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ORIGINAL PAPER

Impact of Irrigation with Treated Wastewater on Physical-Chemical Properties of Two Soil Types and Corn Plant (Zea mays)

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Abstract

Treated wastewater (TWW) reuse for irrigation is becoming more widely disseminated in order to meet the increasing water demands for agriculture, manage its limited natural resources, and promote soil fertility, especially in arid and semi-arid regions. As quality of irrigation water plays an important role in the sustainability of irrigated lands, a study was carried out to assess the effect of irrigation of corn with treated wastewater in two different soils types planting of corn plant in order to determine the suitability of this water for irrigation.

A pot experiment was conducted with a randomized complete block design. Two different soil textures, sandy and silty clay, were tested, and two water qualities, freshwater (FW) and TWW, were used for irrigation of corn plants (*Zea mays* L.). FW and TWW were analyzed for physical–chemical properties. The collected soil samples were analyzed for physical–chemical properties. As to corn plant, growth parameters were assessed. While also macronutrients and metallic trace elements (MTEs) were analyzed. TWW led to change in some physical and chemical properties of the two studied soils and consequently affected the corn growth and nutrition. Indeed, although the increase in soil salinity, plant growth parameters were improved which might be due to an increase of essential micro and macronutrient nutrients such as N, P, K, Ca, Zn, Fe, and Mg in soil. Results revealed also an important increase in toxic metals such as Pb, Ni, and Cd in both soils and, consequently, in plant tissues without exceeding the toxic level except for Ni. According to these findings, the alkalinity of both soils, the increase of organic matter content especially in sandy soil, and the predominance of clay fraction for silty clay soil could prevent the accumulation MTE at toxic levels.

Treated wastewater could be applied for irrigation of the two different soil textures studied. The extent of soil and plant contamination by toxic metals was modulated by soil pH, clay, and carbonates content, organic matter content which were evidenced as aspects to consider at the time of using TWW. However, high levels of some metallic trace elements in harvested part of the plant indicate variable relevance according to what is harvested in different species. Hence, further field studies, applying more recent chemical methods for metal determination to estimate contamination indices and toxicity health risks, are needed, considering also long-term use of TWW, since increasing demands in environmental regulations are imposing more accurate management decisions.

Keywords Treated wastewater · Sandy soil · Silty clay soil · Physical–chemical properties · Corn · Growth · Macronutrients · Metallic trace elements

1 Introduction

The freshwater scarcity is one of the factors generating environmental and social problems especially in many arid and semi-arid regions (Angelakis et al. 1999; Bedbabis et al. 2014). The challenge imposed by the shortage of freshwater is expected to become even greater due to population growth rate, urbanization, climate change, and the increasing water demand for food production (Noemi et al. 2015) which is rising the pressure on limited freshwater resources and increasing the gap between demand for water and water supply (Hussain et al. 2002). Therefore, the use of non-conventional water resources is a necessity for enhancing water supplies of the agricultural activity and for reducing the gap between freshwater availability and demand by other sectors (Toze 2006).

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The valorization of treated wastewater (TWW) for irrigation is widespread. According to the Global Water Intelligence (2010), there are about 20 million ha (presenting about 10% of the total irrigated land and 17% of the total arable land) in 50 countries irrigated with untreated, partially treated, or partially diluted wastewater worldwide. Moreover, wastewater reuse in agriculture offers some advantages which could conserve potable water supplies, promote less fertile soils with organic and inorganic nutrients, reduce the rates of fertilizer for crop plants, and decrease the damage to freshwater ecosystems associated with eutrophication and algal blooms (Nicolita et al. 2020; Abd-Elwahed 2018; Ganjegunte et al. 2018; Ungureanu et al. 2018; Gatta et al. 2016; Vergine et al. 2017).

Although multiple benefits have contributed to the valorization of wastewater use in agriculture, there are also many disadvantages depending on its source and chemical composition. Indeed, TWW may contain toxics and microbial components that contribute to serious environmental and health hazards (Elgallal et al. 2016; Gatta et al. 2016). TWW reuse for irrigation may contribute to high amount of salt content in soils, if not removed during wastewater treatment processes (Bahri 1998), which may cause soil salinization (Klay et al. 2010). It may also lead to elevated levels of exchangeable sodium concentrations. Thereby, sodium (Na^+) replaces exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) by mass action, which can lead to sodicity problems and, consequently, cause deterioration of soil structure, clay dispersion, and permeability reduction (Elgallal et al. 2016; Muyen et al. 2011), thus reducing crop productivity (Krasensky and Jonak 2012).

The continuous reuse of TWW for irrigation may, also, lead to an excessive accumulation of trace elements (TEs), such as copper (Cu), cobalt (Co), zinc (Zn), manganese (Mn), iron (Fe), chromium (Cr), nickel (Ni), lead (Pb), and cadmium (Cd), to a toxic level in topsoil that threaten plant growth (Megateli et al. 2009; Rattan et al. 2005) and subsequent transfer through various food crops and fodders to the food chain generating a potential health risk to consumers (Gatta et al. 2016). The mobility and bioavailability of TEs in soil depend on pH, clay minerals and calcium carbonate ($CaCO_3$) content, and the amount of organic matter (OM) (Avci and Deveci 2013; Elgallal et al. 2016; Olaniran et al. 2013). Indeed, it has been demonstrated that the increase of soil pH and the amount of OM combined with clay in addition to the existence of $CaCO_3$ decreases the mobility and the availability of TE (Avci and Deveci 2013; Kalavrouziotis et al. 2008). The level of TE in soil solution is governed by many processes such as oxidation reduction reactions, inorganic and organic complexation, adsorption/desorption reactions, and precipitation/dissolution reactions (Kabata-Pendias 2004).

With regard to serious problems caused by the inappropriate use of wastewater, it is imperative to inform about the measures of good practice including the permanent assessment of wastewater quality that will be reused to verify the conformity with the standards and monitoring in short and long term the properties of soils and crops irrigated with this water. In this way, various scientists have recently studied the impact of treated wastewater irrigation, at short (Guo et al. 2017; Cary et al. 2015) and long term (Andrews et al. 2016; Bardhan et al. 2016; Bedbabis et al. 2014; Guy et al. 2014), on physicochemical properties of soil. Their results showed that long-term irrigation with reclaimed water contributed to an important increase of salt concentrations, plant nutrients, and significant buildup of metal trace elements (MTEs) in soil. As reported by Khaskhoussy et al. (2019) and Khalid et al. (2017), plants irrigated with wastewater showed elevated contents of MTEs in their tissues. In general, the uptake of MTEs depends on some factors as soil pH, clay amount, and OM. Thus, any increase in soil pH with the presence of a high amount of clay will cause a decrease in metal uptake by plants. A decrease in metal uptake due to an increase in the clay content and soil pH was also mentioned by Khan et al. (2018). Moreover, they also noted that MTEs can be found as chelates in soil rich in OM, which increases the ability of wheat to uptake MTEs (Khan et al. 2018).

The monitoring of wastewater and soil qualities under short- or long-term irrigation with reclaimed wastewater is necessary to limit the influence of salinization and contamination by toxic elements. However, success reuse of TWW without hazardous consequences for crops, soils, surface, and groundwater sources requires proper management strategies including specific irrigation management plan, use of appropriate irrigation method, and the selection of tolerant crops (Assadian et al. 2005). There is also the need to choose a suitable soil texture. Soil type should be chosen based on its capacity to be more productive and sustainable upon reclamation. Based on this, a majority of the studies have assessed soil quality under TWW, but few research studies have investigated the impact of TWW irrigation acting on different management practices. A previous research (Khaskhoussy et al. 2019, 2015) studied the effect of wastewater using different irrigation methods on a single soil texture type and corn. This work aimed to assess the impact of TWW reuse for irrigation on two different soils planted with corn and discusses the suitability of this water for irrigation of different soils types.

