



Salinity management for irrigation with saline-sodic wastewater under corn cultivation

Farzam Moghbel^{*1}, Behrouz Mostafazadeh-Fard², Seyed Ali Mohammad Mirmohammady Maibody³ and Esmail Landi²

¹Water Science and Engineering Dept., Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, 91779-48974, Iran

²Water Engineering Dept., College of Agriculture, Isfahan Univ. of Technology, Isfahan, 84156-83111, Iran

³Agronomy and Plant Breeding Dept., College of Agriculture, Isfahan Univ. of Technology, Isfahan, 84156-83111, Iran

Abstract

Water scarcity is one the main problems of sustainable agriculture. One way to overcome this problem is to use wastewaters for irrigation. To determine the effect of salinity and sodicity of municipal wastewater as irrigation water and leaching application, on some of common soil chemical properties and consequently on growth performance of corn, a soil column experiment was conducted with sandy clay loam soil. Nine treatments including wastewaters with three different salinity levels: 1, 4.7 (blending of 1 and 9 dS/m wastewaters with 1:1 ratio), 9 dS/m, and three levels of leaching fractions: 0, 15 and 30 percent were arranged in a factorial experiment with three replication. Results show that at first and last layer of the soil, the effect of 30 percent leaching on soil salinity (ECe) was statistically significant only for irrigation with 9 dS/m wastewater. Application of the 15 and 30 percent leaching fraction for irrigation with 4.7 dS/m wastewater (SAR = 8.2) significantly reduced soil SAR at first layer of the soil. The application 30 percent leaching fraction significantly increased corn dry yield for irrigation with all of three wastewaters. There was no significant difference between effects of irrigation with 4.7 dS/m wastewater with the 15 and 30 percent leaching fraction and irrigation with 1 dS/m wastewater with 0 and 15 percent leaching fraction on IWUE. Results show that with combination of leaching method and reduction wastewater salinity through blending of wastewaters for irrigation with saline sodic wastewater, high corn biomass can be achieved, without any significant difference in comparison with non-saline or non-sodic wastewater.

Keywords: Corn yield, irrigation, leaching, salinity, sodicity, wastewater

Introduction

Increase of population, has made renewable water resources to be limited specially in arid and semi-arid parts of the world (Steduto *et al.*, 2012). In 2025, more than 1 billion people who live in arid or semi-arid areas of world will suffer severe water scarcity (Seckler *et al.*, 1999). Iran is among the countries around the world which suffers severe shortage of freshwater (Shahabfar *et al.*, 2012). One way of dealing with such problem is to use marginal waters for irrigation such as industrial wastewater, saline groundwater and agricultural drainage water (Murtaza *et al.*, 2006; Chang and Ma, 2012; Chen *et al.*, 2013). These marginal waters contain different amounts of soluble salts and irrigation with these waters may have adverse effect on fertility of the soils. Adverse impact of saline water application in soil is related to osmotic pressure. Salts accumulation in the soil by adsorption of water prevents plants root from smooth water uptake that consequently affects plant growth performance (Katerji, 2003; Kirkham, 2005). Saline irrigating water also may decline soil

performance through soil sodicity induced by irrigation that causes soil structural problems and specific ion effect on crops that can be a hazardous for human or crops health (Shainberg and Letey, 1984; Page *et al.*, 1996; Qadir and Oster, 2004; Grattan *et al.*, 2015). Estimates indicate that 34 million hectare, including 4.1 million hectare of irrigated lands in Iran suffering from different kinds of salinization. The annual economy loss due to salinization is more than US\$ 1 billion (Qadir *et al.*, 2008). Investigation indicates that corn which is one of common crops in Iran, has been produced in 2013 more than ever (Anonymous, 2013). Corn maize seasonal evapotranspiration as reported by some researchers was about 667 mm up to 1003 mm depending on climate conditions. So corn can be categorized as a high water demanding plant (Musick and Duseek, 1980; Eck, 1984). Results of some researches indicated that using marginal waters like industrial wastewater and saline groundwater as irrigation water caused yield reduction of plants such as corn, olive, cucumber and grapevine (Amer 2010; Kang *et al.*, 2010; Wan *et al.*, 2010; Ben Ahmed *et al.*, 2012; Bame *et al.*, 2014). Impacts of wastewater

