沙漠研究 22-1, 65 -68 (2012 )
Journal of Arid Land Studies

"ICAL 1 / DT X"
―Refereed Paper―

# Effects of Treated Wastewater Irrigation on Soil Salinity and Sodicity at El Hajeb Region (Sfax-Tunisia)

**Monem KALLEL[*1)], Nabil BELAID[1)], Tarek AYOUB[2)], Abdelmonem AYADI[3)] and Mohamed KSIBI[1)]**

**Abstract:** The increasing scarcity of water in the world on one hand and the rapid population growth in urban areas on the other require the use of appropriate water management practices. Treated wastewater reuse may be considered as an additional water resource, especially important in arid and semi-arid countries. In arid regions such as near Sfax (Tunisia), treated wastewater effluents (TWE) are often applied as agricultural irrigation. Irrigation TWE usually contains large amounts of fertilizing elements. The objective of this study was to evaluate the impact of TWE irrigation on soil salinity and sodicity. In the city of Sfax, two sites were selected with two soil types (fluvisol and calcisol) having been irrigated for 4 and 15 years, respectively. Irrigated and non-irrigated study soils were analyzed for pH, nitrate and ammonia, electrical conductivity (ECs), exchangeable sodium percentage (ESP), sodium absorption ratio (SAR) and soil organic matter. The fluvisol, irrigated for only four years, is more affected by salinity than the calcisol irrigated for 15 years. In the upper fluvisol layer irrigated by the treated wastewater, ECs reach 8 mS cm$^{-1}$ and ESP a value of 15% while in all layers of the calcisol, ECs and ESP are lower and rarely exceed 4 mS cm$^{-1}$and 6% respectively. This result is due to a combination of factors in the fluvisol treatment area including texture, cation exchange capacity, and irrigation procedure and crop management.

**Key words:** Calcisol, Exchangeable sodium, Fluvisol, Sodium absorption ratio, Wastewater reuse

## 1. Introduction

Tunisia extends from the Mediterranean coast in the North to the Sahara desert in the South and its total surface area is 164, 150 km$^2$. The Tunisian coastline extends over 1300 km. Average annual rainfall is around 600 mm in the North, 300 mm in the Centre, and 150 mm in the South. The annual evaporation varies between 1300 mm in the North to about 2500 mm in the South. The water resources are about 4.8 Milliard m$^3$ of which 2.8 Milliard m$^3$ are from surface water and 2 Milliard m$^3$ from groundwater. Continuing increases in demand of fresh domestic water by the urban sector have indeed produced greater volumes of wastewater. Therefore, in arid and semi-arid countries such as Tunisia which are facing rising serious water shortage problems, reuse of urban wastewater for non potable purpose, such as agriculture (Bahri, 2002; Haruvy, 1997) has become an important concern. Indeed, wastewater reuse for irrigation offers some attractive environmental and socio-economic benefits including: reduction of effluent disposal in receiving water bodies, supply of nutrients as fertilizer and improvement in crop production during the dry season (Yadav *et al*., 2002). This study focuses on the impact of TWE irrigation on soil salinity and sodicity on a calcisol and a fluvisol which have been irrigated for 15 and 4 years respectively in the irrigated area of the arid region of Sfax (Tunisia). At Sfax (second largest city in Tunisia), signs of extremely low groundwater levels have been registered over the last three decades due to the increasing number of wells used for crop irrigation (Bouri *et al*., 2008). The Sfax treated wastewater has been reused for irrigation since 1989. The irrigated area has been extended to an area of 600 ha. This study is part of a research program evaluating the impact of wastewater application on both soil and crop properties. The goals of this study are to aid management of crop irrigation by wastewater, to reduce overexploitation of the local groundwater resources and to improve its recharge.

