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Effects of Underground Water on Soil Salinity and Dates Production in Kebili Oases Area (Tunisia): The Case of El Bahaier Oasis

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Summary: *The risks of increase of the level of the salted underground water and its salinization effect on the soils in oasian creations are inescapable because of their altitude which is very close to that of the next salted depressions. To control this phenomenon, some monitoring points called piezometers were installed in these perimeters, among them the one of El Bahaier located at the north of Kébili city in Tunisia and being the subject of the follow-up of the current study. Two measurement operations of the level of the underground table and its salinity were carried out in the functional piezometers of this oasis in march and april 2011; in parallel, two series of soils samples were taken around these same piezometers on a depth of 1 meter. The determination of the salinity of these soils samples showed that the most waterlogged zones are those which are salinized explaining as well as the increase of the underground water level is a principal cause of the soils salinization in these zones known by their high potential evapotranspiration and very weak rainfall. This observation is confirmed by the correlation tests between various couples of parameters, where the correlation coefficient r was generally high and significant.*

Moreover, the effect of the waterlogging and the soils salinity on the output of the principal culture practised in this perimeter, the date palm (Phœnix dactilifera), was highly significant. The improvement, the clearing out and the cleaning of the drains are necessary to push the level of in-depth subsoil water more and to relieve the trees of its negative effect on their production. However, an optimal level of this water table located at 2 meters of depth would be more beneficial on the yield.

Keywords*: groundwater, soil, oasis, salinization, waterlogging, Tunisia.*

I. Introduction

Salinization of irrigated soils in arid areas, which can be described as secondary salinization because it occurs due to irrigation activities, may have a double origin: (i) irrigation waters which, despite their varied salt concentrations, deposit at long-term significant amounts of salts in the growth zone of roots of cultivated plants, (ii) underground water often salty, approaching the soil surface after receipt of excess irrigation water for salts leaching, communicate to the surface horizons of soil salts dissolved therein. This second category of salinization is usually the most dangerous due to high water concentrations of these layers and also the capillary active in environments with high evaporation. FAO (2006) estimated that the world loses an average of 3 hectares of farmland per minute by salinization and financial losses caused by the degradation factor amount to 250 $/ha.

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). The second case is that of continental oasis of Jerid and Nefzaoua which are located around the big Chott Jerid and Gharsa salt lakes, situations where the difference in elevation between the saline lake and the oasis are low causing difficulties for groundwater discharge (Ben Aissa et al, 2004; Marlet et al, 2007). Almost stagnant waters of the watertable are a constant source of salts to the soil in which the solutions become more concentrated and the osmotic pressures are increasing causing more difficult conditions of absorption of moisture and nutrients. The date palm culture which adapts to conditions of high summer temperatures and high salinities is the main species in these oases, often accompanied of two shrub and herbaceous (vegetable) strata (Job and Marai, 1990). It assumes important roles in the social, economic and ecological aspects (Kadri and Van Ranst, 2002; Belloumi and Matoussi, 2007). It participates in the economic activities of the country (Tunisia) by the production of 102 000 tons of dates (Kadri and Van Ranst, 2002). Its safeguarding and protection against degradation factors and in particular against salinization and waterlogging of soils becomes a necessity. The first steps in this protection are installation of drainage systems for evacuating away from the oasis, excess water and salts (Côte, 1998), the proper management of irrigation water (Legros, 2009 ; Marlet, 2004; Marlet et al, 2007)

and especially monitoring and periodic controls of the evolution of the underground water and soil salinity (Hatira et al, 2005).
Programs to monitor the evolution of soil salinity and underground water levels are set up in almost all oases subject to the effects of waterlogging and salinization. This monitoring is carried out by using piezometers, which are distributed in a way to cover well the perimeter controlled in terms of its surface and its waterlogged area. The current study retains one of these controlled oases, which is El Bahaier, located at the north of Kebili city in the Nefzaoua region (South of Tunisia). It is situated in the basin flow area of Chott El Fejaj. The measurements carried out in spring 2011 had for objective to assess the impact of the underground water level and salinity on soil salinity and also on the date palms production.

