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Effect of different irrigation methods using treated wastewaters on the distribution of traces elements on two different soil textures

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Abstract

Treated wastewaters (TWW) reuse for irrigation contributes to reduce water scarcity in semi arid and arid regions. However, this reuse needs adapted management in order to avoid environmental and health risks. A greenhouse pot experiment was carried out to evaluate the effect of irrigation methods using TWW on distribution of trace elements (TE) in sandy and clay soil textures. Two water qualities were used: TWW and fresh water and four irrigation methods are used: surface irrigation (SI), sprinkler irrigation (SPI), drip irrigation (DI) and subsurface drip irrigation (SDI). A maize crop was cultivated. This paper is limited to the trace elements content on soils. Chemical analyses were done on soils and water (pH, EC, Fe, Mn, Ni, Cu, Co and Pb). The results indicated a significant increase on EC, Mn, Cu, Fe and Pb with TWW for the four irrigation methods in comparison to the fresh water. The pH value, Ni and Co concentrations did not statistically differ among the different treatments. Accumulation of TE in clay soil was higher than in sandy soil. The results indicated that drip and subsurface drip irrigation could reduce soil contamination in comparison with surface and sprinkler irrigation

Keywords: *methods, TWW, sandy soil, clay loam soil, Traces elements, Tunisia.*.

1. Introduction

In arid and semi arid regions, fresh water is becoming scarcer and is being allocated with priority for urban water supply. Therefore, the reuse of unconventional water resources as the wastewater for agricultural irrigation can reduce the amount of water that needs to be extracted from environmental water sources [1].

Wastewater irrigation not only provides substantial amounts of beneficial nutrients as N, P and organic matter (OM) to the soil but also toxic TE, which are creating both opportunities (oligo-elements) and risk for agricultural production (Toxic elements) [2-5]. One of the issues that attracted the attention of many researchers is the fate of chemical and TE found on wastewater especially those which can penetrate into soil, plant and finally food chain [6]. Trace elements represent a portion of important environmental pollutants which can slowly accumulate up to critical levels [7].

Since wastewater is considered as a non-ordinary source of water, its application require an appropriate management which has to have no threat to the environment, plants, soils and surface or subsurface water resources. In addition, many studies indicate that the wastewater resources traditionally classified as unsuitable for irrigation can be used successfully to grow crops without long-term hazardous consequences to crops and soils if proper management strategies are established [8]. These strategies, include adopting advanced irrigation technology, selecting appropriately tolerant crops, choice of soil texture [9-12] and appropriately irrigation methods that may influence the response of the soil to irrigation with TWW [13].

Several studies have documented the impacts of wastewater use on soil chemical properties; some involve flood irrigation [14, 15], furrow irrigation [16, 17] sprinkler application [18, 19] and surface (DI) or subsurface drip irrigation (SDI) [20, 21].

Normally, effluent used in irrigation is delivered through surface or sprinkler irrigation methods; however, in recent years interest in micro-irrigation has increased. Earlier, Pescod [22] had compared the advantages and disadvantages of different methods of irrigation for utilizing the wastewater and concluded that DI is the only method which solves the specific problems of using wastewater. In another research, Oron et al. [20] showed that by using two methods as DI and SDI, the amount of contamination of soil is less in the case of SDI. In the same

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way, other researchers investigated the effect of municipal effluent using two irrigation methods reported that the most important concern was the increase of EC in top soil layer and a decrease of Pb with SDI [1, 23].

The four basic methods of irrigation are surface or gravity irrigation, sprinkler irrigation, drip and subsurface drip irrigation. Sprinkler irrigation throws water through the air to simulate rainfall whereas the three other methods apply the water directly to the soil, other on or below the surface [24]. Most of the previous papers evaluated the effects of wastewater and on chemical properties of the soil when using one, two or three irrigation methods. But a little information is available on the impact of wastewater on TE accumulation using four different methods of irrigation. In this study, we propose to evaluate the effects of irrigation methods using TWW on accumulation of TE in soil. This study involved the application of TWW and fresh water (FW) on two different soil textures and compared the TE status under the four irrigation methods.