2 Materials and Methods

2.1 Experimental Design

A pot experiment was conducted under greenhouse from Jun to August 2012 at the experimentation site of the INRGREF of Tunis. Two soils of silty clay and sandy, belonging to Vertic Xero Fluvent and hydromorphic alluvial soil classes, were taken from the surface layer (0–20 cm) of Cebela-Borj

Touil and Oued Souhil experimental stations. Each pot containing 17 kg of soil was previously perforated on its side to allow the water drainage and filled with quartz gravel up to a thickness of 2 cm. A geotextile filter was placed above the gravel bed to stabilize the soil and filter the water. Two water qualities, freshwater (FW) and TWW, were used for irrigation. The combination between soil type and water quality resulted in 4 treatments: sandy soil (SS) irrigated with FW (SSFW); silty clay soil (SCS) irrigated with FW (CSFW); sandy soil irrigated with TWW (SSTWW); and silty clay soil irrigated with TWW (CSTWW). Each treatment was replicated five times, with a total of 20 pots. All pots were arranged in a randomized block design. The TWW used was supplied by the Chotrana treatment plant located north to Tunis City. The wastewater is mainly domestic and treated up to a secondary biological treatment. A corn (*Zea mays* L.) *Arper* cultivar, which was previously tested and showed to be tolerant to salt stress, was used. Corn seeds were obtained from COTUGRAIN SOCIETY and certified according to council directives 92/117/EEC of 17 December 1992, 99/42 of 10 May 1999, 2009/69 of 12 August 2009, and 2002/621of 19 March 2002. Seeds were directly sowed in the pots (two seeds in each pot). The irrigation water was applied according to the loss by evapotranspiration. Irrigation scheduling was calculated with the climate parameters and water requirement of the crop (evapotranspiration ETc). ETc was estimated based on FAO56 approach; the crop coefficient Kc was estimated from tables, while the estimation of the reference evapotranspiration was calculated according to the standard method of FAO Penman–Monteith equation (Allen et al. 1998). At each irrigation event, the amount of water was applied to cover the evapotranspiration loss during the previous 3 days. The total amount of water applied for corn plant was 377.2 mm for sandy soil and 325.3 mm for silty clay soil. Plant height and diameter were measured weekly by height rule and caliper, respectively. Maximum leaf area was determined by planimeter (Delta-T Devices Ltd), and the total corn biomass was weighed.

2.2 Water Sampling and Analysis

From each water quality (FW and TWW), five water samples were taken for analysis during the experimental period.

The chemical analyses of the two water sources concerned pH, electrical conductivity (EC), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), ammonia nitrogen ($N\text{-}NH_4^+$), phosphorus (P), and MTE content (sulfate or carbonate). Sodium and potassium were measured by flame photometry (NF A20-603. 1989). Ca^{2+} and Mg^{2+} analyses were done using EDTA titration method. The sodium adsorption ratio (SAR) was calculated as follows:

$$SAR = [Na^+]/\sqrt{[(Ca^{2+} + Mg^{2+})/2]},$$

where the concentrations of Na^+, Ca^{2+}, and Mg^{2+} are expressed in meq L^{-1}.

Chloride (Cl^-) determination was done titrimetrically in the presence of silver nitrate (AgNO3) (INNORPI 1989, NT 09.77). Sulfate (SO_4) content was analyzed by EDTA titration method. The nitrogen ($N\text{-}NH_4^+$) determination was carried out by Kjeldahl method (INNORPI NT 09.31. 2006). Phosphorus (P) was determined by spectrophotometric method (Kopacek et al. 2001). MTEs in water were extracted by using a pure nitric acid. After filtration, MTE concentration was measured by flame atomic absorption spectrometry (FAAS) (NF FD T90-112, 1998).

2.3 Soil Sampling and Chemical Analyses

Soil samples were collected from five replicate pots; each soil sample (0–20 cm) represented the whole pot. The collected samples were air-dried and sieved to pass through a 2-mm sieve for preparation before chemical analysis.

The granulometric analysis was done by the pipette method (Jackson and Saeger 1935), and cation exchange capacity (CEC) was measured at pH 7 with ammonium acetate (Chapman 1965). The electrical conductivity (EC) was measured by a conductivity meter on the saturated paste extract of the soil samples. Soil pH was determined, by using a pH meter, in a suspension of soil/distilled water at ratio of 1:2.5. Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and HCO_3^- were quantified from saturation paste extract of the soil samples. Sodium and potassium were determined using flame photometry. Ca^{2+} and Mg^{2+} analyses were analyzed by EDTA titration method. Cl^- was measured titrimetrically with $AgNO_3^-$ (Karaivazoglou et al. 2005). HCO_3^- was determined by sulfuric acid (H_2SO_4 0.01 N) titration method. The total nitrogen (TN) content of the soil was determined according to the Kjeldahl method (Bremner and Mulvaney 1982). Phosphorus was determined by using Olsen method (Olsen and Sommers 1982).

For soil total trace elements determination, 1 g of grounded sieved soil samples was mineralized into solution using a microwave with a mixture of HF (10 mL) and perchloric acid (5 mL of $HClO_4$) (Şerife et al. 2001). Then, 70 mL of $HClO_4$was added to the mixture. Digested soil samples were filtered and diluted using distilled water. The filtrate was analyzed by flame atomic absorption spectrometry (ISO 14869–1. 2001) in order to measure Co, Cu, Mn, Fe, Zn, Pb, Ni, and Cd concentrations.

2.4 Plant Sampling and Chemical Analyses

During the growth stages of corn, plant height, diameter, and maximum leaf area were measured by a graduated ruler, a caliper, and a planimeter (Delta–T Devices LT), respectively.

After harvesting (120 days), nine plants from each treatment were washed with abundant de-ionized water and separated into roots, stems, and leaves. All plant parts were oven-dried for 72 h at 80 °C. After drying, plant parts were ground to < 0.25 mm and stored for different analysis.

From each treatment, 0.5 g of dried and grounded plant sample was digested in a microwave with a mixture of 10 mL of HNO_3 and 5 mL $HClO_4$ acids. After digestion, samples were filtered and analyzed for Na, Cl, Ca, Mg, Fe, Co, Cu, Mn, Zn, and Pb. Different studied elements were determined by flame atomic absorption spectrometry (FAAS) (ISO14869-1). Detection limit values of elements (10^{-3} mg L^{-1}) were found to be 0.12 for Co, 0.07 for Cu, 0.11 for Fe, 0.05 for Mn, and 0.02 for Zn.

The quantity of each analyzed element exported by plant from the soil was calculated according to the expression (Neel et al. 2007):

$$Q_s = C \times Y$$

where Qs is the quantity exported in mg m^{-2}; C is the concentration of element in corn organ expressed per mg kg^{-1}, and Y is the yield expressed per kg (dry matter m^{-2}).
In this study, the exported quantity (Qs) was calculated and expressed per mg as follow:

$$Q_s = C \times DW$$

where C is the concentration of element in corn organ expressed per mg kg^{-1} and DW represents the dry weight of roots, stems, and leaves of corn plant expressed in kg.

2.5 Statistical Analyses

The comparison between TWW and FW characteristics was determined using independent sample statistical *t*-test. For each soil type, the differences between the effects of FW and TWW irrigation on the soil and corn variables were evaluated using one-way ANOVA. The separation of means was determined according to the post hoc Tukey test ($p < 0.05$) when corresponding. The effects of interaction between water quality and soil types on different studied variables were tested using a two-way ANOVA statistical test. All statistical analyses were performed with the SPSS software (20).

3 Results

3.1 Quality of Irrigation Water

The mean values of the physicochemical characteristics of the TWW and FW used for the experiments are presented in Table 1. The FW was alkaline (pH = 8.45) with significantly ($p < 0.05$) higher pH values than those of TWW (7.67). The EC for TWW was higher than FW and slightly above (3.62 dS m^{-1}) 3 dS m^{-1} which exposed a marked degree of restriction for the use in irrigation of crops.

In general, the two irrigation water types were dominated by sodium chloride; nevertheless, their values in TWW were significantly higher ($p < 0.05$) compared to those of FW. The total phosphorus and nitrogen contents were below the Tunisian thresholds (NT 106.03). In case of FW, P and N elements were not detected. TE concentrations in TWW were higher ($p < 0.05$) compared to those of FW but remained below the Tunisian thresholds.

3.2 Physicochemical Characterization of the Soils

According to Table 2, texture of studied soils showed a predominance of the sand fraction (91%) for the sandy soil and the predominance of clay and loamy fractions (42% for clay fractions and 48% for loamy fractions) for the silty clay soil, which shows a higher CEC (30.10 meq 100 g^{-1}) than sandy soil (5.5 meq 100 g^{-1}).

The mean values of pH, EC, SAR, Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, N, and P of the both soils layers before and after irrigation are presented in Table 3. The initial value of the sandy soil (control SS) pH showed that it was significantly ($p < 0.05$) reduced due to TWW irrigation. In the case of the silty clay soil (SCS), there was no significant decrease in pH in response to TWW irrigation ($p < 0.05$). EC showed that irrigation with TWW gave high concentrations of salt components which increased EC values in both soils. For FW treatments (SSFW and SCSFW), the EC values were lower than control values (control SS and control SCS). Irrigation with TWW caused a significant increase ($p < 0.05$) in Na^+, K^+, Ca^{2+}, Mg^{2+}, $HCO3^-$, and Cl^-. The SAR showed also a significant ($p < 0.05$) increase under TWW application. As to SSFW and SCSFW treatments, SAR values showed a slight decrease. A significant increase ($p < 0.05$) in OM, N, and P under TWW treatment for both soils was also observed.

