concerned nine farmers who own parcels located near the sampling points (Figure 2).To perform field measurements and express the spatial distribution of the studied parameters, we resorted to cartographic covering of the study area and geographic information system (GIS).

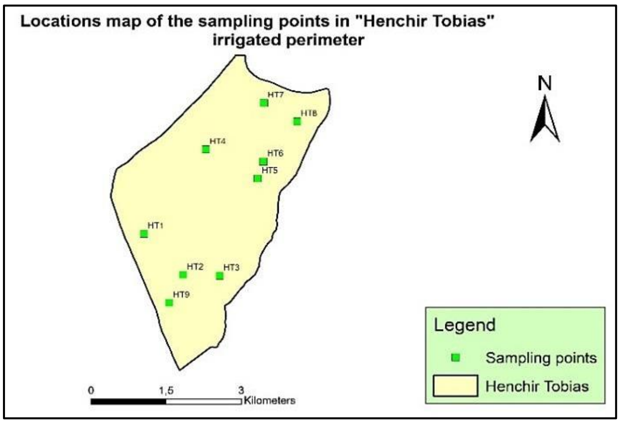

Figure 2: Locations map of the sampling points in "Henchir Tobias" irrigated perimeter

2.4. Analytical procedures

Soil samples were air dried, crushed and sieved to 2 mm; in this state, they are ready for analyses.

2.4. 1. Determination of electrical conductivity (EC)

These soil samples were air dried, crashed, sieved through 2 mm sieve and mixed with water in order to extract the leaching liquid to measure the electrical conductivity of the saturated paste (ECe) (Richards, 1954).

2.4.2. Study of the level and salinity of the water table

Since 1993, the irrigated perimeter of Henchir Tobias was equipped with a network of 35 piezometers as well galvanized tubes covering the entire study area. Currently, only 22 piezometers are operational. This study was conducted during the period of September - October 2014 and March-April 2015 on the 22 existing piezometers (Figure 3). At each piezometer, we determined the depth of the water by graduated meter and taken a water sample. The water samples were analyzed in the laboratory in order to determine their electrical conductivity. This parameter was determined using EC meter.

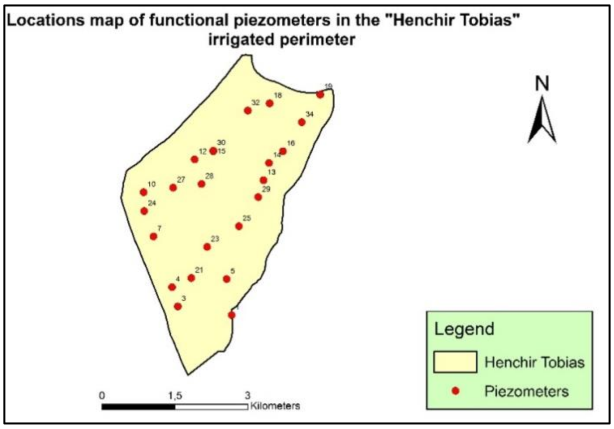

Figure 3: Locations map of functional piezometers in the "Henchir Tobias" irrigated perimeter

2.5. Statistical calculations

Data from the measurements were expressed by their average. Then, the variation between the values of different points was illustrated by calculating the standard deviation and coefficient of variation.

3. Results

3.1. Soils salinity

The results of soils salinity in the irrigated perimeter of Henchir Tobias during the period September and October 2014 is shown in table 1. The points HT3 and HT6 are characterized by higher salinity which reaches respectively 9.79 and 7.8 dS/m in the surface horizons. It remains highest in the underlying horizons. The lowest salinity values are observed in points HT4 and HT8. The points HT1, HT2, HT5, HT7 and HT9 are intermediate salinity, which does not exceed on average of 5.53 dS/m, their profiles are generally vertical saline, except for point HT9 where the salinity of the surface horizon is higher than those of other layers (Table 1).

For the measures of soils salinity carried out in March and April 2015, the point HT6 presented the higher salinity value which reaches 2.2 dS/m in the surface horizons (Table 2). It remains highest in the other horizons. The lowest salinity values are observed in point HT8 where saline profile is nearly vertical. The other points have intermediate values that do not exceed on average of 3.14 dS/m, their saline profiles are generally vertical (Table 2).