*Email: farzam.moghbel2@gmail.com

irrigation on soil chemical components have been reported by Sou/Dakouré *et al.* (2013) and Bedbabis *et al.* (2014, 2015). The increase of soil salinity and sodicity and decrease of soil infiltration rate has been observed by Bedbabis *et al.*, 2014 after long-term irrigation with wastewater. Researchers concluded that irrigation with hyper sodic wastewater destroyed soil structure especially in sub-horizon of soil (Sou/Dakouré *et al.*, 2013; Bedbabis *et al.*, 2014; Bedbabis *et al.*, 2015). Researchers have investigated wastewater application effects on soil ions concentration of Na^+ , Ca^+ , Mg^+ , K^+ and on heavy metals accumulation in the soils and plant tissues. It has been concluded that diverse effects of wastewater irrigation is related to initial condition of soil and irrigation water with respect to their chemical properties (Heidarpour *et al.*, 2007; Mohammad Rusan *et al.*, 2007; Jalali *et al.*, 2008). In addition to fertilizing benefits of wastewater irrigation, which is mainly because of nitrate (NO_3^-) and phosphor (P), leaching of these supplement compounds to groundwater supplies cause groundwater pollution (Magesana *et al.*, 1998; Batziaka *et al.*, 2008; Blum *et al.*, 2013; Zhang *et al.*, 2013; -Lal *et al.*, 2015; Marofi *et al.*, 2015). As indicated by Oster and Grattan (2002), use of marginal water like saline-sodic drainage water for irrigation needs proper management of soil and crop. Blending of marginal waters with good quality waters, cycling use of marginal waters and good quality water and sequential use of marginal waters are management manners of controlling effects of reclaimed water irrigation on soil salinity and crop yield (Grattan *et al.*, 2000). Blending of waters with different qualities in order to use as irrigation water has been tested by Gengmao *et al.* (2010); Grattan *et al.* (2008), which both of these researches demonstrated that with proper dilution of hyper saline water, irrigation of salt tolerant crops can successfully achieve sufficient yield which is economically beneficial. Choudhary *et al.* (2006) investigated effectiveness of cycling method in order to use sodic water for long term irrigating of sunflower in agriculture lands. For dealing with soil salinity and sodicity as consequences of irrigation with saline groundwater or drainage water some results have been published by Mostafazadeh-Fard *et al.* (2009), Heidarpour *et al.* (2009) and Heakal *et al.* (1990) which all of them proved that with increasing leaching fractions, lower soil salinity and higher yield could be achieved. Recently researchers have shown that impact of applying some amendments in combination with leaching methods were reliable for reclamation of sodic soils (Chaganti *et al.*, 2015; Chaganti and Crohn, 2015). Many aspects of salinity and sodicity managements in order to use marginal water like wastewater are still unknown. The aim of this study was to determine effects of using saline-sodic municipal wastewater for irrigation

with proper management on soil chemical properties and corn yield.

Materials and Methods

Soil and column preparation

The soil columns experiment was conducted in greenhouse area at Isfahan University of Technology in 2014. The columns were made of polyethylene (PE) with 60 cm height and 25 cm inside diameter. Coarse gravels with thickness of 2 cm were used as filters at bottom of columns to allow drainage. All columns were filled with soil and the soil height inside each column was 40 cm. Upper part of columns with depth of about 20 cm were left for application of irrigation water. An agricultural soil with texture of sandy clay loam (Table 1) and with wet bulk density of 1.8 g/cm^3 was used for the experiment. The soil was obtained from Mahiar agricultural field located at south of Isfahan province, Iran. The initial physical and chemical characteristics of the soil are presented in Table 1. According to Table 1, the soil is categorized as non-saline or non - sodic soil.