The concentrations of different studied MTEs before (control SS and control SCS) and after treatments (SSF, SSTW, SCFW, and SCSTWW) are also presented in Table 3. Concerning sandy soil (SS), the following elements showed a significant increase in comparison with control values (control SS): Cu (20%), Mn (12%), Fe (12%), Zn (17%), Pb (4%), and Ni (5%) under SSTWW treatment. The apparent slight increase in the average contents of Co is not significant ($p < 0.05$). The contents of different MTEs decreased in case of SSFW treatment (all less than – 20%). As for silty clay soil (SCS), except for Co, the concentrations of different MTEs showed a significant increase under TWW irrigation: 69%, 34%, 22%, 20%, 21%, 40%, and 42% for Cu, Mn, Fe, Zn, Pb, Ni, and Cd, respectively. On the contrary, under SCSTWW treatment, only a slight decrease was observed for Fe. Results indicate that the interactions between soil type and water quality (soil*water) are significant for Cl, Na, K, and all MTEs except for Co.

Table 1 Physicochemical characteristics of freshwater and treated wastewater used for irrigation

Parameter	Water irrigation			
	FW^1	TWW^2	Guideline for TWW reuse^3	Tunisian threshold^4
pH	8.45 ± 0.04a	7.67 ± 0.02b*	6.50–8.40	6.50–8.50
CE (dS m^{-1})	1.38 ± 0.09a	3.62 ± 0.10b	< 3.00	7.00
SAR	5.66 ± 0.70a	10.22 ± 1.30b	-	-
Na^+ (meq L^{-1})	9.47 ± 0.35a	19.35 ± 1.05b	300.00	-
K^+ (meq L^{-1})	0.14 ± 0.05a	0.73 ± 0.24b	50.00	-
Ca_2^+ (meq L^{-1})	6.28 ± 0.12a	7.81 ± 0.06b	-	-
Mg_2^+ (meq L^{-1})	4.91 ± 0.03a	6.53 ± 0.34b	-	-
Cl^- (meq L^{-1})	9.39 ± 0.62a	20.67 ± 1.35b	-	-
$HCO3^-$ (meq L^{-1})	3.21 ± 0.42a	4.15 ± 0.06a	-	-
SO_4^- (meq L^{-1})	6.45 ± 0.23a	15.36 ± 1.32b	500.00	-
N (mg L^{-1})	0.00 ± 0.00a	22.00 ± 0.30b	50.00	-
P (mg L^{-1})	0.00 ± 0.00a	0.08 ± 0.10b	< 0.94	-
Co (mg L^{-1})	0.02 ± 0.03a	0.07 ± 0.01b	0.05	0.10
Cu (mg L^{-1})	0.02 ± 0.01a	0.08 ± 0.04b	0.50	0.50
Mn (mg L^{-1})	0.03 ± 0.01a	0.04 ± 0.01a	0.10	-
Fe (mg L^{-1})	0.08 ± 0.03a	0.15 ± 01b	5.00	-
Zn (mg L^{-1})	0.01 ± 0.01a	0.35 ± 0.08b	3.00	5.00
Pb (mg L^{-1})	0.01 ± 0.02a	0.08 ± 0.04b	0.05	1.00
Ni (mg L^{-1})	0.03 ± 0.05a	0.17 ± 0.03a	0.20	0.20
Cd (mg L^{-1})	0.01 ± 0.02a	0.01 ± 0.04a	0.01	0.01

Data are means ± standard deviation values ($n = 5$), *different letters indicate significant differences between values among water types ($p < 0.05$; *t*-test). ^{1}Freshwater, ^{2}treated wastewater, ^{3}WHO (1989), ^{4}Tunisian threshold (NT 106 03) for treated wastewater reuse in irrigation

Table 2 Soil texture and CEC

Soil type	Parameter				
	Percentages of the three particle sizes (%)			Textural classification according to USDA*	CEC (meq 100 g^{-1})
Common name of soil	Sand (50–2000 µm)	Silt (2–50 µm)	Clay (< 2 µm)		
Sandy	91**	4**	5**	Sandy**	5.5**
Clay	10**	48**	42**	Silty clay	30.1**

*US Department of Agriculture. **All data represent the result of analyses of a composite soil samples (one homogenous sample is the mixing of samples taken from 5 sampling sites of the same area)

3.3 Effect of Wastewater Irrigation on Corn

3.3.1 Plant Growth

The variation of the plant height under different treatments (SSFW, SSTWW, SCSFW, and SCSTWW) according to growth stages of corn is shown in Fig. 1. In the first 2 weeks of growth, height values for plant grown in both soils showed no significant variation ($p < 0.05$) because TWW was applied after the 10 days of plantation. Since 42 days after plantation to the end of vegetative stage (62 days), corn growth got faster and then stabilized when maximum height was reached triggering the beginning of the maturation stage. During the growing period, corn plants under SCSFWW treatment exhibited the highest values with maximum of 139.27 cm of height.

Figure 2 represents the value of biomass, maximum leaf area, and diameter under different treatments. TWW application caused a significant increase in biomass, maximum diameter, and leaf area of plant grown in both soils. Results indicate that corn plant grown on the silty clay soil showed the highest values of diameter, biomass, and leaf values under irrigation with treated wastewater, while the lowest values were obtained in corn grown on sandy soil and

Table 3 Physicochemical characterization of soils at initial condition and at the end of experiment

Parameter	Treatment						
	Control SS[1]	SSFW[2]	SSTWW[3]	Control SCS[4]	SCSFW[5]	SCSTWW[6]	AFNOR (NFU44-041)[6]
pH	8.57 ± 0.06a	8.50 ± 0.08a	8.39 ± 0.02b	8.74 ± 0.20a	8.70 ± 0.50a	8.69 ± 0.31a	-
EC (dS m^{-1})	2.33 ± 0.05d	2.28 ± 0.01d	2.62 ± 0.03c	3.29 ± 0.15b	3.18 ± 0.09b	4.20 ± 0.05a	-
SAR	1.35 ± 0.11d	1.26 ± 0.09d	10.87 ± 0.79b	6.66 ± 0.12c	6.59 ± 0.20c	18.86 ± 2.30a	-
Na (meq L^{-1})	2.82 ± 0.03d	2.60 ± 0.05e	22.40 ± 0.37b	17.50 ± 0.60c	17.10 ± 1.10c	66.30 ± 3.50a	-
K (meq L^{-1})	0.17 ± 0.21d	0.11 ± 0.15e	0.90 ± 0.25b	0.34 ± 0.04c	0.30 ± 0.19c	4.47 ± 0.10a	-
Ca (meq L^{-1})	4.20 ± 0.06c	4.10 ± 0.29c	4.80 ± 0.21b	5.30 ± 0.50b	5.20 ± 0.80b	9.80 ± 0.50a	-
Mg (meq L^{-1})	0.20 ± 0.03d	0.20 ± 0.001d	0.41 ± 0.01c	3.20 ± 0.08b	3.04 ± 0.21b	5.10 ± 0.04a	-
Cl (meq L^{-1})	10.00 ± 0.81a	9.26 ± 1.05d	25.10 ± 1.04b	23.00 ± 1.80bc	21.10 ± 0.90c	60.50 ± 1.90a	-
SO$_4$(meq L^{-1})	3.50 ± 0.01b	3.30 ± 0.16e	8.50 ± 1.20c	14.50 ± 0.23b	14.00 ± 0.71b	27.00 ± 1.04a	-
HCO$_3$ (meq L^{-1})	4.48 ± 0.02b	4.31 ± 0.16b	6.50 ± 0.04a	4.50 ± 0.10b	4.01 ± 0.65b	6.20 ± 0.12a	-
OM%	0.80 ± 0.02e	0.61 ± 0.05f	1.20 ± 0.06d	2.20 ± 0.09b	1.80 ± 0.10c	2.80 ± 0.13a	-
N (mg kg^{-1})	0.14 ± 0.01d	0.09 ± 0.02e	0.21 ± 0.03c	0.80 ± 0.05b	0.76 ± 0.04b	1.20 ± 0.04a	-
P (mg kg^{-1})	15.20 ± 1.50d	11.00 ± 0.29e	17.70 ± 0.20c	22.00 ± 1.20ab	21.20 ± 0.50b	24.00 ± 0.20a	-
Co (mg kg^{-1})	14.80 ± 0.50b	13.85 ± 1.87b	15.61 ± 1.35b	30.90 ± 1.03a	30.85 ± 1.2a	30.91 ± 3.02a	30
Cu (mg kg^{-1})	19.20 ± 0.21c	19.23 ± 0.12c	32.65 ± 3.40b	35.10 ± 4.80ab	31.42 ± 4.10b	41.49 ± 2.32a	100
Mn (mg kg^{-1})	24.96 ± 0.81c	24.05 ± 1.42c	27.81 ± 2.56c	52.48 ± 1.62b	51.93 ± 2.43b	70.70 ± 2.45a	-
Fe (mg kg^{-1})	57.60 ± 1.67d	53.17 ± 5.23d	64.53 ± 1.55b	93.80 ± 2.12b	90.76 ± 3.46b	114.85 ± 4.86a	-
Zn (mg kg^{-1})	21.00 ± 0.3d	20.80 ± 1.06d	24.40 ± 0.60c	40.2 ± 0.01b	40.18 ± 0.09b	58.24 ± 0.54a	300
Pb (mg kg^{-1})	43.00 ± 1.84 cd	42.50 ± 2.20d	45.06 ± 1.33c	90.20 ± 2.98b	87.75 ± 3.32b	95.17 ± 1.78a	100
Cd (mg kg^{-1})	1.10 ± 0.40c	1.10 ± 0.20c	2.00 ± 0.41b	2.20 ± 0.26b	2.00 ± 0.40b	3.00 ± 0.10a	2
Ni (mg kg^{-1})	21.60 ± 0.11d	21.00 ± 0.40d	23.00 ± 0.25c	59.9 ± 0.10b	59.86 ± 0.50b	67.42 ± 0.28a	50