Table 1: Averages of the measures of electrical conductivity (dS/m), carried out in September and October 2014

Soil salinity (campaign Sept-Oct 2014)							
	Depths (cm)						
Sampling point	0-20	20-40	40-60	60-80	80-100	100-120	Average EC*
	Electrical conductivity (EC) of saturated paste extract (mS/cm)						
HT1	2.24	2.52	2.81	4.53	3.23	6.09	2.79
HT2	1.62	2.42	3.35	3.66	5.63	7.79	2.69
HT3	9.79	3.72	4.7	6.17	8.13	9.06	7.58
HT4	1.4	1	1.2	1.2	1.9	1.9	1.34
HT5	5.1	6.2	6	5.5	5.6	5.8	5.53
HT6	7.8	7.9	8.4	16.2	13.6	12.6	9.05
HT7	1.9	2	2.5	2.3	4.4	2.9	2.21
HT8	1.5	1.17	1.21	1.49	1.58	1.35	1.39
HT9	3.5	3.5	2.9	2.8	2.4	2.2	3.27

* Average EC = $([2*CE_{0-20} + CE_{20-40} + 0,25*CE_{40-60} + 0,25*CE_{60-80} + 0,25*CE_{80-100} + 0,25*CE_{100-120}]/4)$ (CRUESI 1970).

Table 2: Averages of the measures of electrical conductivity (dS/m), carried out in March and April 2015

Soil salinity (campaign Mars-Avril 2015)							
	Depths (cm)						
Sampling point	0-20	20-40	40-60	60-80	80-100	100-120	Average EC*
	Electrical conductivity(EC) of saturated paste extract (mS/cm)						
HT1	1.52	2.38	2.67	3.48	4.63	6.79	2.45
HT2	1.16	1.33	1.53	2.18	1.74	2.13	1.39
HT3	1.31	2.61	4.96	6.57	8	9.73	3.14
HT4	1.13	1.31	1.8	3.9	4.3	6	1.89
HT5	1.1	1.5	1.7	2.4	3.6	4.5	1.69
HT6	2.2	1.9	2.2	2.8	4.6	6.3	2.57
HT7	1.2	1.8	3.1	4.6	6	7	2.34
HT8	1.1	1	1.5	1.61	2.03	2.43	1.27
HT9	1.1	1.5	1.4	3.8	4.2	4.7	1.81

* Average EC = $([2*CE_{0-20} + CE_{20-40} + 0,25*CE_{40-60} + 0,25*CE_{60-80} + 0,25*CE_{80-100} + 0,25*CE_{100-120}]/4)$ (CRUESI 1970).

3.2. Spatial variation of soil salinity

The salinity assessment is presented below with soil salinity maps for the two campaigns (in autumn 2014 and spring 2015). The spatial distribution of soil salinity (ECe), for each depth can be seen below in figure 4a and figure

4b (the Universal Transverse Mercator coordinate system have been used for the spatial distribution). In this figures, it can be seen that the highest salinity in October 2014, is generally located in the eastern part of the irrigated perimeter. Only a small surface area, the northeast side, has high salinity. The bright red in the maps indicates the highest concentration.

The appearance of high salinity areas in October 2014 may be the result of reduced rainfall and irrigation water supplies. While in March 2015, salinity can be described as low on the perimeter. These low salinity values can be explained by the leaching of salts by heavy rains received before and during our measurement campaign (Figure 4b).