## 2. Materials and Methods

### 2.1. Study area

The irrigation area is located 10 km West of the town of Sfax (approximately one million inhabitants), next to the sewage treatment plant (**Fig. 1**) in crop fields which are irrigated with TWE. The wastewater treatment plant receives domestic effluents and industrial effluents. The region has an arid climate with mean monthly air temperatures ranging from 11.3 to 26.7°C, dry summers and annual rainfall of 200 mm mostly occurring from October to December. An average annual potential evaporation of 1200 mm, combined with the

* Corresponding Author: monem.kallel@enis.rnu.tn
Route de Soukra Km 3,5 Po. Box 1173, 3038 Sfax, Tunisia
1) University of Sfax, Laboratory of Water, Energy and Environment, National School of Engineering of Sfax (ENIS) 2) CRDA-Sfax
3) École Nationale d'Ingénieurs de Sfax, Laboratoire de Radio-Analyses et Environnement (LRAE)

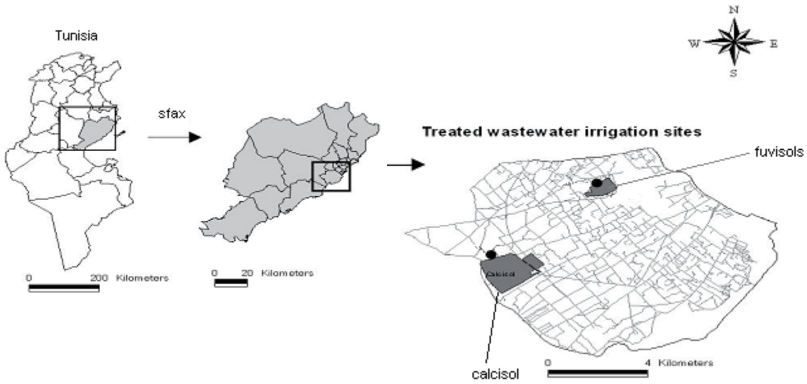


**Fig. 1. Map of study area with location of the Sfax water treatment plant and of calcisol and fluvisol fields within the TWE irrigation perimeter.**

low rainfall and high temperatures, make irrigation essential for crop production. The present survey was carried out at two selected sites chosen to represent both the soil type diversity and the variety of local agricultural practices and irrigation systems. Two main soil types occur in the study area: calcisols and fluvisols (according to the FAO World reference base for soil resources, 1998). The calcisols have a homogeneous sandy to sandy loam texture, whereas the fluvisols present a clayey sand texture at the soil surface and a fine sandy texture below 0.5 m depth. The calcisol field is used for production of successive winter and summer forage crops in association with permanent harvesting of olives. This kind of cropping system requires irrigation by open surface furrows distributed every 24 m in-between each row of olive trees. For the fluvisol field, irrigation is performed by direct surface submersion for the summer crops and by sprinkler aspersion for the winter crops. The two study areas also differ in their irrigation duration. The fluvisol study field has been irrigated with TWE for only 4 years whereas the calcisol has been subjected to TWE irrigation for 15 years. In order to assess the effect of the wastewater, non irrigated fields of both soil types (i.e. control) were selected near each irrigated field.

### 2.2 Sampling preparation and analyses

Treated effluents were sampled at the outlet of the Sfax wastewater treatment plant at different times and conserved at –4°C before characterisation. Different parameters of effluent samples were analyzed with standard methods (AFNOR, 1997). Sampling was carried out with an Edelman-type auger on summer crops plots only. At each sampling point, samples were taken from three layers: 0-30, 30-60 and 60-90 cm depth. After air-drying, the soil samples were sieved at 2 mm. Soil pH was measured in a 2:5 soil:water slurry using a glass electrode. Determination of exchanged $Ca^{2+}$ and $Mg^{2+}$ was performed by Atomic Absorption Spectrophotometry (AAS) whereas exchanged $Na^{+}$ and $K^{+}$ concentrations were determined by Flame Atomic Emission Spectrometry (FAES). Salinity of wastewater and soil was first estimated by measurements of the electrical conductivity (ECw and ECs for water and soil respectively). The electrical conductivity of the soil samples (ECs) was determined on saturated paste extracts of soils (U.S. Salinity Laboratory Staff, 1954). The soil sodicity was also assessed by the exchangeable sodium percentage (ESP). Potential risk of sodification of water and soils has also been estimated by the sodium absorption ratio (SAR); SARs and SARw are respectively the sodium absorption ratio for soil and water samples.