II. Materials And Methods

Location and environmental conditions of the study area

The oasis of El Bahaier covers an area of 40 ha at 31 km north-east of Kebili city in South of Tunisia (figure 1). It takes place between the south Tebaga relief and the north salty depression of Chott El Fejaj. Its location at an altitude close to that of the saline lake, makes that gravity underground water flows are quite slow, which favors the stagnation of excess water and the creation of waterlogging conditions. This oasis is planted with three vegetative strata : date palms (*Phoenix dactilifera*) aged ten years, whose density varies between 93 and 100 plants / ha, fruit trees like olive, pomegranate, fig, grapevine and yearly herbaceous crops consisting of forage and vegetable cultures. Annual rainfall of the area does not exceed 100 mm and annual potential evapotranspiration measured by the Thornthwaite formula is nearly 1300 mm (Kadri and Van Ranst, 2002; Marlet et al, 2007).

Figure 1- Location of Tunisia and the studied region in North Africa (wpmap.org)

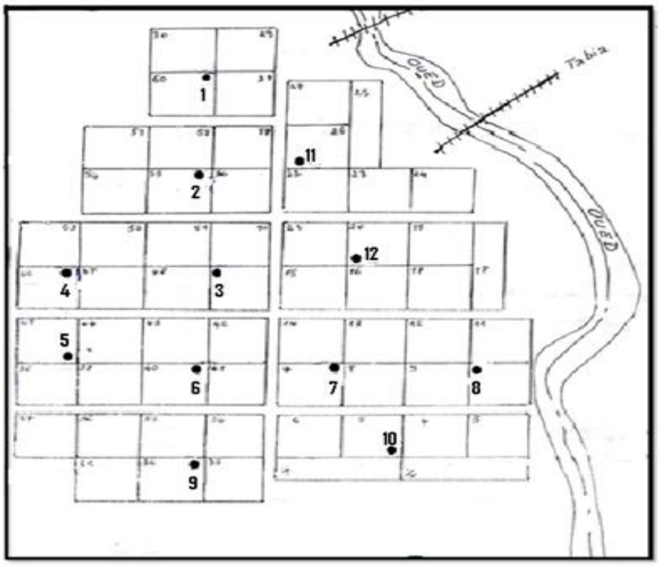

Figure 2- Land plot plan of El Bahaier oasis and location of the piezometers

This oasis is irrigated from a borehole capturing the deep aquifer of the intercalary Continental, whose concentration of salts is close to 3 g/l. Excess irrigation water caused the rise of the topped watertable level. The installation of an open drainage system helped to keep this shallow groundwater in a steady state. To control the evolution of the level, 12 piezometers were located in a fairly homogeneous throughout the perimeter (figure 2). A piezometer is a cylindrical tube of metal or PVC, 8 cm in diameter and 3 m in length, which is drived down into the soil to 2,5 m depth. It is strainer on the bottom half so as to allow the penetration of water from the underground water for measuring level or sampling.

The soils of the oasis

The soil covering the oasis land is gypsiferous and encrusted alluvial deposit, salty in the deep horizons. Salinity increased after starting irrigation in the perimeter. When the crust is superficial, it is a gypsum-limestone type. The surface horizon of 30 cm thick and sandy-loam texture is covering a gypsiferous sandy and encrusted material.

This soil can be classified as “calcimagnésique gypseux” (CPCS, 1967) or Haplic GYPSOSOL, limestone with gypsic horizon in depth (AFES, 2008). To soil taxonomy, we can classify it among aridisols : gypsiorthids (SMSS, 1985).

Field work

Two measurement campaigns of the water level and salinity were carried out in eight functional piezometers in march and april 2011, four piezometers were indeed damaged when passing gear tillage. Level was measured using an electric probe and the sample was taken using a small container attached to a rope. Measuring salinity was performed directly on the field using a portable conductivitymeter.

Meanwhile, two series of soil samples were carried out during the same periods around the eight functional piezometers. Sampling was carried out with auger every 20 cm to a depth of 1 meter. In total, 80 soil samples were collected during two campaigns. The measurement of soil electrical conductivity (EC) was performed on a saturated paste extract.