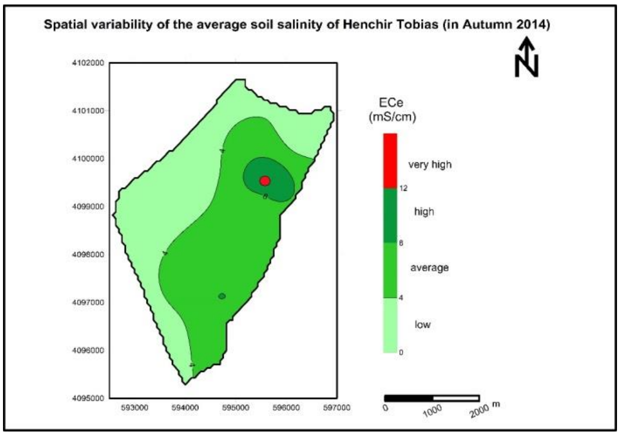

Figure 4a: Spatial variability of the average soil salinity (dS/m) of Henchir Tobias (in autumn 2014)

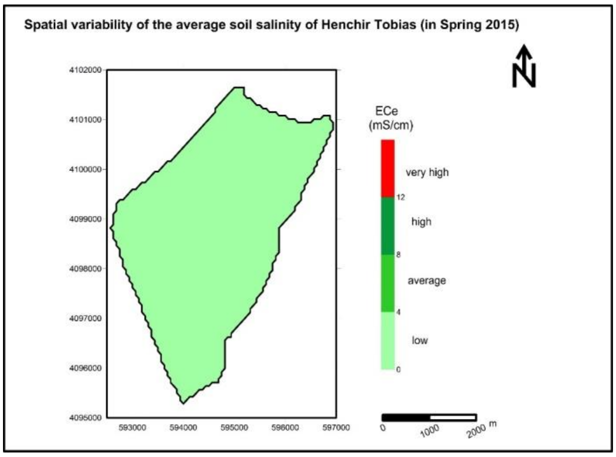

Figure 4b: Spatial variability of the average soil salinity (dS/m) of Henchir Tobias (in spring 2015)

To have a more precise idea on the area affected by salinity, relative frequency histograms are developed (Figure 5).These show that for autumn 2014, the interval (0-4 dS/m) of soil salinity covers 61% of the surface of the perimeter. This percentage increases in spring 2015 to 100%. In October 2014, average soils salinity (4-8 dS/m) covers 21% of the total area and the last 18% of the soils of the perimeter are considered as salinized (ECe > 8 dS/m).

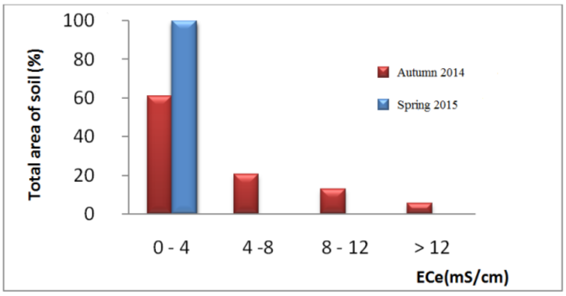

Figure 5: Frequency histogram of soil salinity (in Autumn 2014 and Spring 2015)

3.3. Level of the underground water

The irrigated perimeter "Henchir Tobias" has generally rebounded from the water level (Figure. 6a).Indeed, the water table, in Autumn 2014, is superficial type (groundwater depth <120 cm), shallow type (groundwater depth between 120 and 150 cm) on the major surface of the perimeter. It is only relatively small part, northwest perimeter, of that the table is at high depth (groundwater depth> 200 cm).

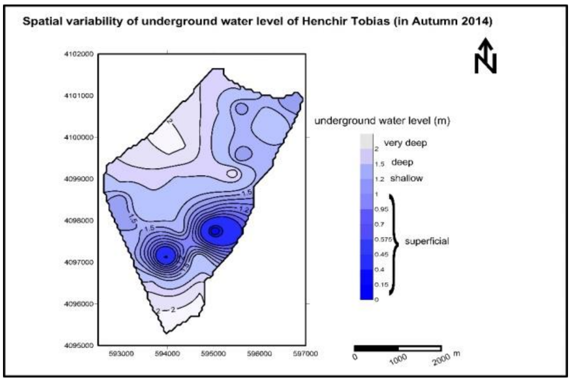

Figure 6a: Spatial variability of underground water level (m) of Henchir Tobias (in Autumn 2014)

