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SALT TRANSFER UNDER IRRIGATION WITH TREATED WASTEWATER IN SEMI-ARID TUNISIA

Salttransport under bevattning med renat avloppsvatten i norra Tunisien

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Abstract

Tunisia is a country with limited water resources and is in need of irrigation to sustain the agriculture. Treated wastewater is used as an irrigation water source in some areas. The use of saline treated wastewater can lead to soil salinization which could pose a serious threat to the agriculture. A field study was performed on a citrus tree field outside the city of Nabeul, Tunisia, to investigate the effects on soil salinity after irrigation using treated wastewater and after rainfall. Electromagnetic induction readings (EM38) in combination with hand auger soil sampling were performed to produce maps over soil salinity (ECe) over this field. This field cannot be considered as saline, the ECe is less than 4 dS/m. However, the observed salinity can still affect the citrus production in a negative way. No clear increase in salinity after irrigation could be seen, although it was expected according to theory. This can be due to the inclination of the field or the irrigation practices. The rainfall might have leached the upper layer in the soil but not the deeper layers where the salinity increased. Further studies are needed to make any clear conclusions about the effects on soil salinity in this field.

Key words – Tunisia, soil salinity, treated wastewater, irrigation, EM38, ECe, agriculture, irrigation efficiency, soil salinity assessment, ESAP

Sammanfattning

Tunisien är ett land med begränsade vattenresurser och är i behov av konstbevattning för att upprätthålla jordbruket. Renat avloppsvatten används till konstbevattning i vissa områden. Användandet av salt, renat avloppsvatten kan leda till försaltning av jorden vilket kan innebära ett allvarligt hot mot jordbruket. En fältstudie genomfördes på ett citrusfält utanför staden Nabeul, Tunisien, för att undersöka effekten på salthalten i marken efter bevattning med renat avloppsvatten och efter regn. Mätningar med elektromagnetisk induktion (EM38) i kombination med handborrade jordprover användes för att producera kartor över salthalten (ECe) på detta fält. Fältet klassas inte som salt, ECe är mindre än 4 dS/m. Dock kan den observerade salthalten ändå påverka citrus produktionen negativt. Ingen tydlig ökning av salthalten efter konstbevattning kunde ses även om detta förväntades enligt teorin. Detta kan ha många orsaker, till exempel lutningen på fältet eller konstbevattningsmetodiken. Regnet kan ha urlakat den övre jorden på salt men inte den undre, där salthalten istället har ökat. Ytterligare studier behövs för att kunna dra några tydliga slutsatser om effekten på salthalten på detta fältet.

Introduction

Tunisia is a semi-arid country located in North African. The country has limited water resources, and the people living in Tunisia can expect a decrease in water supply in the future due to environmental changes (Qadir, et al., 2010). In arid and semi-arid areas, irrigation is of highest importance to ensure a functioning agricultural sector; many people depend on agriculture to support them and their families. The agricultural sector in Tunisia currently uses around 80 % of the available water resources in the country (Bouksila, 2011), and is therefore vulnerable to a decrease in water supply. To meet an increasing demand of water, treated wastewater as an irrigation water source was introduced in the 60s (Bahri, 2000). Treated wastewater is expected to account for 10 % of the total available water resources by the year 2015 (Al Atiri, 2005), and can thus be considered an important water resource. In Tunisia, 97 % of the collected wastewater is treated in public wastewater treatment plants and the larger part of the water is released into streams and the sea (ONAS, 2010). According to Qadir et al. (2010), Tunisia is a country well-developed in using treated wastewater and approximately 8 100 ha of agricultural fields are irrigated using treated wastewater.

The quality of the treated wastewater used for irrigation is regulated according to Tunisian restrictions which approximately follow guidelines from FAO (1985) and WHO (2001). The treated wastewater contains nutrients that can benefit the agriculture by its fertilizing value and improve the harvest. However, the water often also contains salts that can be harmful to the soil and crops subjected to irrigation using treated wastewater by causing soil salinization. The salts present in the treated wastewater could depend on many factors, i.e. seawater intrusion, a large proportion of industrial wastewater or location of the wastewater treatment plant (Bahri, 1998).