Mean value ± standard deviation values from five replicate ($n = 5$). Different letters in each line indicate significant differences among treatments according to Tukey's test ($p < 0.05$). Different treatment: 1, sandy soil before irrigation; 2, sandy soil irrigated with FW; 3, sandy soil irrigated with TWW; 4, silty clay soil before irrigation; 5, silty clay soil irrigated with FW; 6, silty clay soil irrigated with TWW; 7, AFNOR standard

irrigated with FW. Maximum values of biomass, diameter, and leaf were, respectively, 62 g plant^{-1}, 1.84 cm, and 306 cm^2, while minimum values were 50 g plant^{-1}, 1.21 cm, and 233.56 cm^2, respectively.

3.3.2 Macro-elements and MTEs Uptake

ANOVA analysis results for nitrogen, phosphorus, and potassium showed a significant difference ($p < 0.05$) among the types of irrigation water. Corn plant irrigated with TWW contained higher N, P, and K concentrations in different corn organs than those irrigated with FW. The highest N, P, and K contents in the plant tissues of corn crop irrigated with TWW were, respectively, 0.37, 0.03, and 1.7% in case of SS and 1.15, 0.06, and 2.14 in case of SCS (Fig. 3a, b, c, d, e, f).

The effect of irrigation with FW and TWW on macro- (Na, Cl, Ca, and Mg) and microelements (Co, Cu, Mn, Fe Zn, Pb, Ni, and Cd) concentrations in corn tissues grown in sandy and silty clay soil was tested (Figs. 4, 5, and 6). Results indicate that there were significant differences between water treatments ($p < 0.05$). For both soil textures, Na, Cl, Ca, Mg, Co, Cu, Mn, Fe, Zn, and Pb contents in the roots, stems, and leaves of corn irrigated with FW were less than in those irrigated with TWW. The highest concentrations of Na (2.14%),

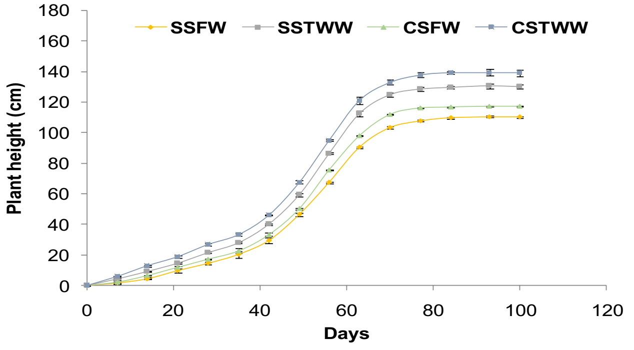


Fig. 1 Corn height evolution throughout the growing period. SSFW treatment: plants grown in sandy soil irrigated with freshwater; SCSFW treatment: plants grown in silty clay soil irrigated with freshwater; SSTWW treatment: plants grown in sandy soil irrigated with treated wastewater; and SCSTWW treatment: plants grown in silty clay soil irrigated with treated wastewater. Vertical bars represent the standard deviation ($p < 0.05$; Tukey's test)

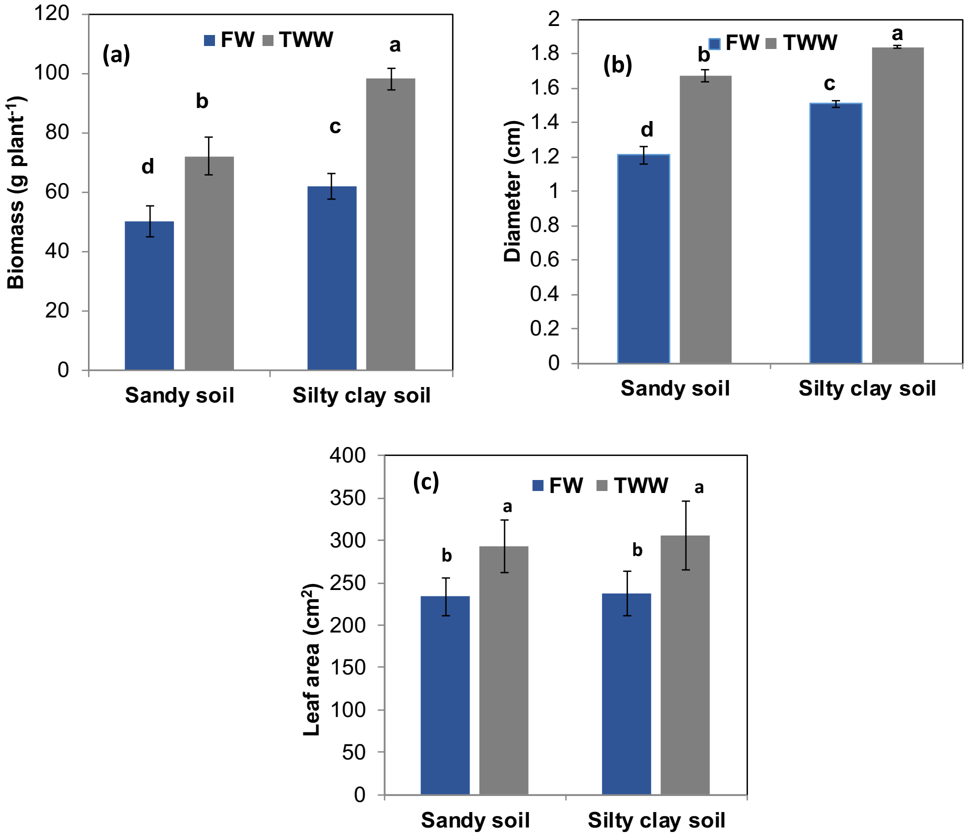


Fig. 2 Variation of biomass (**a**), stem diameter (**b**), and maximum leaf area (**c**) of corn plant grown in two soils under the different water irrigations. Means with different letters indicate that interaction effect (soil type*water quality) is statistically significant ($p < 0.05$) FW freshwater; TWW treated wastewater

Cl (3.08 mg kg^{-1}), Co (13.53 mg kg^{-1}), Fe (173.4 mg kg^{-1}), Zn (40.99 mg kg^{-1}), Pb (7.89 mg kg^{-1}), Ni (15.2 mg kg^{-1}), and Cd (0.04 mg kg^{-1}) were recorded in roots of corn, whereas the highest amounts of Ca (1.28%), Mg (1.94%), and Mn (33.1 mg kg^{-1}) were observed in leaves and stems.

The two-way ANOVA indicates that the interactions between soil and water are significant for Pb in different plant organs; for Na and Co in roots and leaves; for Cl, Mn, and Cu in stems; and for Mg and Fe in roots and stems except for Ca and Zn.

According to Table 4, quantities of different studied elements exported by plant irrigated with TWW were significantly ($p < 0.05$) higher than those exported by plant irrigated with FW. Moreover, total elements assimilated by corn grown in silty clay soil were more important than those assimilated by corn grown in sandy soil. Additionally, Na and Fe are the most exported elements. In contrast, Pb and Cd represent the least exported elements by corn.

4 Discussion

Assessment of soil quality under TWW is important for checking the capacity of soil to sustain biological productivity and support human health and habitation (Thoumazeau et al. 2018). Results for pH show a slight decrease under TWW irrigation, which is similar to the finding of Abegunrin et al. (2013). On the contrary, other research studies (e.g., Abegunrin et al. 2016; Rattan et al. 2005; Rusan et al. 2007) documented an increase in soil pH due to TWW application. Any change in pH level has a repercussion on metal behavior, since any decrease in soil pH would favor availability and mobility of the metals. This change could be conditioned by the addition of organic matter to soils, so the increase or the decrease in soil pH would depend on consumption or release of protons (Sparling and Lowe 1996; Abegunrin et al. 2016). Moreover, the decrease in the pH level of soil can be explained by the decomposition of organic matter producing the organic acids (Khai et al. 2008; Mojiri and Hamidi 2011), and this statement could be linked to our results. Considering the results of both studied soils, the slight decrease in soil pH was more significant in the case of sandy soil than in silty clay soil, which can be attributed to the buffering capacity of the silty clay soil. Consistent with the results of this study, soils containing high amounts of clay and/or organic matter typically had greater buffering capacity (McCauly et al. 2017) that reduced the negative effects of TWW by increasing or decreasing the pH level of the soil.