The economic aspect was associated with the technical study through a survey on the average yield of a date palm tree during the precedent crop, in parcels which were conducted level and salinity measurements of the groundwater and also the salinity of the different soil horizons.

Statistical calculations

Data from the two measurements in march and april 2011 were expressed by their average. Then, the variation between the values of different points was illustrated by calculating the average of the standard deviation and coefficient of variation. The study of the impact of various measured parameters on each other was performed by calculating the correlation coefficients for each pair of values of the parameters taken pairwise.

III. Results

Level and salinity of the underground water

The water level varied between 113,5 cm and 251cm. The average of all points was 168,44 cm with a standard deviation of 60,98 cm and a coefficient of variation of 36,21% (table 1). Points where the level seems closer to the surface are those numbered 1, 3, 4 and to a lesser extent the point 5. The salinity of the water is high in points 1 and 4, moderate in 3, 5, 6 and 7 and quite low in points 8 and 11 (table 1). It seems quite clear that the higher is the level distance from the surface, the greater the salinity decreases and vice versa. So, underground water is more concentrated in salts when approaching the surface.

Table 1- Averages of the two measures of the studied parametrs, carried out in march and april 2011

Piezometers numbers	Level of the water cm	EC of the water mS/cm	Electric conductivity (EC) of saturated paste extract (mS/cm)						Yield kg/tree**
			0-20cm	20-40cm	40-60cm	60-80cm	80-100 cm	Average EC*	
1	119,5	8,31	11,77	9,82	8,48	8,08	8,20	10,42	30
3	113,5	5,55	8,25	5,90	6,58	5,46	5,27	7,09	30
4	117,5	7,57	5,47	5,59	5,92	5,99	5,06	5,56	40
5	130	4,53	5,11	4,90	4,88	4,76	4,17	4,95	55
6	144	5,35	4,61	4,58	5,07	4,37	3,59	4,58	60
7	234,5	5,70	3,95	3,22	3,57	3,98	3,51	3,69	60
8	251	3,18	3,82	3,37	3,69	3,89	3,71	3,69	65
11	237,5	3,61	6,13	4,95	4,49	4,04	3,80	5,35	60
Average	168,44	5,47	6,14	5,29	5,33	5,07	4,66	5,66	50,00
$\sigma/n^{0,5}$	60,98	1,78	2,68	2,06	1,63	1,43	1,58	2,21	14,39
CV %	36,21	32,49	43,63	38,95	30,56	28,20	33,86	39,02	28,78

* Average EC = $(2*EC_{0-20} + EC_{20-40} + 0,5*EC_{40-60} + 0,25*EC_{60-80} + 0,25*EC_{80-100})/4$ (CRUESI, 1970)
** Yield of crop 2010 obtained by a survey with the farmers

Soils salinity

Points 1 and 3 are characterized by higher salinity which reaches respectively 11,77 and 8,25 mS/cm in the surface horizons. It remains high in the underlying horizons, but the saline profile is ascendant. The lowest values are observed in points 7 and 8 where saline profiles are vertical. Points 4, 5, 6 and 11 are intermediate salinity, which is near to 5 mS/cm, their profiles are generally vertical saline, except for point 11 where the salinity of the surface horizon is significantly higher than those of other layers (table 1). The lateral and vertical distribution of salts reveals that there is, a priori, relationship between the underground water level and soil salinity and over the water approaches the surface, the more saline profile tends to become ascendant. The highest value of the coefficient of variation is observed in the surface horizon (0-20cm) followed by the deep (80-100cm), the lowest variation corresponds to the horizon 60-80cm with a value of 28,20 %.
Salinity of the oasis soils, especially important around piezometers 1 and 3 where the level of underground water is closer to the surface, should act negatively on the production of date palm. Indeed, the lowest yields were obtained near of the most waterlogged and salty soils.