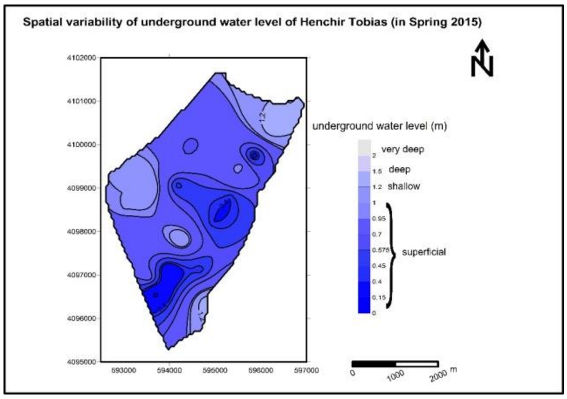

Figure 6b: Spatial variability of underground water level (m) of Henchir Tobias (in spring 2015)

In March-April 2015, the water table rises to 10 cm, it is superficial type on most of the perimeter and shallow on two other small parts located northeast and center-west of the perimeter (Figure 6b).

3.4. Salinity of the underground water

As shown by the figure 7a, almost all of the studied area in autumn 2014 has high salinity to very high of the underground water. The frequency of the presence of low underground water salinity is very small and is localized in the northeastern part of the irrigated perimeter. While in March-April 2015, the salinity of the irrigated perimeter is generally low to moderately low. The frequency of the presence of high or very high underground water salinity is reduced and localized on a tape strangled in the middle, extending from the center-west to east-central irrigated perimeter (Figure 7b).

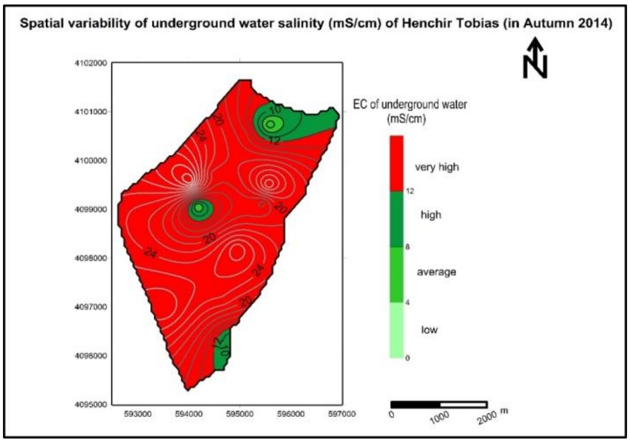

Figure 7a: Spatial variability of underground water salinity (dS/m) of Henchir Tobias (in autumn 2014)

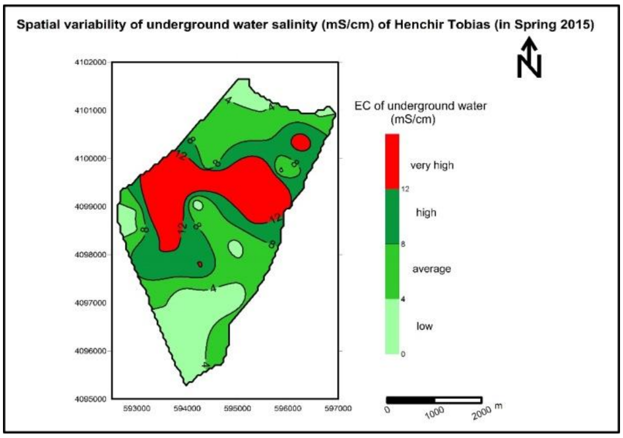

Figure. 7b: Spatial variability of underground water salinity (dS/m) of Henchir Tobias (in Spring 2015).

Frequency histograms of the underground water salinity (Figure. 8) show that in spring 2015, 21% of the surfaces of the irrigated perimeter are occupied by low saline groundwater, 32% have a moderately saline groundwater and 47% have salty and very salty groundwater located within the center of the irrigated perimeter. In autumn 2014, almost 70% of the groundwater surfaces are characterized by an electrical conductivity (EC) greater than 12 dS/m. The water table focuses salts during the summer probably by high evaporation.