## 3. Results and Discussion

### 3.1. Treated wastewater characteristics

Characteristics of treated wastewater (TWE) used for irrigation varied within and among the years of application (**Table 1**). The applied wastewater always remained alkaline with an average pH of 7.7. It always presented a high level of total dissolved solids (TDS) of 3.7 g $L^{-1}$ and a high level of suspended matter (SS).

Levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) indeed always largely exceeded the Tunisian standards for wastewater reuse in irrigation (NT 106.03).

### 3.2. Factors controlling soil salinity and sodicity

Use of wastewater for irrigation has been recognized to be hazardous with regard to soil salinity as well as soil sodicity. In our case, the applied treated wastewater contains several anionic species (chlorides, sulfates) that are mostly associated with sodium (Table 1). Soils are generally classified as saline when they present an ECs of 4 mS $cm^{-1}$ or more and are classified as sodic when they present a SARs greater than 13 or an ESP greater than 15% (Sumner, 1995). Using these guidelines, the control fluvisol as well as the irrigated fluvisol (Fig. 3 b) are both saline, with ECs values exceeding the level

**Table 1. Minimum and maximum values of water quality parameters in the treated wastewater effluent (TWE) generated by the Wastewater Treatment Plant of Sfax, as characterized since 1984.**

| Parameter | Sfax effluent | Standards* |
|---|---|---|
| pH | (7.1-8.7) | 6.5 - 8.5 |
| ECw mS/cm | (4-7.7) | 7 |
| TDS g/L | (3.56-5.13) | - |
| SS mg/L | (29-275) | 30 |
| COD mg/L | (123-700) | 90 |
| $BOD_5$ mg/L | (37-220) | 30 |
| Pt mg/L | (2.9-12.5) | - |
| $NO_3^-$ mg/L | (0.35-50) | - |
| $CL^-$ mg/L | (903-2580) | 2000 |
| $SO_4^{2-}$ mg/L | (508-1950) | - |
| $HCO_3^-$ mg/L | (490-732) | - |
| $Na^+$ mg/L | (780-2100) | - |
| $K^+$ mg/L | (17-105) | - |
| $Mg^{2+}$ mg/L | (129-209) | - |
| $Ca^{2+}$ mg/L | (103-521) | - |
| $NH_4^+$ mg/L | (61-73) | - |
| SARw | (9.7-15.6) | - |

EC: electric conductivity; TDS: total dissolved solids; SS: suspended matter; COD: chemical oxygen demand; BOD: biochemical oxygen demand; SARw: sodium absorption ratio of water.
* Tunisian standards for wastewater reuse (NT 106.03)

of 4 mS $cm^{-1}$, whereas the control calcisol is not saline. The irrigated calcisol (**Fig. 2**) is of moderate salinity (Tedeschi and Dell' Aquila, 2005). The calcisol is not sodic whether irrigated for 15 years by the Sfax TWE or not. In contrast, the fluvisol irrigated for only 4-years is sodic with an ESP ranging between 5 and 15% whereas the control fluvisol is not sodic (**Fig. 3**). It appears that irrigation by the same saline-sodic Sfax wastewater impacted salinity and sodicity in different manners, depending on the soil properties, the irrigation procedure used and the type of crop management. The studied calcisol and fluvisol mostly differ by their texture. Soil texture strongly influences the soil permeability, the rate of water infiltration and the ability of soil particles to adsorb or desorb chemical ions (exchange capacity) such as $Na^+$ (Bauder *et al*., 2008). Consequently, a clay textured soil of relatively high CEC, such as the studied fluvisol, presents the greatest risk for binding the excess of sodium supplied by the wastewater. The fluvisol is also likely to better retain the salty TWE. For this reason, the studied fluvisol samples present higher contents of exchangeable $Na^+$. The sandy calcisol has a good permeability and a low CEC (few exchange sites), retains less water and naturally loses water as well as soluble salts from the root zone.