Effects of underground water on soil salinity

Underground water acts on the soil by the rise of its waters through capillary porosity at a height which varies depending on the texture, this rise is the most active in loamy soils (Ben Hassine, 2005). The correlation coefficient (r) between the underground water level and soil salinity is always less than -0,5 explaining that there is a more or less significant correlation between the two parameters. Indeed, the greater the depth of the water decreases as salinity increases, which explains the negative value of r. The most significant correlations (threshold 0,05 at n-2 degrees of freedom) were obtained for levels 40-60 cm and 60-80 cm (table 2).

Table 2- Correlations matrix between the measured parameters

	Water level cm	EC water mS/cm	EC (0-20) mS/cm	EC (20-40) mS/cm	EC (40-60) mS/cm	EC (60-80) mS/cm	EC (80-100) mS/cm	Average EC mS/cm	Yield kg/tree
Water level cm	1								
EC water mS/cm	-0,677	1							
EC (0-20) mS/cm	-0,540	0,622	1						
EC (20-40) mS/cm	-0,633	0,723*	0,960***	1					
EC (40-60) mS/cm	-0,775*	0,773*	0,933***	0,963***	1				
EC (60-80) mS/cm	-0,700*	0,858**	0,884**	0,953***	0,954***	1			
EC (80-100) mS/cm	-0,588	0,766*	0,941***	0,966***	0,942***	0,978***	1		
Average EC mS/cm	-0,600	0,685	0,993***	0,985***	0,962***	0,929***	0,966***	1	
Yield kg/tree	0,771*	-0,759*	-0,835**	-0,808*	-0,910**	-0,866**	-0,846**	-0,851**	1

* : significative correlation at threshold 0,05, with 6 degrees of freedom (n-2)
**: significative correlation at threshold 0,01, with 6 degrees of freedom (n-2)
*** : significative correlation at threshold 0,001, with 6 degrees of freedom (n-2)

Salinity of the underground water and salinity of soil horizons are better correlated since the electrical conductivities of the last four horizons (20-100cm) are significantly related (thresholds 0,01 and 0,05) to the water salinity (table 2). The salt concentration of the water would have obviously an effect on the accumulation of salts in different soil depths and particularly in the 60-80cm layer. Only the surface horizon has no significant relationship with the water salinity probably because firstly of its location farther and secondly for receiving permanent irrigation water that disrupts this relationship.

The average salinity is not significantly related either to the depth of the water nor its salinity. It more or less reflects the values of the surface horizon, that are doubled in the calculating formula of the average value on each sampling point.

We must not omit to mention the very highly significant correlations between salinities of various soil horizons (table 2), which reflects the inter-communicating salinity in the profile even between the most distant horizons (0–20 cm and 80-100 cm).

Effect of underground water on the yield of date palm

The date palm yield increases when the water level move away from the soil surface, to a certain limit. Indeed, the correlation curve which is polynomial and has a high coefficient of determination R^2, increases to the level of 75,8 kg/tree and then relapse again explaining that when the water is too far from the surface, the palm tree bends in production (figure 3). The level at which yield begins to decrease is 199 cm, that is equal to approximately 2 meters. It draws the consequence that the date palm produces better when the water is at 2 meters; going up or away from the optimal level, the underground water would have a negative effect on the production of this species.

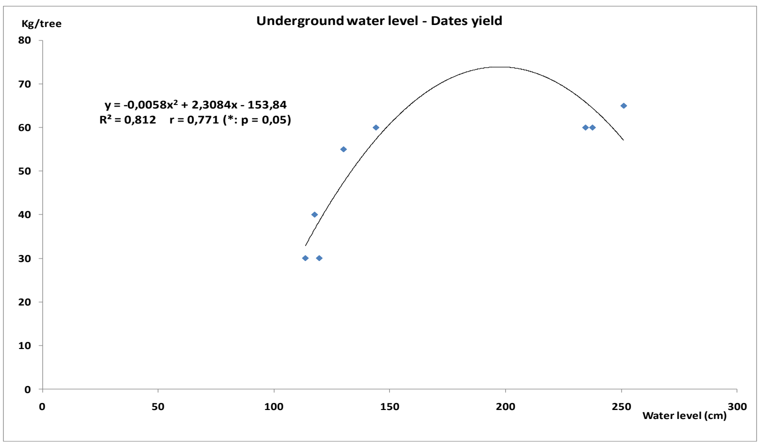

Figure 3- Correlation curve between the underground water level and yield of palm trees

For the relationship between the salinity of the water and the dates yield, it is illustrated by the linear equation of the form -ax + b (figure 4). The shape of the right means more than the water salinity is increasing the yield decreases. The relationship is significant at the 0,05 threshold. The highest concentration of salts in the underground water should create more difficult conditions of water supply and extreme toxicity for the root system of the tree.