Soil salinity is an important indicator of soil productivity. Indeed, any increase in EC could affect soil processes and productivity (Adviento-Borbe et al. 2006). Results of EC in

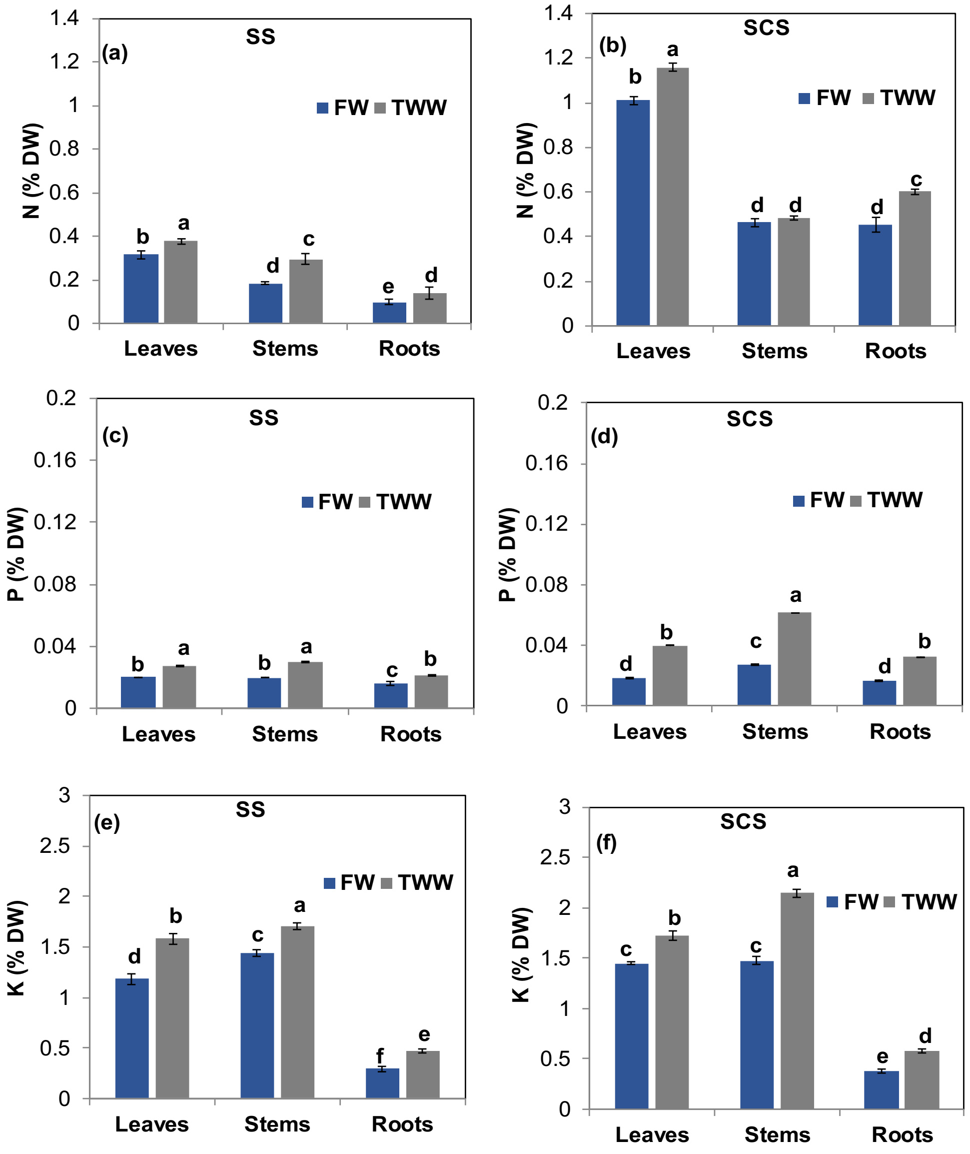


Fig. 3 Effect of water quality on nitrogen (**a**, **b**), phosphorus (**c** and **d**), and potassium (**e** and **f**) content in different corn parts. Different letters indicate significant differences ($p < 0.05$) among treatments according to Tukey's test. SS sandy soil, SCS silty clay soil, FW freshwater, TWW treated wastewater

soils revealed a significant increase in salinity of soil irrigated with treated wastewater in comparison with soil irrigated with freshwater. An increase in soil salinity has been also documented (Mojiri and Hamidi 2011; Xiaomin et al. 2019). The increment of the EC values has been explained by the increase of cation concentration (Ca, Mg, K, and Na) in effluent water (Abegunrin et al. 2016), and this explanation could be linked to our results that revealed a significant increase in Ca, Mg, K, and Na concentrations. Generally, the increase of cations as sodium in the irrigation water could increase the risk of soil sodicity, which is assessed by the SAR. In this investigation, SAR ranges between 10 and 18 indicated a moderate risk of soil sodicity. Similar to the present study, reclaimed water increased the exchangeable sodium level in the surface of soil (ESP levels > 8), and this increase could be the origin of physical problems associated with clay dispersion, surface crusting, and pore plugging (Bauder et al. 2014; Guy et al. 2014). These problems would be more accentuated in the case of the silty clay soil.

TWW is well known as a source of nutrients and organic matter. The presence of NPK (nitrogen, phosphorus, and potassium) in the secondary effluent serves as a fertilizer which is necessary for plant growth (Segal et al. 2011). As presented in this study, irrigation with TWW increased organic matter, phosphorus, and total nitrogen contents in both studied soils. Similar results were obtained by Osakwe (2012) and Thapliyal et al. (2011). In accordance with this finding, WW can bring between 4 and 10 times of N and P amounts more than the amounts adequate to meet the needs of the crop (Burns et al. 1985). The increase in total nitrogen concentration in soil was due to nitrogen mineralization as a result of the addition of organic matter (Abegunrin et al.

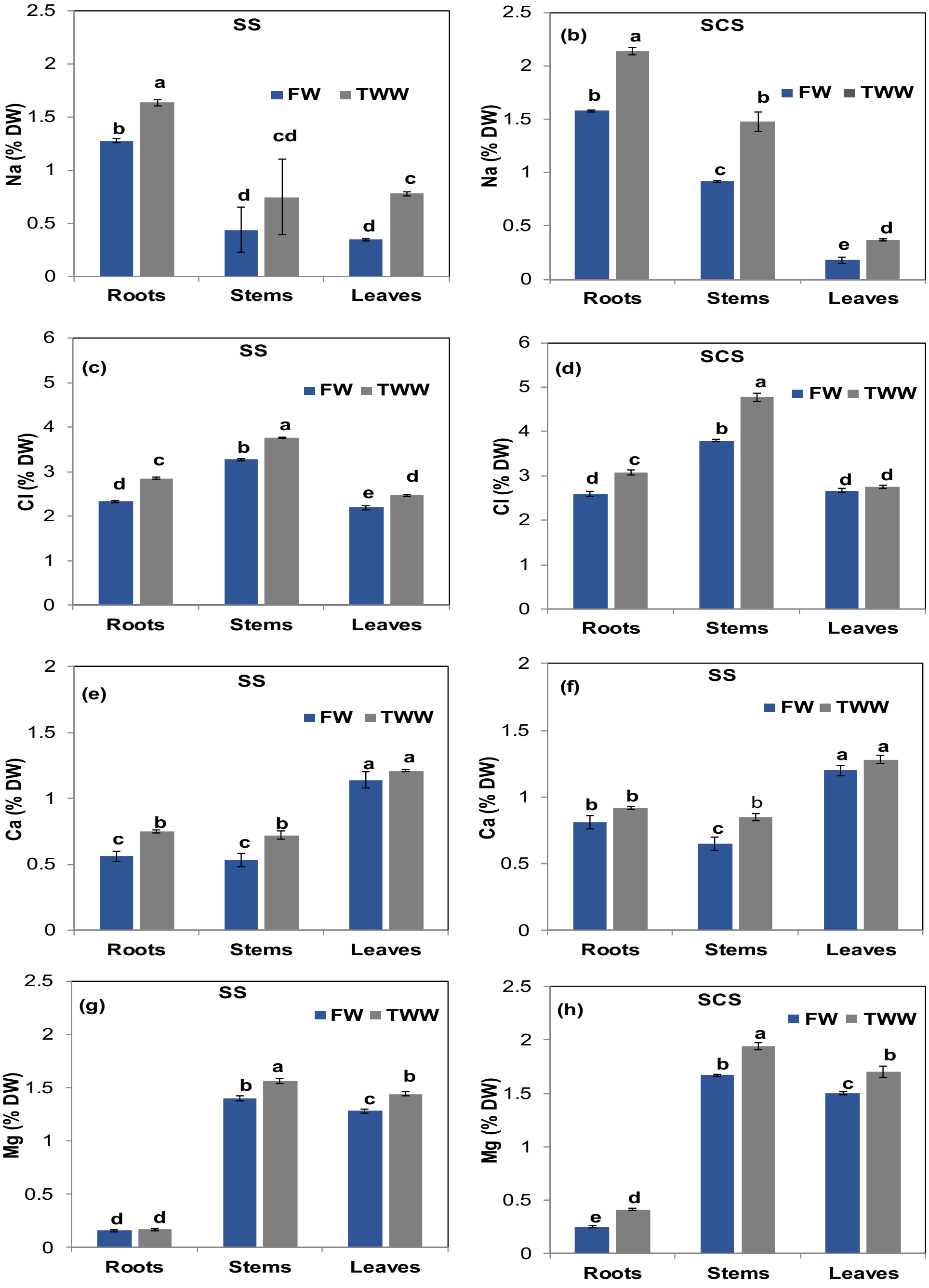


Fig. 4 Mean value of Na (**a** and **b**), Cl (**c** and **d**), Ca (**e** and **f**), and Mg (**g** and **h**) in different corn parts grown in both soils and irrigated with two FW and TWW. Different letters indicate significant differences ($p < 0.05$) among treatments according to Tukey's test. SS sandy soil, SCS silty clay soil, FW freshwater, TWW treated wastewater

