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ORIGINAL ARTICLES

Effect of treated wastewater on Soil and Corn Crop in the Tunisian Area

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ABSTRACT

The reuse of treated wastewater (TWW) led to some consequences on soil, water and plants such as contamination by the toxic traces elements and salts. For this reason, we have carried out an experiment with three small parcels irrigated with TWW and three others irrigated with freshwater (FW). The effect of the TWW on both soil and corn (*Zea mays*) components is considered. The results showed that the irrigation with TWW increased significantly ($P \leq 0.05$) the soil EC_e, majors elements contents as Na, Cl, Ca, Mg and fertilizer elements as N, P and K and heavy metals such as Cu, Zn, Co, Cd, Pb and Ni and decreased significantly ($P \leq 0.05$) the soil pH. The results on corn plant (*Zea mays*) showed that irrigation with TWW led to significant increase of these elements on different organs of corn.

Key words: TWW; soil; corn; heavy metals; salinity; Tunisia.

Introduction

A competition for freshwater among different water-use sectors already exists in several arid and semi-arid regions, causing a decreased allocation of freshwater to agriculture. For this reason, dwindling supplies of water quality for irrigation and increasing demand from other users are forcing farmers to use of non-conventional waters resources (Shani and Dudley, 2001). Among these various water conservation practices, the use of TWW has taken on greater significance. Indeed, this quality of water for agriculture offers the greatest scope for application because it usually has the potential to meet growing water demands, conserve potable supplies, reduce disposal of pollution effluent into surface water bodies, allow lower treatment costs and enhance the economic benefits for growers due to reduced application rates for fertilizer (Jimenez-Cisneros, 1995; Paranychianakis *et al*., 2006).

Along with the reuse of wastewater for irrigation comes the need to understand potential environmental impacts of this practice. Many authors (Michael *et al*., 2010; Mojiri and Hamidi, 2011; Allaham *et al*., 2007; Mapanda *et al*., 2005 and Mahallapa, 2010) were tested the effect of municipal wastewater on soil and plant. Amin (2011) studied the effects of municipal wastewater treatments on physical and chemical properties of saline soil, showed an increase of EC, P, OM, TN, K, Na, Cl, Fe, Cd and Zn but a decrease of soil pH. In the similar way, Mohammad and Mazahreh (2003) reported a decrease of pH by the presence of high content of ammonium in wastewater. They also found an increase of soil salinity level due to the wastewater salt content. According to the others researchers, the wastewater irrigations increased soil nitrogen (N), phosphorus (P) and potassium (K) (Rahmani, 2007), while high levels of heavy metal build-up on the soil with the long-term use of wastewater on irrigation (Rattan *et al*., 2002; Larchevêque *et al*., 2006). When the capacity of soil to retain heavy metals is reduced due to repeated use of wastewater, soil can release heavy metals into groundwater or soil solution available for plant uptake (Sharma *et al*., 2007).

TWW can be used for the irrigation of a variety of field crops. It can be applied for trees like olive (Bedbabis *et al*., 2010) as well for cereal or forage crops. Karami *et al*. (2008) investigated the effects of municipal sewage sludge on the concentration of lead (Pb) and cadmium (Cd) on wheat yield. They reported that the application of sewage sludge caused an increase of concentration of Cd and Pb concentration in root and shoot of wheat. Indeed, the majority of the researches, as Arora *et al*. (2008), conducted on wastewater reuse in agriculture focuses mainly on its short-term effect on plant growth. Day *et al*. (1974) compared the effect of irrigation with wastewater than pump water on wheat. They concluded that wastewater irrigation produced taller plants, heavier seeds and higher grain yields than pump water. In the other hand, Kiziloglu *et al*. (2008) showed that wastewater irrigation treatments increase the availability of phosphorus and microelements as well as N, P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, to plant witch lead to increase of cauliflower and red cabbage yields.

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The aim of our research is to assess the effects of irrigation with TWW reuse on soil properties and corn crop.

Materials and Methods

Study area and experimental plot:

An experiment was conducted, using a Randomized Statistical Design, in the field of the Cebela Borj-Touil area located in the Low Valley of Mejerda, about 20 km North of Tunis City (Tunisia;Fig.1). The climate is semi-arid with hot and dry summer. The average annual precipitation is about 470 mm and potential of evapotranspiration is about 1400 mm/year. Soil texture of the experimental site is clay-loam.