### 3.3. Factors controlling the extent of salt leaching

The ECs of the soil surface layers decreases with the leaching of salt by the TWE and by the autumn-spring rainfalls and increases during the crop season in between periods of irrigation, due to rise of saline water by evaporation or by root uptake. In the present case, the main factors governing the soil salinisation and sodification are the irrigation procedures and choice of crop management. Rate of irrigation during the crop season is regular enough to prevent the rise of salt from the deeper layers. Because crops only remove small amounts of salt (Nakayama and Bucks, 1986), vertical distribution of salt in soil is directly related to the water movements, which are directly governed by the rate of irrigation. In the studied calcisol, water movement is enhanced first by the good permeability due to the sandy to sandy loam texture and secondly by the dismantlement of the deep calcareous crust that has been performed in the irrigated fields only.

In addition, drainage of wastewater is favoured by the density of the permanent irrigation network and finally by the intensive rate of irrigation. Indeed, 1000 mm of treated wastewater are applied by a furrow irrigation system during the summer in the calcisol fields. This irrigation rate largely exceeds the amount of water required for plant growth, enabling the leaching of salts. Conversely, the irrigation procedure used in the fluvisol mostly led to the salinisation of the surface soil layer. Because of its clay texture, its higher CEC and thus its higher water retention capacity, the fluvisol retains more $Na^+$ and is less permeable than the calcisol.

## 4. Conclusions

Irrigation by the Sfax saline-sodic treated wastewater (TWE) has significantly increased the soil salinisation and sodification of both studied soil types, particularly in the study area of Sfax characterized by limited rainfall and high evaporation. Generally, wastewater irrigation management aims at ensuring leaching of salts below the root systems (Mohammad Rusan *et al*., 2007). Here, this is not the case either for the calcisol or the fluvisoil, which both display elevated SARs and ESP in the deepest soil layers. Irrigation by the Sfax TWE has affected the salinity, sodicity and soil organic matter content of the two studied soils in different manners, not only because of the different soil properties but also due to the different crop management and irrigation procedures. Soil CEC and buffer capacity as well as initial soluble carbonate and salt contents are the main factors controlling the extent of soil salinisation and salt leaching. Organic matter addition, soil tillage and rate of irrigation are the human factors determining the risk of further permanent structural degradation of the soil.

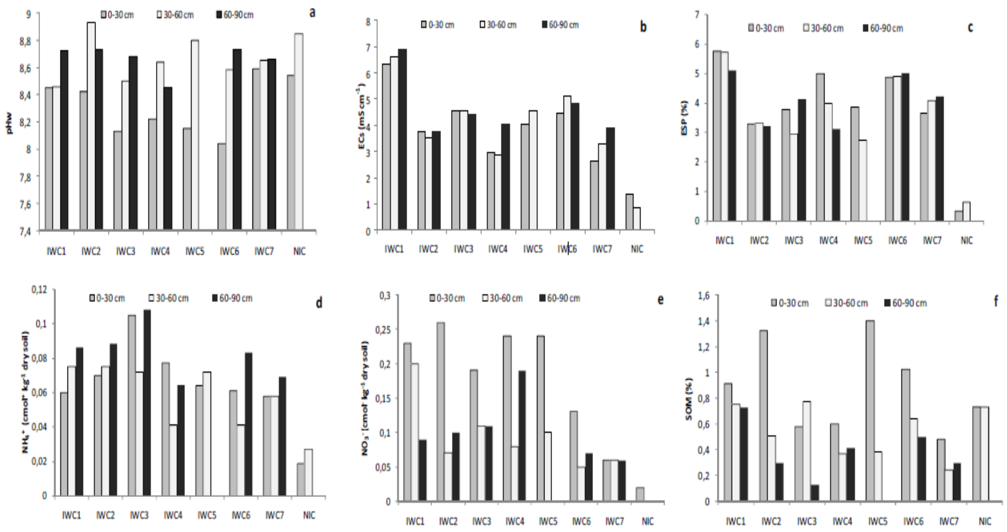


**Fig. 2. Calcisol properties in irrigated (IWC) and non irrigated (NIC= control) field.** a) pH in soil-water extract. b) Electrical conductivity of extract past (ECs). c) Exchangeable sodium percentage (ESP). d) $NH^{4+}$ content in water extract. e) $NO_3^-$ content in water extract. f) Soil organic matter content (SOM).