2016). The increase of organic matter in both soils, in this study, was also demonstrated. In similar way, it was supposed that soil organic carbon levels can be significantly increased in sandy soils under agriculture when amendments are made in combination with irrigation (Jenifer and Alfred, 2019). Generally, irrigation with FW showed a decrease in the amounts of nutrients, particularly for the sandy soil. This decrease was due to the leaching of nutrients in soil with high water infiltration rate and low nutrient retention capacity with low organic matter content (Uexküll 1986).

Regardless of the benefits provided by reducing the rates of fertilizer for crop plants, one of the major limitations of using TWW is the presence of toxic substances, in particular, heavy metals, in their composition. This fact created both opportunities and risks for agricultural production (Xu et al. 2010). As presented in this study, TWW increased MTEs (Co, Cu, Mn, Fe, Zn, Pb, Ni, and Cd) in both studied soils. In agreement with this result, total and available Zn, Cu, Pb, Cd, Cr, and Ni increased following wastewater water application to soils (Xiaomin et al. 2019). The increase in trace metals presents a significant problem as it negatively

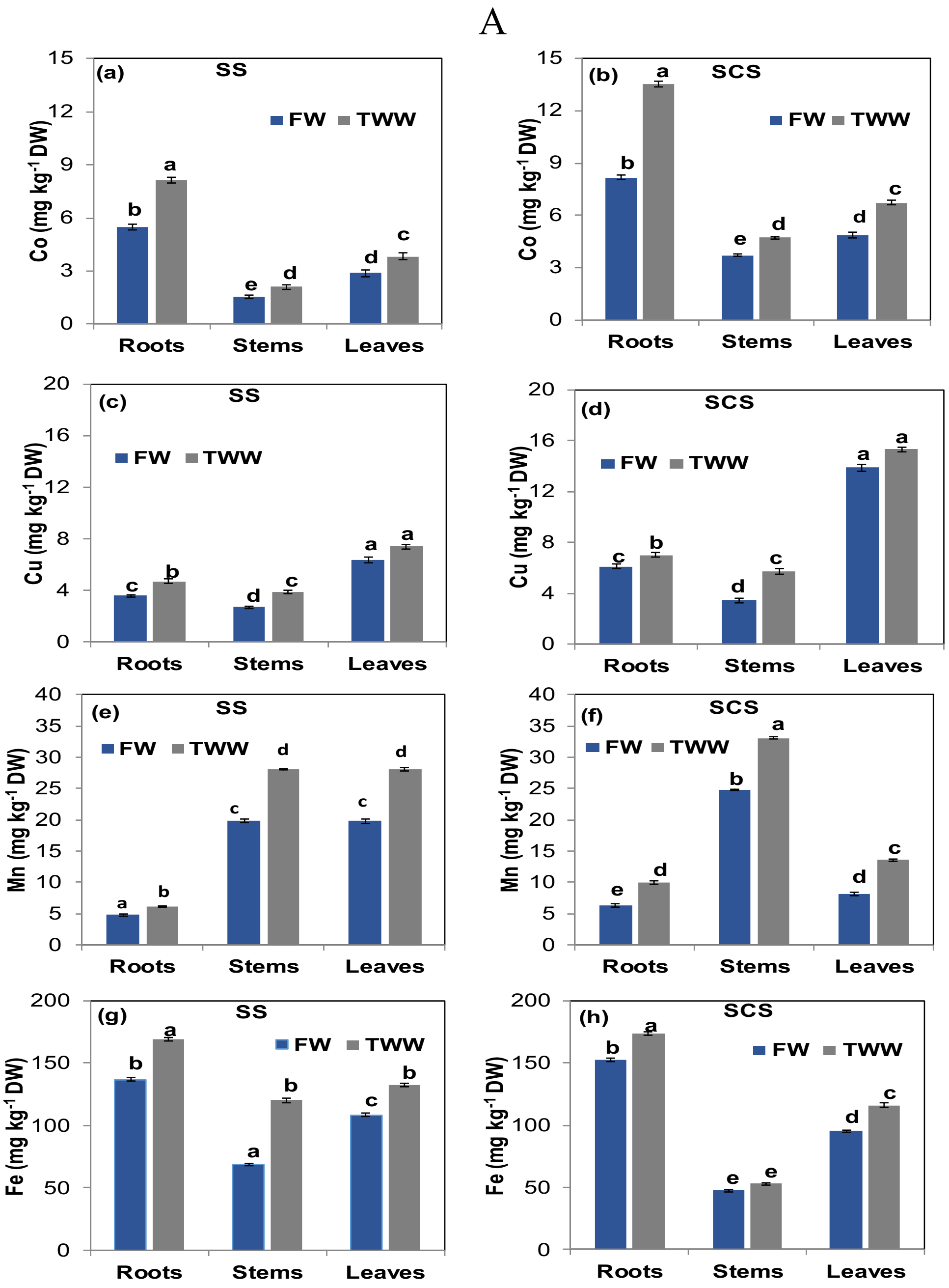
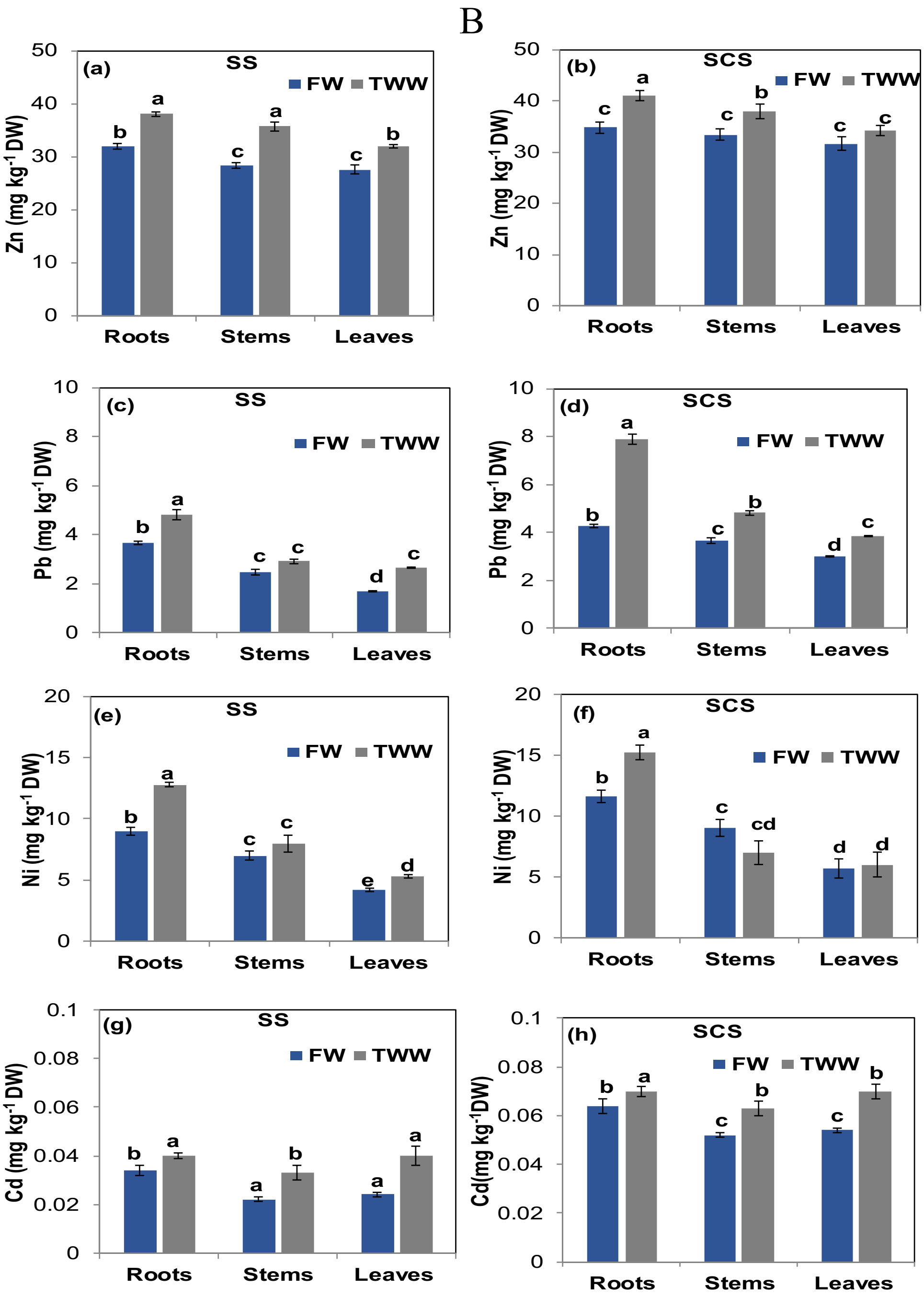