2. Material and Methods

2.1 Experimental design

The study was carried out in greenhouse during summer from June to August 2011. The experiment was a factorial completely randomized design arranged on four blocks and consisted of eight treatments including two soil textures: sandy soil (SS) and clay soil (CS), two water qualities: treated wastewater (TWW) and fresh water (FW), and four irrigation methods: surface irrigation (SI), sprinkler irrigation (SPI), drip irrigation (DI) and subsurface drip irrigation (SDI). Thus, eight treatments were applied: T1: SI with FW, T2: SPI with FW, T3: DI with FW, T4: SDI with FW, T5: SI with TWW, T6: SPI with TWW, T7: DI with TWW and T8: SDI with TWW. For each treatment, there were 3 replicate pots leading to a total of 48 pots (Figure 1).
The TWW used in this experiment was from the wastewater treatment plant of Choutrana in North of Tunis city.

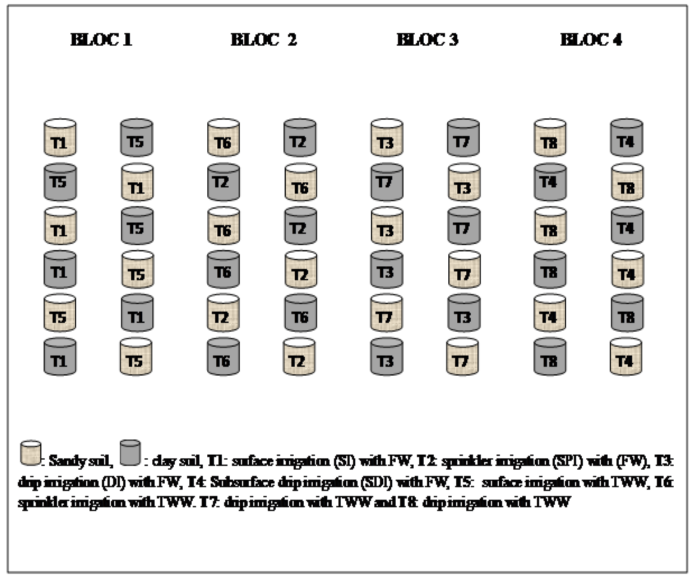

Fig. 1: Experimental design

The same amount of water was applied to all treatments 40 times and water samples were collected periodically during the experimental period (3 months) and the chemical characteristics are described below (Table 1).

Table 1: Chemical properties of fresh water (FW) and treated wastewater (TWW).

water	pH	EC[1]	Co[2]	Cu[2]	Pb[2]	Ni[2]	Fe[2]	Mn[2]
FW	8.06	1.36	0.02	0.017	0.08	0.03	0.08	0.02
TWW	7.73	3.78	0.04	0.190	0.10	0.05	0.13	0.04

1: dS/m, 2: mg/l

2.2. Soil sampling and chemical analysis

The characteristics of two soil types were determined at the beginning of the study (Table 2).

Table 2: Initial characteristics of the two soil textures (trace elements were in mg kg^{-1})

soil	pH	EC[1]	Co[2]	Cu[2]	Pb[2]	Ni[2]	Fe[2]	Mn[2]
sandy	8.56	30.1	15.5	41.1	90.2	22.6	57.6	24.9
clay	8.78	5.50	30.9	19.2	430	56.9	93.8	52.4

1: dS/m, 2: mg/kg

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At the end of the study, soil samples were taken from three random points on each pot. Thirty six soil samples were taken in each treatment and 144 soil samples were taken in total. The samples were prepared by being air dried and sieved for chemical measure.

Soil EC was measured by a conductivity meter on soil saturated paste extract and pH was measured by a pH meter on mixture soil and water (1/2.5). The total traces elements concentration of soil samples were determined by digesting of dried soil samples with HF-$HClO_4$ mixture.

The procedure based on acid digestion induced by microwave energy was optimized in order to measure the total TE contents in soils. Each soil sample (1 g) was placed in a Teflon vessel (100 mL) with HF (10 mL) and $HClO_4$ (5 mL) and then digested in a microwave. After that, 70 ml of perchloric acid was added to the mixture. After digestion, the samples were filtered and transferred into 100 ml volumetric flasks and brought to volume of 100 ml by added of distilled water. The filtrate was analyzed by atomic absorption for the determination of the following: Mn, Cu, Fe, Pb, Co and Ni (ISO 14869-1 (2001)).

2.3. Statistical analyses

Data were statistically analyzed by using the Duncan test at the 5% significance level. Data analysis was done using SPSS software.