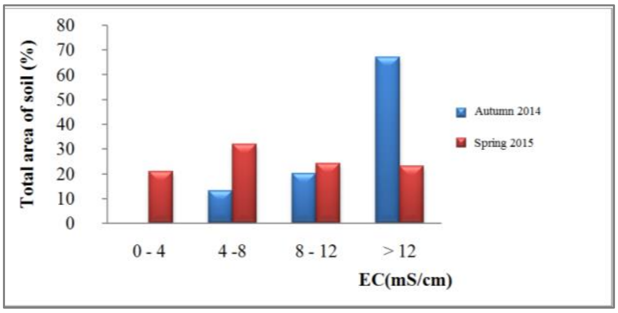

Figure 8: Frequency histogram of underground water salinity (in autumn 2014 and spring 2015)

3.5. Correlation between the underground water salinity and underground level

As shown in the figure 9, a significant linear and positive correlation (r = 0.477) between underground water salinity and underground water level were established (threshold 0.05 at n-2 degrees of freedom) for the spring campaign 2015. This explains that the greater the water depth rises, the bigger its salinity decreases and the superficial levels are either diluted by rainwater or those of irrigation.

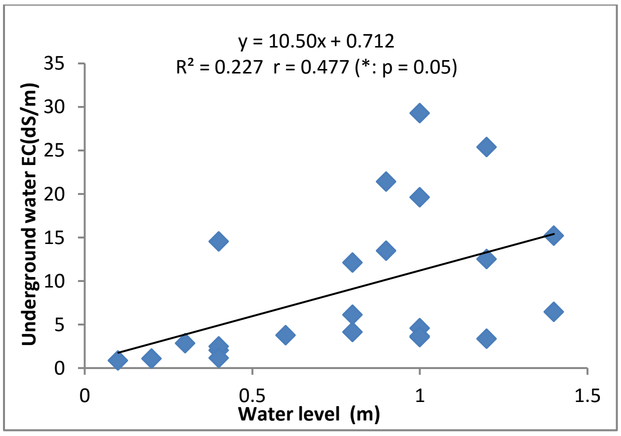

Figure. 9: Correlation straight line between the underground water salinity and underground level (in Spring 2015).

For the campaign of autumn 2014, the correlation coefficient (r = -0.164) between the underground water salinity and underground water levels so weak, explaining that there is not a significant correlation between the two parameters. Indeed, these two variables are not always sensitive in the same way to the influencing factors (surface conditions, summer drought, rainfall, waterlogging)

3.6. Correlation between the underground water level and soil salinity

The correlation coefficients (r) between the underground water level and soil salinity for both campaigns(Autumn 2014 and Spring 2015) have shown that there is not a significant correlation between the two measured parameters, explaining that the phenomenon of the rise of the underground water level did not cause the increase in soil salinity. Overall, soil salinity is low and practically constant regardless of underground water level. Considering the quality of irrigation water, the perimeter's soil doesn't suffer any assignment by salinity. The relatively abundant rains in the region contribute also to the maintenance of soil salinity at this low level by leaching of salts.

3.7. Correlation between the underground water salinity and soil salinity

The figure 10 shows that there is a relationship between salinity of the groundwater and soil salinity for the campaign of autumn 2014 (r = 0.73). Indeed, the rise of the groundwater salinity affects negatively the soil composition. Thus, more salinity of the groundwater is high more soil salinity increases.

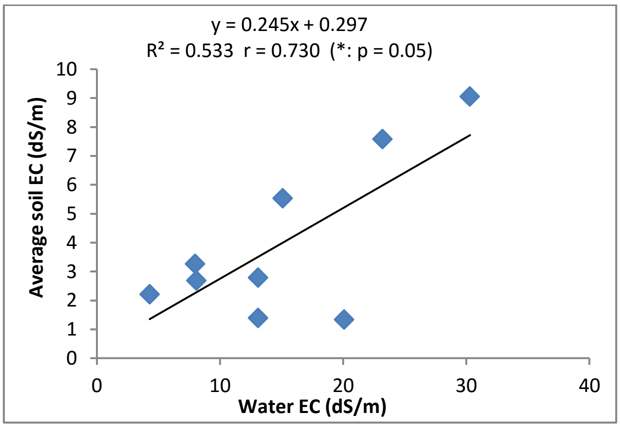

Figure 10: Correlation straight line between the underground water salinity and average of soil salinity (in autumn 2014)