Fig. 5 Mean value of Co (**a** and **b**), Cu (**c** and **d**), Mn (**e** and **f**), and Fe (**g** and **h**) in corn tissues grown in sandy soil (SS) and silty clay soil (SCS) and irrigated with freshwater (FW) and treated wastewater (TWW). Different letters indicate significant differences ($p < 0.05$) among treatments according to Tukey's test

influences soil characteristics that potentially influence the quality of the soil (Abd-Elwahed, 2018). The magnitude of the risk from MTEs in wastewater depends on TWW composition, the level of treatment, physicochemical properties of soil, and the duration of wastewater application for irrigation (Klay et al. 2010). The evidence provided in this study indicates two aspects to consider. On one side, the low retention of MTEs in sandy soil is explained by its high infiltration rates, low amount of OM, and low cation exchange capacity (CEC = 5.5 meq 100 g^{-1}). On the other side, the increase of MTEs linkages with mineral of silty clay soil is explained by the higher pH, high cation exchange capacity (CEC = 30.1 meq 100 g^{-1}), and the presence of clay content. It has been also well stated that cation adsorption is favored at higher pH level (pH = 8) (Dzombak and Morel 1990). Majority of MTEs concentrations remained under permissible limits except for Cd (2.7 > 2 mg kg^{-1}) and Ni concentration (64.7 > 50 mg kg^{-1}) which exceeded the permissible limits set by AFNOR (Baize 1997). Generally, soil texture, organic matter, carbonates, and pH can be found among factors affecting mobility of heavy metals in soil (Alloway 2013). The increase in available trace metals in soil can be considered an adverse influence on its quality. Moreover, it not only affects negatively soil characteristics but also has

Fig. 6 Mean value of Zn (**a** and **b**), Pb (**c** and **d**), Ni (**e** and **f**), and Cd (**g** and **h**) in corn tissues grown in sandy soil (SS) and silty clay soil (SCS) and irrigated with freshwater (FW) and treated wastewater (TWW). Different letters indicate significant differences ($p < 0.05$) among treatments according to Tukey's test



adverse effects on plant growth and the microbial community composition (Guo et al. 2017). The risk of toxic elements can be minimized by the increase of organic matter content in soil which induces a high adsorption and retention capacity of soils all which reduce the risk of potentially toxic elements leaching into deep layers or shallow groundwater (Xiaomin et al. 2019). On the basis of the results of this research, it can be noted that despite the enrichment of soils with toxic metals, their alkalinity and the increase of organic matter content especially in sandy soil and the predominance of clay fraction prevented the accumulation of MTEs at toxic levels.

TWW has been recognized as an important source of nutrients and hence been proven to improve crop yield (Jimenez, 1995; Oliveira and Sperling, 2008) because it gives supplement amounts of nutrients as nitrogen, phosphorus, and OM that enhance the fertility and increase the productivity of soil (Gatta et al. 2016). Our results show that irrigation with TWW led to significant increases in all plant growth parameters in comparison with plant irrigated

Table 4 Quantity of Na, Cl, Ca, Mg, Co, Cu, Mn, Fe, Zn, Pb, Ni, and Cd exported by different corn parts grown under different treatments (mg)

Element	Corn parts	Treatment			
		SSFW	SSTWW	SCSFW	SCSTWW
Na	Roots	7.77 ± 0.84 h*	13.77 ± 3.66f	8.81 ± 2.3gh	23.94 ± 3.2e
	Stems	31.97 ± 5.71e	80.83 ± 8.12c	210.75 ± 15.84b	370.64 ± 30.21a
	Leaves	6.07 ± 1.32 h	15.85 ± 2.65f	11.92 ± 1.71 g	47.58 ± 5.6d
Cl	Roots	1.82 ± 0.52i	2.38 ± 0.67i	14.5 ± 2.13 g	30.41 ± 6.23e
	Stems	19.71 ± 1.94f	29.09 ± 2.34e	109.01 ± 11.5c	132.45 ± 5.89b
	Leaves	7.44 ± 0.87 h	11.76 ± 2.23 g	88.14 ± 7.79d	191.11 ± 15.33a
Ca	Roots	0.34 ± 0.02 g	0.56 ± 0.06e	0.45 ± 0.04f	0.4 ± 0.01f
	Stems	2.73 ± 0.14d	5.41 ± 1.02ab	3.58 ± 0.84c	6.61 ± 1.24a
	Leaves	2.74 ± 08d	5.09 ± 0.57b	4.07 ± 1.02bc	7.03 ± 0.97a
Mg	Roots	0.09 ± 0.001 h	0.14 ± 0.002 g	0.14 ± 0.001 g	0.91 ± 0.001f
	Stems	7.28 ± 1.04c	11.65 ± 2.13b	9.24 ± 1.08b	15.1 ± 3.41a
	Leaves	3.1 ± 0.45e	6.09 ± 0.95c	5.09 ± 0.97d	9.35 ± 1.02b
Co	Roots	0.01 ± 0.002f	0.03 ± 0.008e	0.05 ± 0.006d	0.14 ± 0.01c
	Stems	0.05 ± 0.007d	0.1 ± 0.04c	0.21 ± 0.011b	0.369 ± 0.03a
	Leaves	0.05 ± 0.003d	0.12 ± 0.027c	0.16 ± 0.03c	0.37 ± 0.025a
Cu	Roots	0.01 ± 0.002 h	0.03 ± 0.001 g	0.03 ± 0.002 g	0.11 ± 0.01f
	Stems	0.1 ± 0.01a	0.16 ± 0.05e	0.25 ± 0.013d	0.55 ± 0.02b
	Leaves	0.14 ± 0.009e	0.27 ± 0.02d	0.47 ± 0.04c	1.1 ± 0.001a
Mn	Roots	0.04 ± 0.007 k	0.1 ± 0.005j	0.11 ± 0.008i	0.2 ± 0.007 h
	Stems	0.005 ± 0.001 l	0.3 ± 0.02 g	0.38 ± 0.023f	9.48 ± 0.01a
	Leaves	0.46 ± 0.02e	0.98 ± 0.16d	1.19 ± 0.01c	2.16 ± 0.07b
Fe	Roots	0.51 ± 0.016f	1.13 ± 0.05d	1.06 ± 0.03e	2.4 ± 0.74c
	Stems	1.52 ± 0.07c	2.72 ± 0.41c	4.73 ± 1.02b	11.76 ± 2.56a
	Leaves	1.83 ± 0.11c	4.04 ± 0.89b	5.13 ± 1.21b	8.58 ± 1.36a
Zn	Roots	0.09 ± 0.004j	0.14 ± 0.006i	0.2 ± 0.006 h	0.4 ± 0.005 g
	Stems	0.86 ± 0.013f	1.42 ± 0.04c	1.85 ± 0.12b	2.95 ± 0.14a
	Leaves	2.95 ± 0.14a	0.91 ± 0.01e	1.07 ± 0.09d	1.88 ± 0.2b
Pb	Roots	0.01 ± 0.003 g	0.02 ± 0.0015f	0.03 ± 0.007e	0.08 ± 0.009d
	Stems	0.075 ± 0.01d	0.14 ± 0.005c	0.22 ± 0.004b	0.43 ± 0.03a
	Leaves	0.03 ± 0.008e	0.08 ± 0.01d	0.03 ± 0.001e	0.08 ± 0.002d
Ni	Roots	0.24 ± 0.07f	0.47 ± 0.06e	0.64 ± 0.06d	1.44 ± 0.08c
	Stems	2.05 ± 0.45b	3.06 ± 0.52b	4.8 ± 1.01a	5.23 ± 1.49a
	Leaves	0.76 ± 0.11d	1.44 ± 0.33c	1.86 ± 0.43b	3.17 ± 0.76ab
Cd	Roots	0.001 ± 0.000 g	0.001 ± 0.000 g	0.003 ± 0.0002f	0.005 ± 0.0001e
	Stems	0.005 ± 0.001e	0.02 ± 0.003d	0.027 ± 0.011c	0.05 ± 0.004a
	Leaves	0.003 ± 0.000b	0.018 ± 0.001d	0.017 ± 0.003d	0.036 ± 0.001b