3. Results

3.2. Soil pH and EC

The soil EC and pH in the eight treatments were presented and compared in Table 3. Minimum EC for both soils equal to 1.44 dS m^{-1} for sandy soil and 1.94 dS m^{-1} for clay soil were recorded in T4 (SDI with FW), and maximum EC equal to 4.13 dS m^{-1} and 5.80 dS m^{-1}, respectively, were related to T5 (SI with TWW).

Result for pH in both soils, showed no significant ($p < 0.05$) effect on pH status due to TWW use under different irrigation methods (T1, T2, T3, T4) as compared to fresh water (T5, T6, T7, T8).

Table 3: TWW effects on pH and EC of two soil texture under different irrigation methods

Treatment	parameters			
	pH		EC	
	Soil texture		Soil texture	
	Sandy	clay	Sandy	clay
T1	8.60 a	8.75 b	2.39 d	3.30 d
T2	8.61 a	8.77 b	1.85 bc	3.28 d
T3	8.58 a	8.75 b	1.66 ab	2.15 b
T4	8.56 a	8.77 b	1.44 a	1.94 a
T5	8.40 a	8.71 b	4.13 f	5.80 g
T6	8.41 a	8.72 b	3.09 e	5.13 f
T7	8.48 a	8.70 b	2.58 d	3.45 d
T8	8.47 a	8.71 b	2.08 c	2.84 c

All values are the mean of nine repetitions (n=9) and bars with different letters are significantly different at P ≤ 0.05 according to Duncan test..

3.3. Copper (Cu)

The results for Cu, in both soils showed a significant increase under different irrigation methods with TWW (T5, T6, T7 and T8) as compared to those with FW (T1, T2, T3 and T4). Among the TWW treatment, the highest Cu levels equal to 41.49 and 32.60 mg kg^{-1} for respectively sandy (SS) (Fig. 2a) and clay soil (CS) (Fig. 2b) were recorded in T5 and the lowest equal to 29.80 and 24.12 mg kg^{-1} were observed with T8 (Fig. 2).

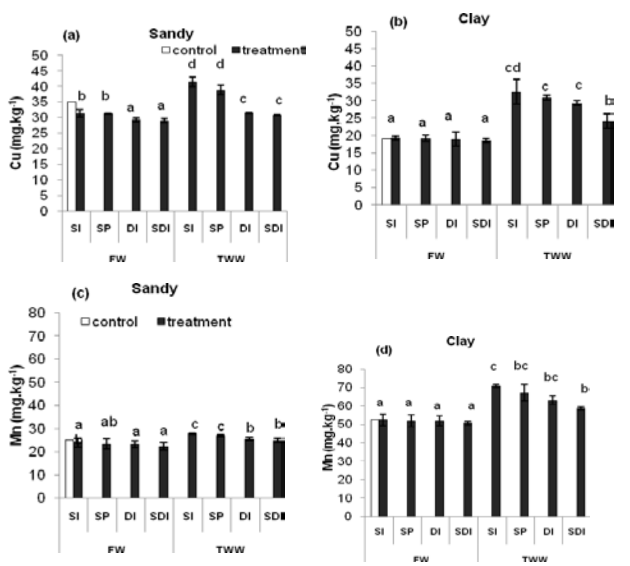

Figure 2: Accumulation of Cu and Mn in two soil textures under different treatments (all values are the mean of nine repetitions (n=9) and bars with different letters are significantly different at P ≤ 0.05 according to Duncan test).

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3.3. Manganese (Mn)

As seen in the Figure 2, the irrigation methods with TWW (T5, T6, T7 and T8) had a significant ($p < 0.05$) effect on Mn accumulation in both soil textures as compared to those with FW (T1, T2, T3 and T4). The highest Mn levels were obtained with T5 and T6 treatments. It was, also shown the accumulation of this element in clay texture (Fig. 2d) was more important than in sandy texture (Fig. 2c).

3.4. Iron (Fe)

As shown in Figure 3 (Fig. 3a and 3b), Fe content in both textures was significantly ($p<0.05$) affected by TWW irrigation under different irrigation methods (T5, T6, T7 and T8). Furthermore, Fe accumulation under T5, T6, T7 and T8 in comparison with T1, T2, T3 and T4 treatments are much higher in clay than in sandy texture and the highest increase in Fe level by 21% was obtained with T5.