Sowing of plant seed

Planting of corn seeds was done after soil filling of the columns. KSC 704 forage maize (corn) hybrid was the type of plant seed which was sown in this experiment. At the beginning of the experiment five seed were sown in each column and columns were irrigated with municipal freshwater but after reaching 4 leaves stage of plant growth, the number of plants were reduced to two plants in each columns and experimental treatments were applied.

Experimental design and treatments

A factorial experiment with completely randomized design based was used with three replications for each treatment. As shown in Table 2, the treatments were three types of wastewater as irrigation water with classification of saline-sodic with EC of 9 dS/ m (W_1), non-saline or non-sodic with EC of 1 dS/m (W_2) and saline with EC of 4.7 dS/m (W_3). The sub-treatments were leaching fractions of 0 % (LF_1), 15 % (LF_2) and 30 % (LF_3). The saline-sodic wastewater (W_1) was obtained from municipal wastewater of Varzaneh city located at southeast of Isfahan Province of Iran. The non-saline or non-sodic (W_2) wastewater was obtained from treatment lagoon of Isfahan University of Technology's wastewater plan. The saline wastewater (W_3) was obtained by blending W_1 and W_2 wastewaters with 1:1 ratio. The leaching fraction was considered in gross depth of irrigation water which is:

$$dg = \frac{dn}{(1-LF)E_n} \quad (1)$$



Table 1: The initial soil physical and chemical properties

Soil physical characteristics						
Sand	Silt	Clay	Bulk density(g/cm3)		Soil texture	
	(%)					
73	7	23	1.8		Sandy clay loam	
Soil chemical characteristics						
EC(dS/m)	pH	Ions (meq/L)			SAR	USSL classification
		Na+	Ca2++Mg2+	K+		
2.13	8.5	9.62	9	2.20	3.2	Non-saline or non-sodic soil

Table 2: Chemical properties of wastewaters used as irrigation water

EC (dS/m)		pH	Ions (meq/L)			NO ₃ -N(mg.L ⁻¹)	SAR	Classification
			Na ⁺	Ca ²⁺ +Mg ²⁺	K ⁺			
W ₁	9	8.7	45.37	24	1.2	13.9	13.1	Saline-Sodic
W ₂	1	8.5	4.29	6.2	0.43	14.62	2.44	Non-saline or non-sodic
W ₃	4.7	8.56	22.28	14.8	0.77	14.10	8.19	Saline

W₁ = Varzaneh wastewater, W₂ = Isfahan university of technology's wastewater, W₃ = blended wastewater (blending of W₁ and W₂ wastewaters with 1:1 ratio), SAR = sodium adsorption ratio

where dg is gross depth of irrigation water, dn is net depth of irrigation water, LF is leaching fraction, and Ea is application efficiency. Ea is assumed as 1, because irrigation was done soil columns and no loss was due to application of water (Keller and Bliesner 1990).

Irrigation operation

Irrigation was applied following depletion of 50 % of available water, based on reduction of soil column weight. All columns were weighed daily to determine when to irrigate. The soil columns were irrigated for 3 months using above wastewaters and leaching fractions.

Yield and yield components measurement

About three days before the termination of the process, leaf area and some other plant components like stem diameter and stem height have been measured. All of plants had been cut from their base on the soil surface and soil columns were emptied gradually to prevent the root from being harmed. For measuring of corn yield, plants were weighted two times: before and after being dried. All of roots had been revealed from the columns and their volumes were recorded by Archimedes changing of water volume method. Irrigation water use efficiency (IWUE) as ratio of plant dry weight to the amount of water applied during irrigation season was calculated using the following equation (Payero *et al.*, 2008):

$$IWUE = \frac{Y}{I} \quad (2)$$

where Y = yield (kg ha⁻¹) and I = seasonal irrigation applied water (mm).