*Mean value ± standard deviation values from five replicate ($n = 5$). Different letters in line and column of each element indicate significant differences among treatments according to Tukey's test ($p < 0.05$). SSFW treatment: for plant grown in sandy soil irrigated with freshwater; SCSFW treatment: for plant grown in silty clay soil irrigated with freshwater; SSTWW treatment: for plant grown in sandy soil irrigated with treated wastewater and SCSTWW treatment: for plant grown in silty clay soil irrigated with treated wastewater

with FW. This increase could be attributed to the supplement amount of organic matter and other nutrients (N, K, and P) added to soils which corroborate the findings of other scientists (Abegunrin et al. 2013; Noori et al. 2014) who reported an increase in crop growth and improved yield under sludge and wastewater irrigation. The positive effects of total nitrogen in reclaimed irrigation water on corn growth and shoot length of *Lepidium sativum* were also reported (Mojiri et al. 2013). According to our study, maximum values of leaf area and plant height matched in plant grown under TWW irrigation may be attributed to the increase in N available for plants. The increase of N, P, and K content in corn tissue was also manifested, suggesting that the increase of the nutrients concentration positively affected the growth of corn plants. A similar finding was stated by Magwaza et al. 2020). The increase in vegetative growth and plant biomass has been attributed to the increase in available TN (Abegunrin et al. 2016). As shown in this study, plants grown in the silty clay soil was significantly higher than those grown in the sandy soil. The difference in the response of the plant to TWW can be explained by the presence of nutrients and the higher level of organic matter in the silty clay soil than in the sandy soil, and this explanation could be linked to the finding of Ezzo et al. (2010) who stated that highest contents of total soluble solids (TSS) and highest water use efficiency were recorded with clayey soils. It can also be added that although the high salinity level in water used for irrigation (above 3.6 $\mu S\ cm^{-1}$), plant growth was not affected, suggesting an acclimation of plant to salinity stress. This acclimation to salinity condition was attributed to the accumulation of proline that, besides preventing salt accumulation within plant cells, presents a metabolic response of the plant to salinity stress (Kahlaoui et al. 2014). These presented findings indicate that TWW has the potential to be used as a source of fertilizer for corn grown in both soils. In addition to N, P, and OM, an important accumulation of sodium, chloride, calcium, and magnesium in corn plant tissues was also shown. The increase of Na was mainly in the roots and Cl in the stems. Ca and Mg were accumulated at leaf level. A similar result was stated by Gadallah (1994) who demonstrated that irrigation of sunflower with reclaimed water induced elevated concentrations of Ca, Mg, and Cl in leaves and high concentrations of Na in roots. The increase of these elements in corn tissue could be explained by their increase in the soil surface. These findings are in agreement with the several previous research studies (AL-Jaloud AA, Hussain G, AL-Saati AJ, Karimulla S, , 1995; Moazzam et al. 2009; Rusan et al. 2007).

Wastewater is not only an important source of OM and other nutrients, but also an origin of toxic metals. Accumulation of these elements in excessive amounts in the receiving soil severely limits the beneficial use of this water. When plants are exposed to elevated toxic levels of MTEs, they exhibit considerable reduced growth accompanied with poor productivity and yields (Vaibhav et al. 2017). In this study, the concentrations of Pb, Mn, Co, Fe, Zn, Cu, Ni, and Cd in different corn organs were investigated. Results showed that irrigation with TWW led to significant increase of these elements, which is in agreement with other researchers (Arora et al. 2008; Chary et al. 2008; Demirezen and Aksoy 2006; Galavi et al. 2010; Tiwari et al. 2011) indicating that plants irrigated with TWW accumulated high levels of MTEs in their tissues. In a majority of cases, a trace metal element accumulated in tissues of crops grown under irrigation with TWW tends to concentrate in roots, while only a little fraction of these elements are transported to the edible part and, finally, reach the fruit. As mentioned by Al-Absi et al. (2009), elevated concentrations of metals in the rhizosphere under TWW irrigation resulted in the increase of these elements in the roots. According to our investigation, each element shows a different distribution in the different corn organs. Some elements, such as Fe, Co, and Pb, have low solubility in soils and are, generally, maintained in roots (Ait Ali et al. 2002; Chandra et al. 2009; Masona et al. 2011). While some others such as Mn and Cu and Zn have a high solubility in soil which increase their bioavailability and consequently can be easily transported and accumulated in leaves of plants (Khaskhoussy et al. 2019; Luo et al. 2011). The findings of these studies could be linked to our results. The experiment conducted by Itanna (2002) showed that the distribution of metals in different plant organs depends on their forms, water transport, and plant species. Moreover, several studies have demonstrated that vegetation is an important factor affecting, directly or indirectly, the mobility of metals in the soil (Caron et al. 1996; Shabanpour et al. 2000). Thus, metal mobility could be increased through the formation of channels along the root or through the complexation of heavy metals with exudates offered in the rhizosphere. MTEs become more toxic when their accumulation in plant tissue exceeds the permissible limits. Accumulation of MTEs on plant tissue depends not only on their concentrations in soil but also on the type and characteristics of this soil. Thereby, when soil is alkaline, calcareous, and clayey and contains high concentrations of TEs, maize grains are not found with elevated TE contents (Antoniadis et al. 2019). As monitoring toxicity level of toxic metals is of great importance in protecting plant from the adverse effects of these elements, a comparison with the common tolerable toxic concentrations of Co, Cu, Mn, Zn, Pb, Ni, and Cd in mature leaf tissue generalized for various plant species was made. Results of this analysis show that a majority studied elements except for Ni (> 10) did not reach the toxic levels of 15, 20, 400, 30, and 5 $mg\ kg^{-1}$ for Cu, Mn, Zn, Pb, and Cd, respectively (Kabata-Pendias and Mukherjee 2007; Kabata-Pendias, 2011). A similar finding was previously stated by Chen et al. (2004) and Olowoyo et al. (2012). Our study found that the increase of organic matter content especially in sandy soil and the predominance of clay fraction for silty clay soil prevented the accumulation of toxic elevated contents of MTE in corn tissue.

As a complement of the chemical analysis carried out for macro and microelements, the quantity of each studied element exported by plants from the soil surface was calculated. Results for Na, Cl, Ca, and Mg show that Na has the highest contents in corn tissue, especially in roots parts, followed by Cl which has a higher amount in the stems. Quantities subtracted by corn are lower under irrigation with FW compared to those calculated under irrigation with TWW. MTEs accumulation in the different parts of corn (Fe, Mn, Pb, Cu, Co Zn, Ni, and Cd) was, also, affected by water quality. Indeed, irrigation with reclaimed water resulted in an excessive accumulation of these elements in corn tissues. Overall, the type of the soil did not affect the distribution of different elements in the organs of corn. However, corn plants grown in silty clay soil have shown a greater accumulation of Cu, Ni, Co, and Pb than those cultivated in sandy soil. In our case, the increase of these elements in plant tissues was closely related to their content in the silty clay soil, which was higher than in the sandy soil.

5 Conclusion

The irrigation with TWW changed some physical and chemical properties of the two studied soils and consequently affected corn growth and nutrition. It was found that treated wastewater showed the potential to be used as a source of fertilizer for corn grown in both soils. Indeed, despite the increase in soil salinity, plant growth parameters were improved. This could be associated with the increase of essential micro- and macronutrient such as nitrogen, phosphorus, potassium, calcium, zinc, iron, and magnesium in soil and consequently in plant tissue. Results observed from this study also indicated that soils were highly enriched with toxic metals such as lead, nickel, and cadmium. However, the alkalinity of both soils, the increase of organic matter content especially in sandy soil, and the predominance of clay fraction for silty clay soil prevented the accumulation of toxic MTE contents. Extrapolating our results, treated wastewater could be applied for irrigation of the two different soil textures. The extent of soil and plant contamination by toxic metals is controlled by soil pH, clay and carbonate content, and even organic matter content. However, high levels of some trace elements in harvested part of the plant indicate variable relevance according to what is harvested in different species. Hence, further field studies, applying more recent chemical methods for metal determination to estimate contamination indices and toxicity health risks, are needed, considering also long-term use of TWW, since increasing demands in environmental regulations are imposing more accurate management decisions.

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Writing—review and editing: Mohamed Hachicha, Besma Kahlaoui, and Enrique Misle.

Supervision: Mohamed Hachicha.

Availability of Data and Materials The data that support the findings of this study are available from the corresponding author (Khawla Khaskhoussy), upon reasonable request.

Code Availability Not applicable.

Declarations

Conflict of Interest The authors declare no competing interests.

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