3.5. Lead (Pb)

According to the Figure 3, in the case of sandy soil (Fig. 3c), there were no significant differences ($p<0.05$) in Pb (Fig. 3d) soil accumulation due to TWW use or irrigation methods. While, in the case of clay soil, the results showed that Pb amount in TWW irrigated soil exhibited 19% higher than those in FW irrigated soil. In this way, Pb soil accumulation was unaffected by irrigation methods.

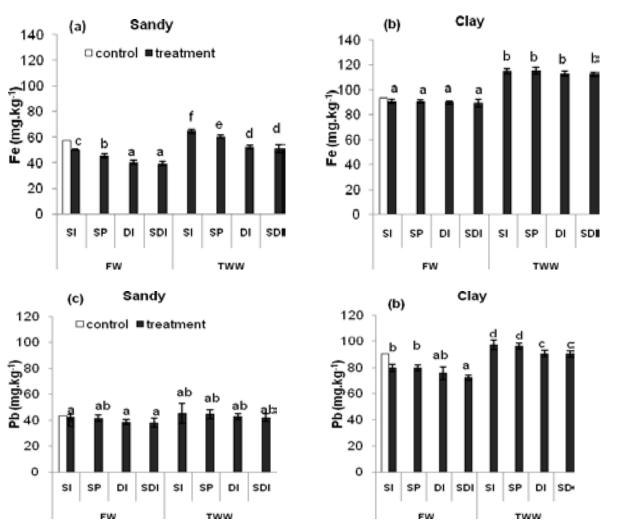

Figure 3: Accumulation of Fe and Pb in two different soil textures among different treatments (all values are the mean of nine repetitions (n=9) and bars with different letters are significantly different at $P \leq 0.05$ according to Duncan test).

3.6. Nickel (Ni)

The results from different treatments for Ni level showed a significant increase under different irrigated method ($p<0.05$) in TWW irrigated soil in comparison with FW irrigated soil (Fig. 4). This statement was shown only for clay soil (Fig. 4b). Indeed, the highest Ni concentration of 61.00 mg kg^{-1} was obtained with T5 and the lowest Ni concentration of 57.47 mg kg^{-1} was obtained with T8. For sandy soil (Fig. 4a), except the slight increase shown with T5 treatment, there were no significant difference in Ni concentrations under different irrigation methods with TWW as compared to those with FW.

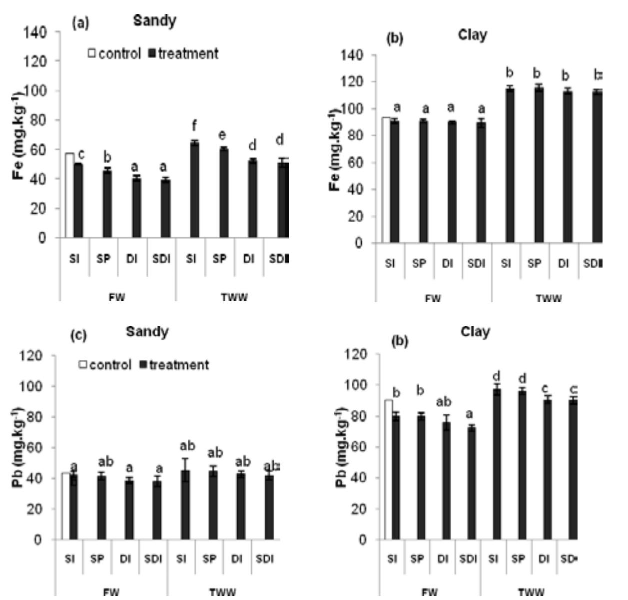

Figure 3: Accumulation of Fe and Pb in two different soil textures among different treatments (all values are the mean of nine repetitions (n=9) and bars with different letters are significantly different at $P \leq 0.05$ according to Duncan test).

3.7. Cobalt (Co)

Based on analysis of variance, result for Co content in two different soil textures (Fig. 4c and 4d) showed that there were no significant differences ($p<0.05$) between Co concentrations among different treatments (T1, T2, T3, T4, T5, T6, T7 and T8) (Fig. 4).