The statistical design used included two water quality of irrigation: (a) TWW; (b) freshwater (FW) and (c) one vegetable plant, corn (*zea mays L.*). The experiment was conducted in three replications, with a total of 2 ×1× 3 = 6 experimental plots of 3 m × 3 m = 9 m^2 sizes. The plots were separated by each other by 3 m. Corn seeds were planted on 28/05/2008. The TWW used was supplied by the treatment plant of Chotrana in north of Tunis city. In total, the TWW and freshwater were applied 11 times during the growth period, at average rate of 48 mm and the total was1056 mm.

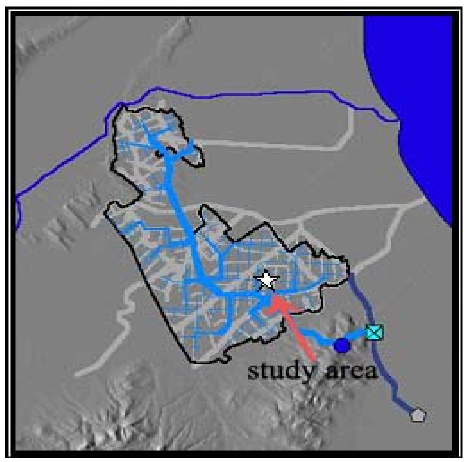

Fig. 1: Cebela Borj-Touil irrigated area in North of Tunisia.

Irrigated water quality:

Water samples were collected periodically during the experimental period. The pH and EC in these water samples were determined directly after sampling. The water chemical characteristics are described in Tab.1.

Irrigated soil samples analysis:

Soil samples were collected from different experimental plots at depths of 0-30 cm, were air-dried and sifted through a 2-mm mesh sieve for preparation to physic-chemical analyses.

Soil pH:

Soil pH was determined on a soil-water mixture (20 g soil + 50 ml distilled water) and measured with a pH meter.

Electrical Conductivity (EC):

EC was determined in 1:5 aqueous soil extracts and measured by conductivimeter. A significant linear relationship permitted to convert the electrical conductivity EC(1/5) to the electrical conductivity of the saturated paste extract (ECe):

$EC_e = 5.853*EC(1/5) – 0.262$ (n = 134 and R^2 =0.91)
with $1.2 < EC_e < 8.3$ dS/m and $0.2 < EC (1/5) < 1.4$ dS/m

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

Irrigated water	pH	ECw (dS/m)	SAR	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	K (mg/l)	P (mg/l)	N (mg/l)	Cd (mg/l)	Co (mg/l)	Cu (mg/l)	Ni (mg/l)	Pb (mg/l)	Zn (mg/l)
FW	8.16a	1.4a	4a	104.00a	125.6a	59.00a	160.14a	14.33a	0.13a	0.00a	0.01a	0.0003a	0.02a	0.0023a	0.025a	0.20a
TWW	7.04b	3.4b	7b	212.81b	156.33a	78.36b	351.39b	40.6b	7.8a	30.9b	0.35a	0.056a	0.09b	0.3b	1.10b	0.55b
Tunisian Standard (INNORPI NT 1989)	6.5-8.5	7	-	-	-	-	-	-	-	-	0.01	0.1	0.5	0.2	1	5
*Threshold levels of trace elements for crops production	-	-	-	-	-	-	-	-	-	-	0.01	0.05	0.2	0.2	5	2

All values are the mean of three repetitions (n=3) and bars with different letters are significantly different at $P \leq 0.05$ according to LSD test.

Na, Ca, Mg, K, TN, P and heavy metals analysis:

Concentrations of soluble Ca and Mg were measured using the EDTA titration method. Na and K were measured by Flame photometry. Total nitrogen (TN) was measured by Kjeldahl method (Bremner and Mulvaney, 1982). Phosphorus was determined by Olsen method (Olsen and Sommers, 1982). Heavy metals in soil samples were carried out by using an Atomic Absorption Spectro-photometry (ISO 14869-1 l).

Main characteristics of the soil in the experimental field are shown in Tab. 2.

Table 2: Initial characteristics of the soil at the experimental field.