In the above relation, dry weight of corn was considered for yield term because one of main aims of planting forage corn in agricultural area of Isfahan province is feeding of livestock with corn leaves.

Soil sampling and measurement

Soil sampling was done simultaneously with emptying of the soil columns. Soil samples at three depths of 0-10 cm, 10-25 cm and 25-40 cm were obtained. The soil samples were air dried, passed through 2 mm sieve and soil saturated paste extract was obtained. The electrical conductivity of soil saturated paste extract was measured by Ohaus Starter 3000C electrical conductivity meter. The pH of soil saturated paste extract was measured by Metrohum pH meter. Sodium adsorption ratio was calculated using the following relation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (3)$$

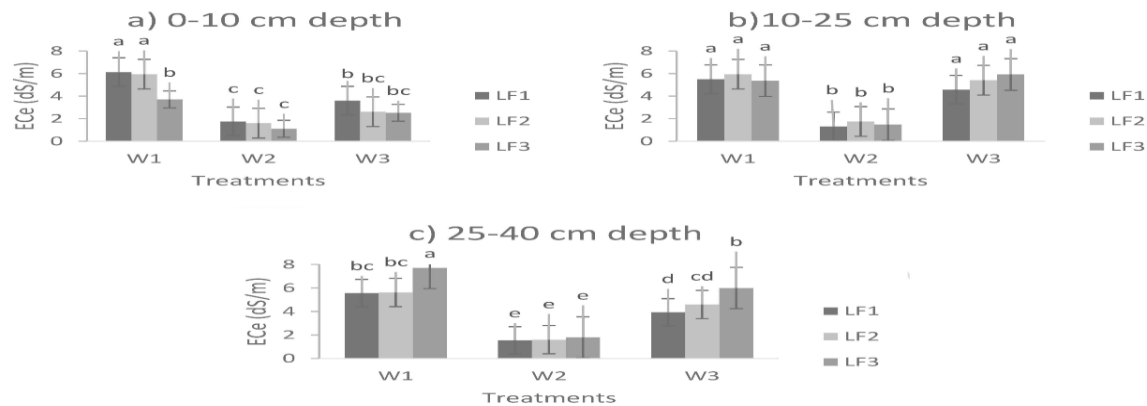
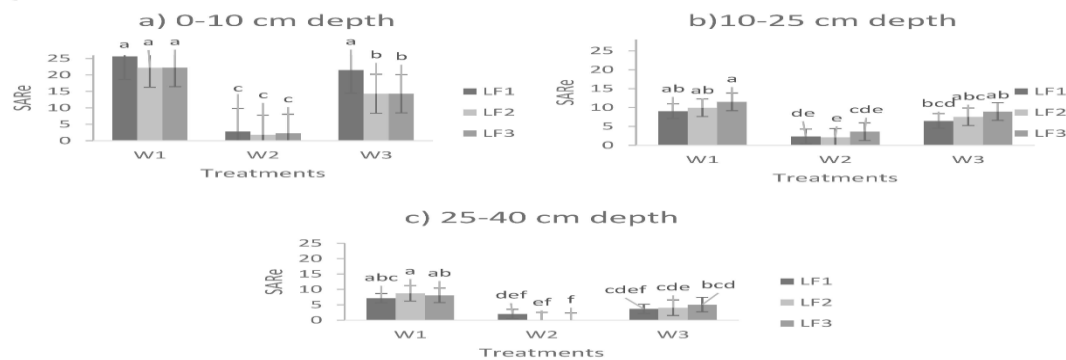
where Na⁺, Ca²⁺ and Mg²⁺ = concentration (meq/l) of sodium, calcium and magnesium in soil saturated paste extract. Sodium concentrations were measured by flame photometer. Other soil cations such as Ca²⁺ and Mg²⁺ were also measured for soils saturated paste extract using titration method (Estefan and Sommer, 2013). Potassium (K⁺) concentration as an element, which has potential to be reason of clay swelling and dispersion of soil content, was measured by flame photometer (Marchuk and Rengasamy, 2010).