Soil salinization is a serious problem and poses a threat to agriculture with its devastating consequences like crop failure and soil degradation. Soil salinization is mainly a result of evapotranspiration that removes the water and leaves the salts to accumulate in the soil (Corwin & Lesch, 2005). The soil salinity increases with increasing salinity in the irrigation water (CRUESI, 1970), and thus the risk of soil salinization is larger when using treated wastewater. In Tunisia today, 30 % of the irrigated areas are highly sensitive to salinization (Bouksila, 2011). However, it is possible use saline water for irrigation purposes if proper irrigation and soil salinity management exists (Bouksila, 2011), and for this the soil salinity needs to be assessed and known for a specific agricultural field. After the assessment it is possible to form a management plan to diminish the risk of severe soil salinization. A soil salinity management plan can include good irrigation scheduling, drainage and leaching practices (USSL, 1954).

Measuring soil saturation extract salinity (ECe) of soil samples taken at many locations to assess an entire agricultural field is costly and inefficient. Therefore the measurement of the apparent electrical conductivity (ECa) using electromagnetic induction is the most common way to measure soil salinity. However, the standard way to express soil salinity is still ECe and therefore a conversion from ECa to ECe is needed when assessing soil salinity (Corwin & Lesch, 2005). ESAP (vs. 2.35, Lesch et al. (2006)) is a software package that provide tools for assessing soil salinity using a combination of electromagnetic induction, measured with an EM38 (Geonics Ltd, Ontario, Canada), and a small amount of soil samples taken at representative points in the field. ESAP can convert ECa to ECe and produce soil salinity maps using statistical or deterministic models included in the programs.

The studied area, outside the city of Nabuel in northern Tunisia, has semi-arid climate and the agricultural fields often need to be irrigated. Due to water shortages and very saline groundwater, treated wastewater is used as irrigation water source in this irrigation district. However, this water contains salts and is often of poor quality, since the local wastewater treatment plant is currently not functioning perfectly; the inflow of wastewater greatly exceeds the capacity of the plant and some treatment steps are broken. This, in combination with poor farmer practices, results in high risk of soil salinization which can have an effect on the sustainability of the agriculture in this area. The objective of this field study is to assess the effects on soil salinity from irrigation with treated wastewater and from rainfall on one agricultural field.

Method

Study area

This field study was conducted in September and October 2012 in an agricultural field outside the city of Nabeul. The average temperature in this area is 26°C during the summer and 15°C during winter. It rains annually about 455 mm and the annual potential evapotranspiration is about 1200 mm. The climatic data is based on observations from the Oued Souhil weather station, close to the studied field.

The studied field is about 0.35 ha, with both olive and citrus trees being cultivated. However, it is only the citrus trees that are irrigated. In total there are 104 citrus trees and 42 olive trees that are equally spaced 4 m apart. The field is irrigated using basin irrigation with treated wastewater, which has an electrical conductivity of about 3.0 dS/m. The salt tolerance for citrus trees is approximately 1.3 dS/m. The field is irrigated 6 times every year. The total amount of added water, including irrigation and rainfall, during September and October was 220 mm and 230 mm, respectively. The field has a small inclination towards the south and the groundwater level is below 5 m.

Field measurements

EM38 readings were taken by each of the 104 citrus trees, in both a horizontal (EMh) and vertical (EMv) coil position. To convert the EM38 readings to the reference temperature 25°C a WET sensor was used to measure the temperature down to 0.9 m depth. At the same time representative soil samples were taken at 7 points over the field for EM38 calibrating purposes. The soil samples were taken with a hand auger at 0.3 m increments down to 1.5 m depth. Also, the bulk density was measured at some of the representative points in the field using standard methods (USSL, 1954). The soil samples were dried and sieved (<2 mm) and analyzed for ECe, soil water content (θ), pH, pF and soil particle size in a laboratory according to standard methods (USSL, 1954 and Dane & Hopmans, 2002). These procedures were repeated three times; for initial conditions, after two irrigation events and after a period of rainfall (57.5 mm). The first campaign was performed in the middle of September, the second in the middle of October and the last one in the beginning of November. The campaign following irrigation took place approximately 3 days after the second irrigation event and each event added 640 m^3 of irrigation water to the field.