4. Discussion

Soils are the most important sink of toxic trace elements [25]. Thus, excessive accumulation of trace elements in

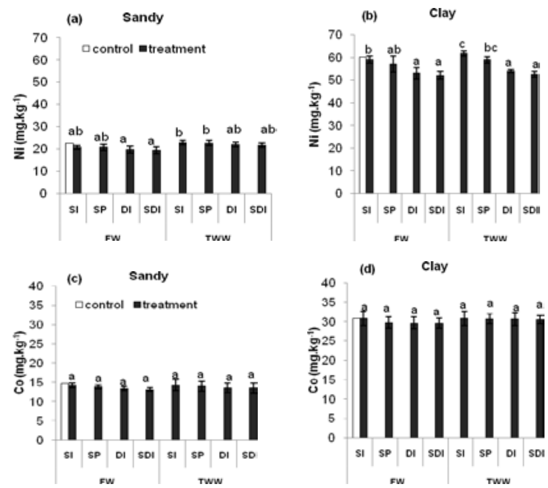

Figure 4: Accumulation of Ni and Co among different treatments (all values are the mean of nine repetitions (n=9) and bars with different letters are significantly different at $P \leq 0.05$ according to Duncan test).

agricultural soils through wastewater irrigation may not only result in soil contamination, but also affect food quality and safety [26-28]. Therefore alternative irrigation management as choice of soil texture and/or irrigation methods should be developed to overcome the problems associated with TWW irrigation. This further experiment was designed to study the effects of the four irrigation methods (S, SP, DI and SDI) using TWW on accumulation of six selective trace elements as Cu, Fe, Mn, Pb, Co and Ni in two different soil textures. The evidences provided by this study indicated that TWW caused increase of EC and this is in line with findings of Rusan et al. [29], Jahantigh [30], Khai et al. [31] and Mojiri and Hamidi [28]. The increase of EC in soil under SI and SPI methods was higher than under DI and SDI methods and the same result were observed by Tabatabaei and Najafi [32] when testing effects of irrigation with two water qualities (TWW and fresh water) under furrow, drip irrigation and subsurface drip irrigation on soil properties. They concluded that soil EC was reduced relative to the initial conditions by using the fresh water and the SDI treatment. As for pH, no significant effects of TWW was shown for this element in soil and this statement was shown for different irrigation methods, which is similar to results reported by Alhands et al. [33]. Some investigations showed that irrigation with wastewater decreased soil pH. The reason is likely due to the decomposition of organic matter and production of organic acids in soils irrigated with wastewater [24, 28, 31]. Other studies showed that the soil irrigation with wastewater increased soil pH [29, 35]. Most of these investigations described the long term impact of irrigation with wastewater effluents on soil properties.

Results for Cu, Mn and Fe showed a significant increase of these elements in both soil textures with TWW. Our results were corroborated with these obtained by other researchers [29, 30, 43, 36]. In this way, Rusan et al. [29] reported that accumulation of micronutrients and TE as a result of wastewater could be caused directly by the wastewater composition or indirectly through the increasing solubility of the indigenous insoluble soil TE as a result of the chelation or acidification action of the applied wastewater. As for Pb and Ni, the significant effect of TWW had only shown in clay soil. However, no significant effect of TWW on the amount of Co compared to FW was shown in both soil textures.

Based on our result, the irrigation methods with TWW treatments were significantly affected the Cu, Mn and Fe levels. However, no significant effect was observed for Pb, Ni and Co. The higher TE levels were obtained with surface and sprinkler irrigation as compared to DI and SDI irrigation. In addition, the highest TE level was obtained under surface irrigation with TWW and the lowest one was obtained under SDI. Similarly, Oron et al. [20] and Najafi [37] when testing the impact of municipal wastewater on chemical soil properties showed that soil contamination is reduced when using SDI.

The combination of irrigation methods, water quality and soil texture affected significantly the soil trace metal status. Indeed, the trace metal accumulation in soil decreased in order SI<SPI<DI<SDI. In general terms, irrigation methods with TWW lead, to build up of significant amount of toxic trace elements on heavier textured soil. While, this significant amount can be reduced under the different irrigation methods with TWW in the case of sandy textured soil.

5. Conclusion

A statistical analysis of the different treatments showed that the irrigation method had significantly affected the accumulation of trace elements in both soil textures. The highest amount of different elements was obtained with surface irrigation and the lowest was obtained with SDI. Irrigation with TWW led, also, to a significant increase on EC, Mn, Cu, Fe and Pb compared to irrigation with fresh water. However, the pH value, Ni and Co concentrations did not statistically differ among the different treatments. The experiment dealing with combinations of irrigation method soil texture and water quality demonstrated that use of DI with TWW in a light textured soil diminished the possible adverse effects.

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