Elements	soil	Normal range in soil [a,b,c]	Upper limit range*
pH	8.0	-	-
EC (dS/m)	2.73	-	-
Ca^{2+} (meq/l)	5.45	-	-
Mg^{2+}(meq/l)	3.22	-	-
Na^{+} (meq/l)	17.17	-	-
Cl^{-} (meq/l)	15.69	-	-
N (mg/kg)	0.9	-	-
P (mg/kg)	17.2	-	-
K (mg/kg)	109	-	-
Cd (mg/kg)	13.7	0.01-2	0.01-2
Co (mg/kg)	10.0	10-15	-
Ni (mg/kg)	59.5	15-30	5-500
Pb (mg/kg)	67.5	15-30	2-200
Cu (mg/kg)	11.1	15-40	100
Zn (mg/kg)	66.8	50-100	400

[a] Adriano, 1986; [b] Aubert and Pinta; [c] Kabata -Pendias and Pendias *Source: WHO, 1989.

Plant analyses:

The vegetative growth was performed by fresh and dry weight of leaves, stems and roots. For chemical analyses tissues of leaf, stem and roots were used. The organic ions were extracted from dry matter by HNO_3 at room temperature for 48 hours. K and Na were analysed by flame emission using an Eppendorf spectrophotometer. Ca, Mg and heavy metals (Cu, Zn, Co, Cd, Ni and Pb) were determined by atomic absorption spectrophotometry. Cl was quantified by a colorimetric assay with a Buchler chloridimeter. N was determined by the Kjeldahl method (NF T 90-110). Phosphorus was estimated by the chlorosstannous molybdophosphoric blue colour method.

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Statistical analysis:

Statistical processing was achieved by the software STATISTICA, Version 5 (Statsoft France, 1997) and the parameters recorded were subjected to analysis of variance with one way. Means comparison were carried out as needed by the LSD test at the significant level of 0.05.

Results:

TWW Effect on soil properties:

Soil pH:

The pH results are in table 3. The irrigation with TWW induces significant ($P<0.05$) increase of soil pH with comparison to the control treatment (fresh water).

Soil Electrical Conductivity (EC_e):

The TWW affects significantly the EC_e (Table 3). Indeed, in comparison with fresh water, EC_e is greater with TWW treatment.

Major elements contents and nutrients fertilizer:

As observed in table 3, the irrigation with TWW led to a significant increase of Ca^{2+}, Mg^{2+}, Na^{+}, N, P and K^{+} in comparison with the control (freshwater). The significant increase was in particular concerned P and K^{+} contents by 17% for P and 31% for K^{+} in comparison to the control. For Cl^{-}, the irrigation with TWW has no effect on the Cl of soil (Tab. 3).

Table 3: TWW Effect on pH, EC_e, macro- and micro-nutrients of soil.

	Depth of soil (0-30 cm)								
Treatment	pH	EC (dS/m)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	Na^{+} (meq/l)	Cl^{-} (meq/l)	N (mg/kg)	P (mg/kg)	K (mg/kg)
FW	7.9a	2.73 a	6.74a	5.00 a	19.06 a	14.78 a	0.7 a	8.6 a	116 a
TWW	7.7b	4.70 b	10.89b	7.6 b	32.75 b	30.33 b	0.8 a	24.7 c	153ab

All values are the mean of three repetitions (n = 3) and bars with different letters are significantly different at $P \leq 0.05$ according to LSD test.

Heavy metals:

For the heavy metal in comparison to the control, the TWW has a significant ($P < 0.05$) effect in all elements (Table 4). The significant increase was noticed for Pb, about 97%. According to Table 2, the Cd content was depressed the upper limit range of Cd in soil (WHO, 1989).

Table 4: TWW Effect on heavy metals (mg/kg) (Cd, Co, Ni, Pb, Cu and Zn) in soil.

Soil depth (0-30cm)				
Parameters	Treatment			
		Soil irrigated with FW	Soil irrigated with TWW	
Cd		5.30 b	17.0 c	
Co		8.00 a	27.6 b	
Ni		39.3 a	93.0 c	
Pb		54.0 a	106.8 c	
Cu		9.0 a	13.7 a	
Zn		59.5 a	74.0 b	

All values are the mean of three repetitions (n = 3) and bars with different letters are significantly different at $P \leq 0.05$ according to LSD test.