Data analysis

The EM38 readings and ECe values were analyzed using the ESAP software. Firstly the basic statistic parameters were analyzed. Secondly a calibration equation to convert EM38 readings to ECe was estimated using Multi Linear Regression (MLR) models. For these models log-transformed parameters were used (lnEMh, lnEMv, lnECe) together with trend surface parameters. An MLR model was decided for the depths 0–0.3 m, 0–0.9 m (the root zone) and 0–1.5 m. Based on best model fit (high R^2-value) the following MLR was used for all the depths

$$\ln(ECe) = b_0 + b_1(z_1) + b_2(z_2) + b_3(x) \quad (1)$$

where z_1 and z_2 are the decorrelated EM38 readings, that were used to eliminate the colinearity between the EM38 readings, and x is a surface parameter. The decorrelated EM38 were calculated according to

$$z_1 = a_1(s_1 - mean[s_1]) + a_2(s_2 - mean[s_2]) \quad (2)$$

$$z_2 = a_3(s_1 - mean[s_1]) + a_4(s_2 - mean[s_2]) \quad (3)$$

where, a_1, a_2, a_3 and a_4 are determined by the principal components analysis. A principal components analysis is a method of transformation to reduce the number of dimensions of the data (Härdle & Simar, 2007). s_1 and s_2 are the raw EM38 data. The surface parameter x was calculated according to

$$x = \frac{(u - \min[u])}{k} \quad (4)$$

where u = a local coordinate and

k = the greater of (max[u]–min[u]) or (max[v]–min[v]) (5)

where v = a local coordinate.

The models were validated using jack-knife predictions. Jack-knifing is a technique in which each known value is removed, one at a time, and the model is estimated based on the remaining values. The predicted value, based on this model, is then compared with, and plotted against, the true value, and so on until all known values have been removed. The resulting graph should display points close to a 1:1 line originating from origo (Lesch, et al., 2000).

Finally, using the decided calibration models ECe was predicted at the remaining unsampled points, with EM38 readings, for the three depths. These predicted ECe values were then used to plot the spatial variability of ECe over the entire field, by interpolation between the points.

Result and discussion

The basic statistical parameters for the EMh, EMv and ECe for the different data collecting campaigns can be seen in Table 1. The relatively low maximum and average ECe values in all the campaigns indicate that the soil in this field never exceeds 4 dS/m, and can thus not be regarded as saline soil.

Table 1. *The basic statistical parameters for the EM38 readings and ECe.*

Statistical parameters	Initial conditions			After two irrigation events			After rain		
	EMh (dS/m)	EMv (dS/m)	ECe (dS/m)	EMh (dS/m)	EMv (dS/m)	ECe (dS/m)	EMh (dS/m)	EMv (dS/m)	ECe (dS/m)
Average	0.38	0.51	1.88	0.42	0.53	1.40	0.344	0.482	1.83
Min	0.23	0.32	1.03	0.23	0.30	0.71	0.220	0.270	0.80
Max	0.65	0.90	2.35	0.70	0.91	1.96	0.058	0.820	2.77
Std	0.11	0.14	0.33	0.12	0.14	0.31	0.103	0.134	0.49

Table 2. *The model performance parameters displaying accurate model performance for all three campaigns.*

Model performance parameter	Initial conditions			After two irrigation events			After rain		
	0–0.3 (m)	0–0.9 (m)	0–1.5 (m)	0–0.3 (m)	0–0.9 (m)	0–1.5 (m)	0–0.3 (m)	0–0.9 (m)	0–1.5 (m)
R^2	0.89	0.96	0.95	0.98	0.97	0.97	0.90	0.95	0.98
PRESS Score	0.54	0.34	0.05	0.13	0.12	0.13	0.58	0.57	0.17
RSME	0.06	0.05	0.03	0.05	0.07	0.05	0.20	0.11	0.06

For each of the calibration models the R^2 values exceeded 0.89, thus these models explained >89 % of the soil variability in this soil at these depths. Furthermore, the PRESS scores and RSME are relatively low, which further indicates accurate models. These parameters can be seen in Table 2. Also, the validation with jack-knife predictions indicated accurate models.