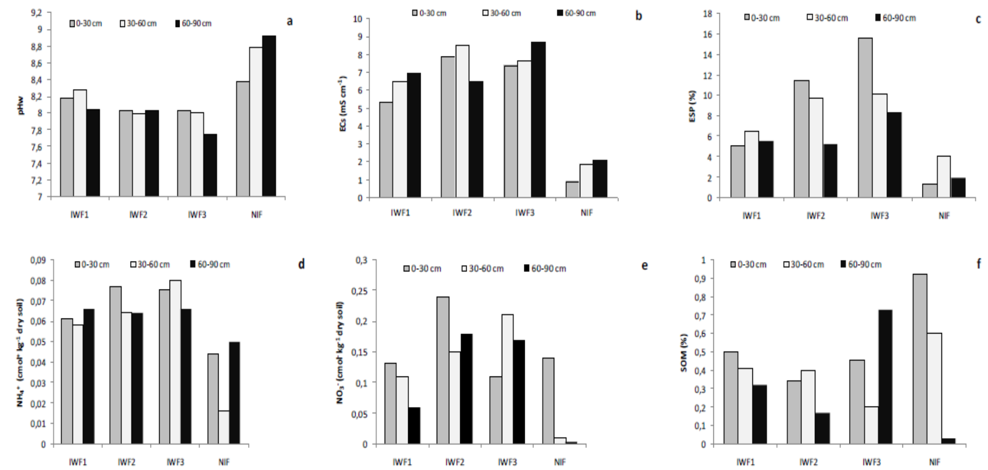


**Fig. 3. Fluvisol properties in irrigated (IWF) and non irrigated (NIF= control) soil.** a) pH in soil-water extract. b) Electrical conductivity of extract past (ECs). c) Exchangeable sodium percentage (ESP). d) $NH_4^+$ content in water extract. e) $NO_3^-$ content in water extract. f) Soil organic matter content (SOM).

## References


AFNOR (1997): *Qualité de l'eau, méthodes d'analyses 3,* tome 4, pp 296.

Bahri A. (2002): Water reuse in Tunisia: stakes and prospects; *Actes de l'atelier du PCSI*, 28-29 mai Montpellier, France, 11p.

Bauder J.W., Hershberger K.R., Bowning L.S. (2008): Soil solution and exchange complex response to repeated wetting–drying with modestly saline–sodic water. *Irrig. Sci.*, **26**: 121-130.

Bouri S., Abida H., Khanfir H. (2008): Impacts of wastewater irrigation in arid and semi arid regions: case of Sidi Abid region. *Tunisia. Environ. Geol.*, **53**: 1421-1432.

Haruvy N. (1997): Agricultural reuse of wastewater: nation-wide cost-benefit analysis. *Agri. Ecosyst. Environ.*, **66**: 113-119.

Mohammad Rusan M.J., Hinnawi S., Rousan L. (2007): Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. *Desalination*, **215**: 143-152.

Nakayama F.S. and Bucks D.A. (1986): *Trickle Irrigation for Crop Production: Design, Operation and Management.* Elsevier, New York, NY.

Tedeschi A., Dell' Aquila R. (2005): Effects of irrigation with saline waters, at different concentrations, on soil physical and chemical characteristics. *Agric. Water Manage.*, **77**: 308-322.

U.S. Salinity Laboratory Staff (1954): Diagnosis and improvement of saline and alkali soils, *USDA Handbook 60*. U.S. Government Printing Office, Washington, DC, USA, 160p.

Yadav R.K., Goyal B., Sharma R.K., Dubey S.K., Minhas P.S (2002): Post-irrigation impact of domestic sewage effluent on composition of soils, crops and groundwater - A case study. *Environ. Internat.*, **28**: 481-486.