TWW Effect on corn crop:

Major contents:

At the leaves and stems, the TWW has no significant effect on Na^{+} compared to the control. For roots and stems, no significant differences noted between Na^{+} in the TWW treatment and the control (Fig. 2). However, at the roots level, Na^{+} was significantly higher in crop irrigated with TWW than with the freshwater. As shown in Figure 3, the TWW has a significant effect on Cl, Ca, Mg and Na. It leads to increase Cl, Ca, Mg and Na on all crop organs. The Mg content was very low in roots than other organs (leaves and stems). This significant decrease is about 88% for the both treatments (TWW and FW).

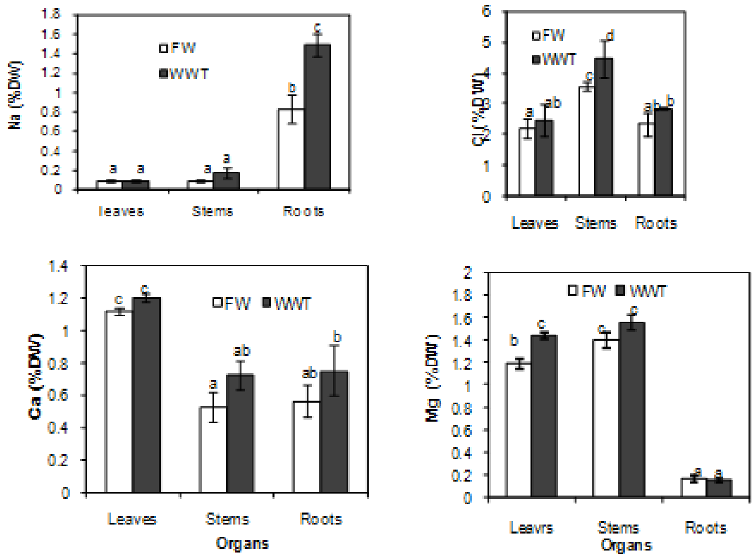

Fig. 2: Effect of TWW on major elements contents (Na, Cl, Ca and Mg) of different organs of corn crop. All values are the mean of three replications (n=3) and bars with different letters are significantly different at ($P \leq 0.05$) according to the LSD test (FW: Fresh water; TWW: Treated wastewater).

N, P and K contents:

According to Fig. 3, roots were poor in K content. The irrigation with TWW showed a significant ($p < 0.05$) increase of N, P on all crop organs. A low amount of K was shown in roots than in leaves and stems. This decrease is about 70% for the both treatments (wastewater and freshwater).

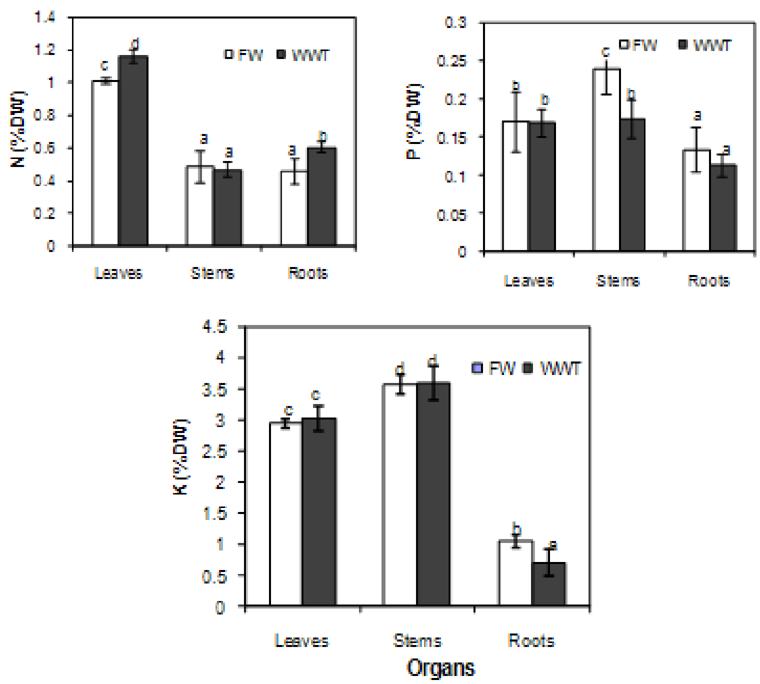

Fig. 3: Effect of TWW on N, P and K contents of different organs of corn crop. All values are the mean of three replications (n=3) and bars with different letters are significantly different at ($P \leq 0.05$) according to the LSD test (FW: Fresh water; TWW: Treated wastewater).