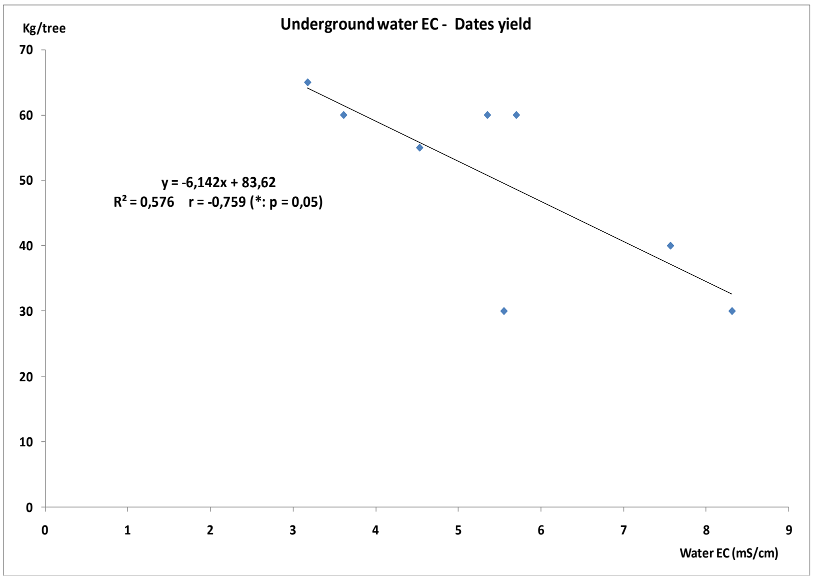

Figure 4- Correlation straight line between the underground water salinity and yield of palm trees

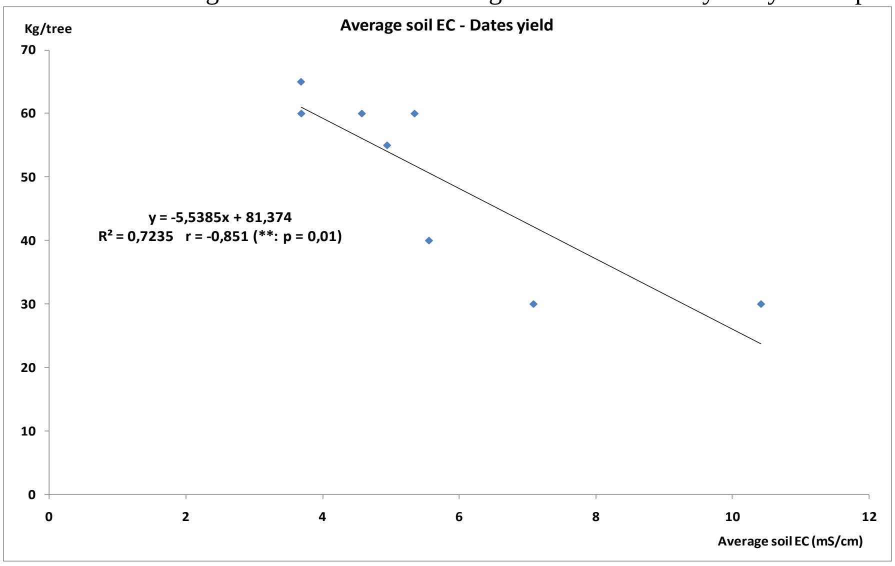

Figure 5- Correlation straight line between the average of soil salinity and yield of palm trees

Effect of soil salinity on the yield of date palm trees

Almost all horizons showed a significant correlation between their salinity and the yield of date palm trees (table 2). To illustrate this correlation in one figure, it has been realized between the average soil salinity and yield (figure 5). The right is of the form -ax + b, and that means more soil salinity increases, yield decreases, which should reflect the difficulties of tree nutrition in solutions highly concentrated in salts.