It was expected that the salinity would increase after irrigation and then a decrease after rainfall. When comparing Figure 1–3 with Figure 4–6, and Figure 4–6 with Figure 7–9, it is not evident that this is the case and it seems difficult to observe a general decrease or increase. In some areas of the field the salinity has in fact increased after two irrigation events, but in other areas it has instead decreased. The most visual increase in soil salinity in the south part of the field might be due to the natural inclination of the field, irrigation practice or to lateral flow in the soil. However, when looking at the general

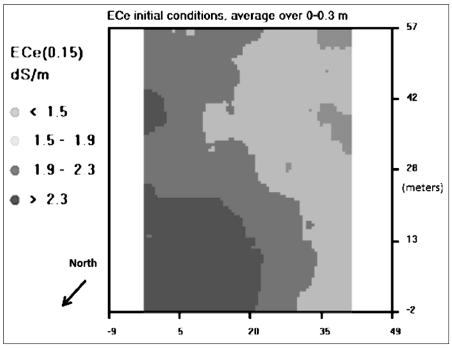

Figure 1. *The soil salinity distribution for the initial conditions, average over 0–0.3 m.*

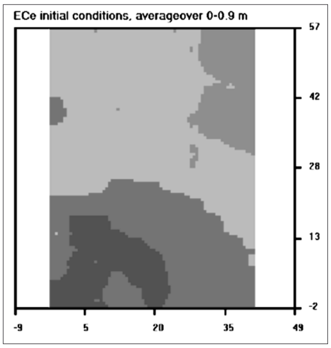

Figure 2. *The soil salinity distribution for the initial conditions, average over 0–0.9 m.*

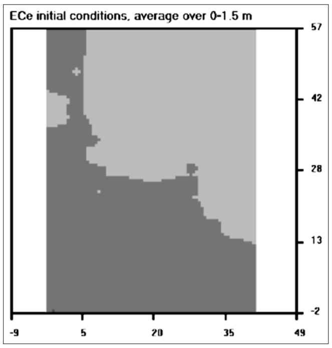

Figure 3. *The soil salinity distribution for the initial conditions, average over 0–1.5 m.*

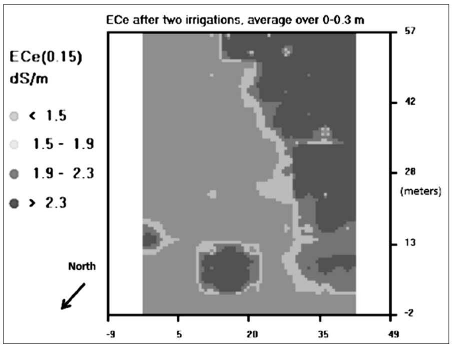

Figure 4. *The soil salinity distribution after two irrigation events, average over 0–0.3 m.*

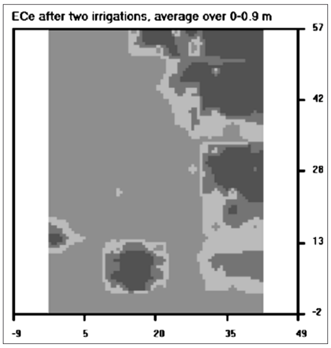

Figure 5. *The soil salinity distribution after two irrigation events, average over 0–0.9 m.*

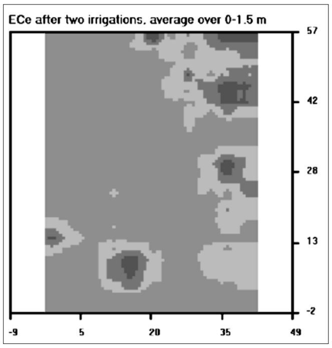

Figure 6. *The soil salinity distribution after two irrigation events, average over 0–1.5 m.*