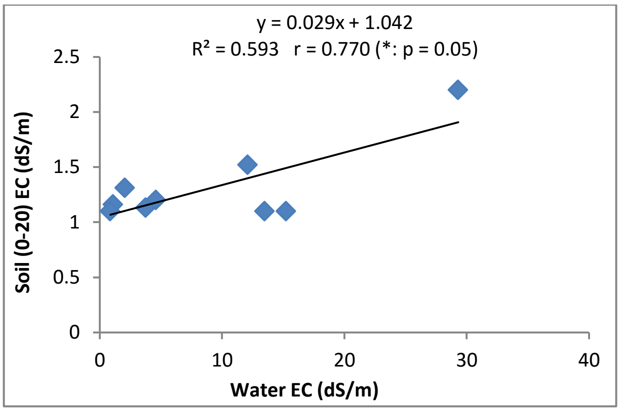

Figure 11: Correlation straight line between the underground water salinity and soil salinity of the horizon (0-20 cm) (in Spring 2015)

For the campaign of spring 2015, there is a positive correlation (r = 0.77) between the underground water salinity and the soil salinity only for the horizon (0-20 cm). This is explained by natural phenomena having direct influence between salinity of the groundwater and the soil salinity; the upper soil layers are affected by capillary rise from this groundwater (Figure 11).

3.8. Interaction between soil and underground water salinities and plant production

For the purpose of establishing a relationship between soils characteristics and plant production, we conducted an investigating from the owners of the plots where we have sampled the soils. Indeed, there is a good correlation between the average of soil salinity and yield of artichoke (*Cynara scolymus* L.).This relationship shows that beyond a low conductivity threshold, the crop will decrease steadily with soil salinity (Figure 12). However, salinity and groundwater levels have strong negative effect on the yield of the crops.

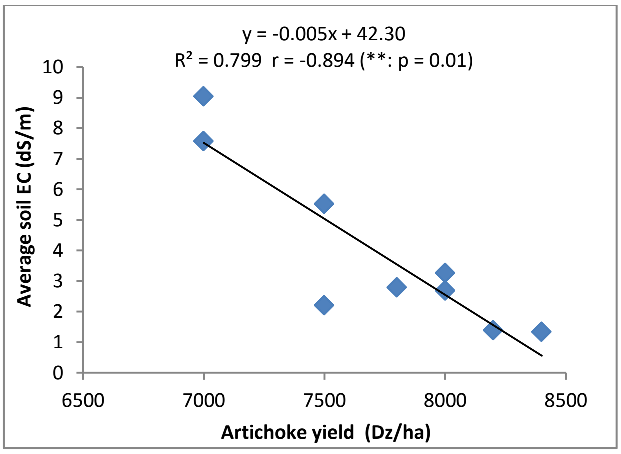

Figure 12: Correlation straight line between the average of soil salinity and yield of artichoke capitulates (campaign 2014)

4. Discussion

Irrigated agriculture is threatened by soil salinity in numerous arid and semiarid areas of the Mediterranean basin (Aragüés *et al*., 2011).This study is interested in synthesizing the diagnostic results of the halomorphy and waterlogging in the irrigated perimeter of "Henchir Tobias". This irrigated perimeter covers 1450 hectares overall, with texture soils ranging from clay to clay-silt. The low slope, fine texture, surface water table and its location in the vicinity of Mejreda river basin, increase the risk of salinization and waterlogging mainly during the winter seasons.