IV. Discussion

The oasis of El Bahaier, although located outside the basin Chott El Jerid, has climate, soil and crop similarities with all those of the Nefzaoua region. Indeed, low rainfall, the very high potential evapotranspiration, soils enriched in gypsum and the proximity of saline depressions are common criteria for almost all oases of this region. Their irrigation by deep water, little or not related to groundwater, produces the rise of the water level causing both waterlogging and salinization. The installation of drainage systems has decreased at a certain depth of the underground water, but their conception as open ditches reducing their effectiveness evacuation of water excess, was behind the creation waterlogged and saline areas in these oases. This impacts on soils and crops. Indeed, the water table is not static and moves by ascendant movements by following the capillary pores of the soil. These movements are also accompanied by those of the salts dissolved in the groundwater which is more concentrated by receiving leaching waters passed through the soil (FAO, 2006).

The results obtained in this study can conclude that the effect of the underground water is evident on soil salinity both by the depth of its level or concentration of salts in its waters. The accumulation of salts in the soil is not only a degradation factor acting negatively on their physico-chemical properties but is an indication of loss of fertility of these soils (Legros, 2009) and a weakening of the balance of the oasis system which sustainability is threatened (Ben Aissa et al, 2004).

These conditions of waterlogging and salinity affect the trees of the main crop produced in these areas characterized by specific soil and climatic conditions, disrupting their nutrition solutions with high osmotic pressures. Such conditions negatively affect the physiology of the tree which reacts in two ways (Kadri and Van Ranst, 2002):

- A decrease in tree vigor by reducing the height, diminution of trunk circumference and number of green palms.
- A significant reduction in the production of the trees and the quality of dates.

The yields decrease was demonstrated by the results of this study and also by those of Daddy Bouhoun et al (2011) and Zidi (1997). Yield is indeed negatively affected by both the rise of the groundwater level, the salt concentration and high salinity of soils. Daddy Bouhoun et al (2011) identified an additional factor which acts negatively on the yield; it is the presence of a crust of compact gypsum horizon in the root zone. The proper functioning of the drainage system and the possibility of its improvement that would lead to permanent removal of the underground water to 2 meters deep, would be a solution to both reduce the risk of capillary rise from concentrated groundwater and to not deprive the roots of the date palm trees from a beneficial source of moisture.

The case studied is one of many similar cases of soils salinization around Nefzaoua chotts on initially low salted soils; this process leads to a lateral extension of waterlogging and salinization. It is a kind of human and progressive endoreisation (Mhiri et al, 1998) which extends the vast land of saline area in the region. More rigorous management of irrigation water and soil (Cheverry and Robert, 1998) across the entire watershed basin of Chott El Jerid is to adopt in order to minimize the spread of salinization and save resources by preserving available soils against all forms of degradation.

V. Conclusion

Problems of waterlogging and salinization of soils from saline underground water are common to all Nefzaoua oases concentrated mostly around saline depressions known locally as chotts. The oasis of El Bahaier is a representative example of these processes which are almost similar for the majority of irrigated area in the region. Altitude close enough to those of neighboring saline areas and using irrigation water pumped from deep aquifers often coupled with incomplete execution of a drainage system, make that the underground water rises progressively and will be distributed unequally in the irrigated area. The lower parts of the oasis suffers a more pronounced engorgement which leads to soil salinization. Indeed, the soil is more salty near the points where the water is closer to the surface. Statistical correlations have also confirmed this relationship because the underground water level and its salinity were almost always highly correlated with soil salinity. These degradation parameters of soil quality have impacted negatively on the main agricultural production in the region, the dates palm tree whose yield was lower in salinized and waterlogged areas. The relationship between the underground water level and the yield was realized by a polynomial equation which showed that date palm does not provide the best production in a highly waterlogged and salty zone but prefer not survive in a dry environment with low moisture in depth. An underground water level maintained at 2 meters depth would be an optimal situation.

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