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Heavy metals:

As shown in Fig. 4, corn irrigated with TWW caused a significant increase ($p < 0.05$) of Cu and Zn in different corn parts as compared to corn irrigated with freshwater. While no significant effect in roots content was shown for Co. Heavy metal concentrations as Cd, Pb and Ni (Fig. 4), put in light the effect of TWW by increasing significantly the Cd, Pb and Ni content on all organs.

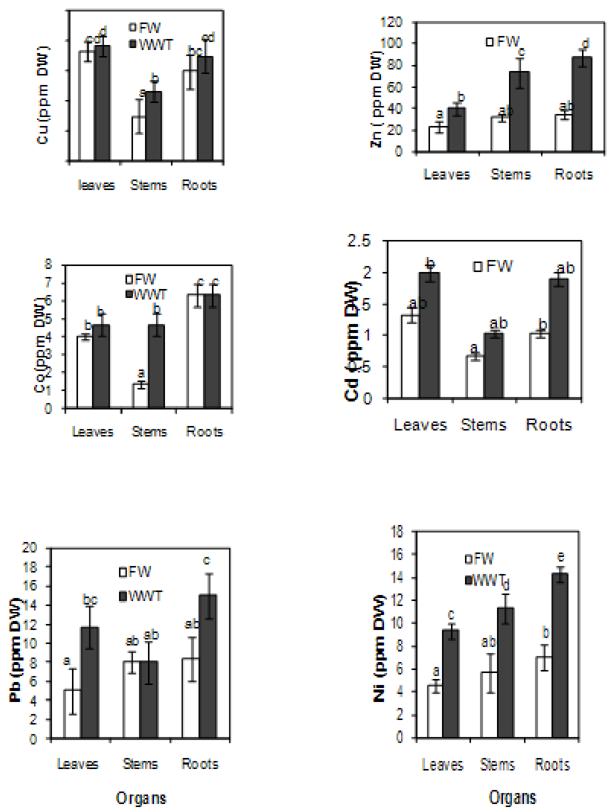

Fig. 4: Effect Of Tww On Heavy Metals (Cu, Zn, Co, Cd, Pb And Ni) Of Different Organs Of Corn Crop. All Values Are The Mean Of Three Replications (N=3) And Bars With Different Letters Are Significantly Different At ($P \leq 0.05$) According To The Lsd Test (Fw: Fresh Water; Tww: Treated Wastewater)

Discussion:

Soil salinity (EC_e) was significantly higher with TWW irrigation (Tab. 3). These results were in agreement with several authors as Rusan *et al*. (2007) and Jahantigh (2008). Mohammad and Mazahreh (2003) stated that the increase in EC for soil irrigated with TWW compared with soil irrigated with drink water attributed to the original high level of (TDS) of the TWW. In similar way, our study showed that the TWW reuse lead to a significant ($P \leq 0.05$) increase of Na and K in soil. This observation was confirmed by Khai *et al*. (2008) and Mojiri and Hamidi (2011). They reported that higher concentration of cations as Na and K in TWW led to an increase in EC_e and exchangeable Na and K in soils irrigated with TWW. As obtained in our study, the N and P were increased in the soil due to TWW use. Our investigation was in agreement with the previous works obtained by Rusan *et al*. (2007) and Khai *et al*. (2008). For soil pH, we obtained a significant increase of pH in soil surface. This is similar result of Vaseghi *et al*. (2005), Khai *et al*. (2008) and Rattan *et al*. (2005). Mohammad and Mazahreh (2003) and Kiziloglu *et al*. (2008) found significantly lower soil pH when TWW was used attributing this decrease to the high content of ammonium in TWW, which its nitrification would serve as a source of hydrogen ions thus causing a decrease in soil pH.

For heavy metals (Tab.4), we obtained a significant ($P \leq 0.05$) increase of concentrations of Cd, Co, Ni, Pb and Zn in the soil with TWW irrigation. The average values of Ni, Pb, Cu and Zn in the soil are lower than the upper limits of Ni, Pb, Cu and Zn concentrations which are, respectively,500, 200 100 and 400 $mg.kg^{-1}$, according to WHO, 1989. The accumulation of cadmium is higher than the limit mentioned in literature. The irrigation with this water quality led to enrich the soils with heavy metals in the first layer (0-30 cm). Similar results were noticed by Mapanda *et al*. (2005), Rusan *et al*. (2007) and Al-Lahham *et al*. (2007).