In this irrigated perimeter, a drainage system was set up as part of a soil protection strategy but, unfortunately, this drainage system is, sometimes, inefficient. In Tunisia, all drainage systems installed in irrigated areas, require maintenance after their establishment (FAO, 2002). For the management of salinization and waterlogging, a combination of agricultural management techniques are used, the first being modern methods of irrigation and drainage (Hachicha and Ben Aissa, 2014). In order to fight against the stagnation of surface water in soils suffering from waterlogging, it is essential to clean the pipes of the drainage network. Proper drainage will allow control of the water table, limiting capillary rise and creating an underground stream for discharging excess salts out of the perimeter. This allows a good root system development and uptake of fertilizers by plants (Fausey *et al.*, 1987; Chandra *et al.*, 1997). The results obtained show that, in the majority of cases, the correlations are not significant, but with correlation coefficients approaching the significance level at (n-2) degrees of freedom. This is valid both for the depth of the water and soil salinity. There is a relationship between the groundwater salinity and soil salinity for the campaign of autumn 2014 explaining that soil salinity is linked to salinity of the groundwater. However, the addition of water and amendments to the soil, like fertilizers, can affect the soil salinity. Some animal manure contains salts that can increase the soil salinity (Tanji and Kielen, 2002). The dose and frequency of the irrigation water can also have an effect on soil salinity wich is also affected by the water movement at the surface and depends on the irrigation method (CRUESI, 1970). According to Ferjani *et al.* (2013), 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 accumulation on the soil surface may be on the rise after long-term application of drip irrigation. Soil salinization is mainly a result of evaporation that removes the water from the soil but leaves the salts (Corwin and Lesch, 2005). When salts, like dispersive cations, accumulate in the soil, the clay swells and the pores in the soil and the soil structure are changed. This affects the soil permeability and the water retention negatively (Keren, 2000). The soil salt accumulation increases with increasing salinity of irrigation water (CRUESI, 1970). Thus, addition of organic matter to soil can affect the soil salinity. At high rates of organic manure addition, the soil salinity could increase (Haynes and Naidu, 1998). However, the organic matter also, has positive effects on the soil properties. The water holding capacity and the infiltration rate increases while surface crusting and runoff decreases (Haynes and Naidu, 1998). These effects from organic matter on soil properties could lead to a higher soil leaching which could lead to a decrease of soil salinity. Soil salinity is a major abiotic factor that affects both crop production and crop quality. Most crops have a negative reaction to a too saline environment (Chinnusamy and JZhu, 2004). The osmotic pressure in the soil solution in the root zone, increases with salinity and it becomes more difficult for the plants to take up enough water. This leads to water stress and the farmer can experience a yield loss (Tanji and Kielen, 2002).

Conclusion

The present work was realized in the irrigated perimeter of Henchir Tobias in northeast of Tunisia. The measurements were carried out in Autumn 2014 and Spring 2015. In Spring 2015, a water table depth less than 1 meter occupies 72% of the area of the perimeter. Only 15% of the total areas have a water table depth greater than 1.2 meters. The higher salty part of groundwater is located within the center of the irrigated perimeter. But, in autumn of 2014, almost the surfaces of the groundwater are characterized by an electrical conductivity greater than 12 dS/m. In 2015, we found a low soil salinity and homogeneous spatial distribution on the whole irrigated perimeter. In 2014, only part of small area (<5%) in north-eastern perimeter, has very high salinity. Outside this part, the soil salinity is generally low to medium. However, if the halomorphy doesn’t affect the studied area, waterlogging has net effect despite the existence of a network of drains in place. These effects are manifested by the presence of more or less prolonged waterlogging areas. Water stagnation is the result of a malfunction of the drainage network, the low permeability of the soil resulting from a fine texture of the irrigated perimeter and almost flat topography does not favor the external drainage of accumulated water. To assess the effect of the underground water level and its salinity on soil salinity, simple correlation tests were established between variables couple’s existing. The results expressed by the determination and correlation coefficients showed generally few significant relationships but reflect the occurrence of partial links between the two variables of the water table and soil salinity. Soil salinization from the water table is not direct and total, but often partial. Soil salinity has negative effects on the soils productivity of the irrigated perimeter. There was a negative correlation between the average of soil salinity and yield of artichoke.

It is possible to make the irrigated perimeter and similar areas in Tunisia and the world, better functional and more productive for a set of measures including the rehabilitation of the drainage network, the correct management of irrigation schemes, the organic amendment of soils and the rational fertilization.

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