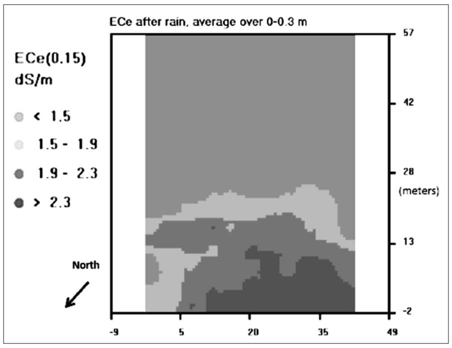

Figure 7. *The soil salinity distribution after rainfall, average over 0–0.3 m.*

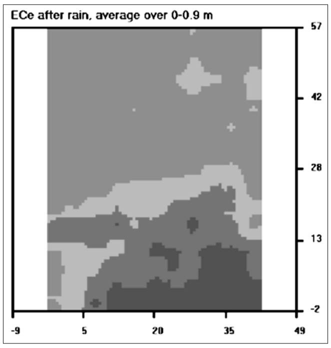

Figure 8. *The soil salinity distribution after rainfall, average over 0–0.9 m.*

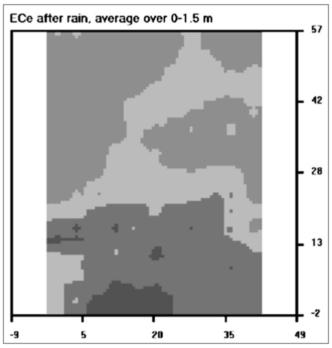

Figure 9. *The soil salinity distribution after rainfall, average over 0–1.5 m.*

soil salinity over the entire field it seems like the soil salinity has actually decreased from the initial conditions to after two irrigation events. This might indicate that the amount of added water during irrigation helped leach the soil of salts instead of to adding more salts. By evaluating the irrigation efficiency, it can be noticed that the farmer on this field irrigates too much. The calculated crop water need for citrus was about 94.8 and 31.4 mm in September and October, respectively, which is less than the added amount of water (220 and 230 mm).

Comparing Figure 4–6 with Figure 7–9 it seems like the rain have resulted in a general decrease in the soil salinity at 0–0.3 m depth, but in the deeper soils it is more difficult to see any clear change in salinity. An indication might thus be seen that the rain has leached the salts in the upper most soil. The salts leached from the upper most soil should have been transported to the underlying soil, however since the salinity in 0–0.9 m has not increased significantly one can draw the conclusion that some leaching has occurred also between 0.3 and 0.9 m. In the deepest soil salinity map, 0–1.5 m, one might see a small increase in the salinity, indicating that some of the leached salts have accumulated between 0.9–1.5 m. The accumulation might be due to the clay layer here, or that not enough water was added to leach the salts further down.

Figure 2, 5 and 8 displays the salinity in the root zone. This soil depth (0–0.9 m) was chosen because of its relevance when assessing the impacts on the citrus trees. In these figures it can be seen that a large amount of the field has an ECe above 1.5 dS/m. This means that a large amount of the field has an ECe above the salt tolerance for citrus, 1.3 dS/m. Even though, the soil in the field cannot be regarded as saline the crops can still greatly be affected by the existing salinity.

The results of this field study are not unequivocally. This mainly depends on the short period of time over which the study was conducted. Often, the results do not agree with theory which also indicates the need for further studies.

Conclusions

The field cannot be considered saline as the soil salinity never exceeds 4 dS/m. However, due to the low salt tolerance of the crops grown on the field, the salinity can still pose a threat to the fruit production. The local conditions, such as soil properties, irrigation practices and the inclination of the field can affect the soil salinity distribution caused by irrigation using treated wastewater. The results of this field study do not always agree with the theory of soil salinity. Further and longer studies are needed to find any clear relationships between the irrigation, with treated wastewater, and the soil salinity on this field. These further studies are also necessary to be able to draw any conclusions about the sustainability of this agricultural field.

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