Accumulation of micronutrients and heavy metals could be caused directly by the TWW composition or indirectly through increasing solubility of insoluble soil heavy metals as a result of the chelation or acidification action of the applied TWW (Rusan *et al*., 2007). Based on this consideration, the study showed a significant ($P \leq 0.05$) increase of concentrations of heavy metals as Cd, Co, Ni, Pb, Cu and Zn in the soil with the TWW irrigation. We can deduce that the irrigation with TWW led to enrich the soils with heavy metals in the first layer (0-30 cm). These data was obtained by Mapanda *et al*. (2005), Rusan *et al*. (2007) and Al-Lahham *et al*. (2007). Abedi-Koupai *et al*. (2006) investigated the effect of TWW on the soil chemical properties in an arid region. They reported that the TWW reuse showed no effect on the increase of these elements during growing season.

At the level of corn, our investigation showed that irrigation with TWW reuse led to a significant increase ($P \leq 0.05$) of N, P, Ca and Mg contents in different organs of corn. This corroborates the results of Gadallah (1994), Moazzam *et al*. (2009) on sunflower crop and Rusan *et al*., (2007) on forage crops. Our result presented also a significant increase of Na^+ level in root but decrease of K^+ content in TWW use compared to fresh water. These confirm the previous study of Gadallah (1994). In addition, Bai *et al*. (2008) explained this phenomenon by the strong competition between those elements on binding sites. Moreover, Fonseca *et al*. (2005) reported that antagonistic effect between Na and K was more pronounced under low K concentrations in soil. Cl^- content watched also a significant increase in all corn parts (leaves, stems and roots). The same conclusion was reported by Gori *et al*. (2000) on *Laurustinus* specie.

Concerning Cu, Zn and Co, their contents in corn irrigated with TWW increased significantly ($P \leq 0.05$) on all organs as compared to corn irrigated with freshwater. Similar results were observed by Arora *et al*. (2008) and Galavi *et al*. (2010). Moreover, the maximum accumulation of Zn and Co was noticed in the roots parts. These results were in agreement with the results of Palit *et al*. (1994) on vegetables, Ait Ali *et al*. (2002) on corn and phragmites and Chandra *et al*. (2009) on wheat and Indian mustard. For Cd, Pb and Ni level, our study was corroborated with these obtained by Rusan *et al*. (2007) on Barely, Kiziloglu *et al*. (2008) on cauliflower and red cabbage and Yesser *et al*. (2011) on corn. Whereas, the highest amounts of Ni and Pb were found in the root parts of corn, their concentration are found to be within its natural conditions in plant tissues, (0-4 and 3-20 $mg.kg^{-1}$) (Kalra, 1998). These data was performed by others works as of these Chen *et al*. (2004) and Olowoyo *et al*. (2012).

Cadmium is one of the most toxic heavy metals due to its high mobility and the small concentration at which its effects on crops begin to show (Barcelo and Poschenfieder, 1992). As results obtained on Cd, the both roots and leaves absorbed a significant amount of Cd higher than in natural plant (0.02-1.2 $mg.kg^{-1}$). The same results were reported by Kabata-Pendias and Pendias (2001). However, Hinsely *et al*. (1984) reported that soil pH had great influence on Cd transport in corn (*Zea rnays* L.). In the contrast of our view, other authors as Jarvis *et al*. (1976) found that the roots of lettuce released much more of their absorbed Cd for translocation to the shoots than other crops (ryegrass and orchardgrass). This greater translocation is due to active transport or lack of metal absorption to fixed or soluble chelators in the root or perhaps due to exchange with the Ca, Mn and Zn moving through the roots (John, 1976). According to this hypothesis, Moral *et al*. (1994) reported also that Cd was easily transported to aerial parts of tomato.

Conclusion:

The reuse of TWW in agriculture had a significant effects on both soil and corn crop. Compared to the control treatment, the irrigation with the TWW led to increase soil salinity, majors elements as Na, Cl, Ca, Mg and fertilizer elements as N, P and K and heavy metals such as Cu, Zn, Co, Cd, Pb and Ni and decrease pH soil. For the corn crop, TWW led to significant increase of the macronutrients and heavy metals amounts.

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