Table 3: Mean comparisons of the effects of treatments on soil EC_e (dS/m)

Soil depth	Irrigation water salinity			Leaching fraction		
	W1	W2	W3	LF1	LF2	LF3
0-10 cm	5.26 a	1.49 c	2.92 b	3.84 a	3.39 ab	2.45 b
10-25 cm	5.60 a	1.51 b	5.30 a	3.79 a	4.37 a	4.26 a
25-40 cm	6.30 a	1.65 c	4.84 b	3.68 b	3.94 b	5.16 a

Note: The values followed by at least one same character are not statistically different at 5 % probability level. W₁ = varzaneh wastewater (9 dS/m), W₂ = Isfahan university of technology's wastewater (1 dS/m), W₃ = blended wastewater (blending of W₁ and W₂ wastewaters with 1:1 ratio, 4.7 dS/m). LF₁ = 0 % leaching fraction, LF₂ = 15 % leaching fraction, LF₃ = 30 % leaching fraction

**Figure 1: Interaction effects of the treatments on soil EC_e at the depth of a) 0-10, b) 10-25 and c) 25-40 cm****Figure 2: The interaction effects of the treatments on soil SAR at depth of a) 0-10, b) 10-25 and c) 25-40 cm**

Statistical analysis

Statistical analysis has been done using SAS 9.2 and Statistix 8.0 software. LSD (least significant difference) and Duncan Multiple Range test methods have been used to determine the statistical differences between mean effects of the treatments on soil chemical characteristics and corn yield.

Results and Discussion

Soil EC_e (dS/m)

Before the start of the experiment, the initial mean soil EC_e was about 2.13 dS/m. The soil analysis at the end of study showed that irrigation water salinities and leaching fractions had significantly influenced soil salinities for all soil depths (Table 3). Increasing irrigation water salinity



caused increase in soil E_{Ce} which is correspond with results obtained by Ben Ahmed *et al.* (2012). The soil salinity of W₃ treatment was significantly less than soil salinity of W₁ treatment. Leaching treatments significantly affected soil salinity in soil depths of 0-10 and 25-40 cm. The leaching fractions of 15 and 30 percent caused salts to be removed from upper parts of the root zone to the lower parts. Ayers and Westcot (1985) reported similar results. In treatments without leaching fractions, salinity accumulated in the upper parts of the soil (0-10 cm). This result is consistent with results reported by Li *et al.* (2015). Mean comparisons show that 30 percent leaching fraction, reduces soil salinity in the upper part of soil 25 percent more than the 15 percent leaching fraction (Table 3).

Similar results were obtained by Heakal *et al.* (1990). Interaction effects of irrigation water salinities and leaching levels on soil salinity are presented in Fig.1. Interaction effects results show that at the depth of 0-10 and 25-40 cm, the effect of 30 percent leaching was statistically significant only for irrigation with W₁ wastewater. Results indicates that the application of 30 percent leaching for irrigation with W₁ wastewater did not significantly reduced soil salinity at 0-10 cm soil depth in comparison with W₃ treatments (with or without leaching application).

Soil pH

As shown in Table 4, irrigation water salinities significantly decreased soil pH at soil depths of 10-25 cm

Table 4: Mean comparisons of the effects of treatments on soil pH ($p < 0.05$)

Soil depth	Irrigation water salinity			Leaching fraction		
	W1	W2	W3	LF1	LF2	LF3
0-10 cm	8.53 a	8.45 a	8.49 a	8.45 a	8.54 a	8.47 a
10-25 cm	8.40 b	8.75 a	8.40 b	8.60 a	8.35 b	8.61 a
25-40 cm	8.19 b	8.39 a	8.10 b	8.26 a	8.21 a	8.21 a

Note: The values followed by at least one same character are not statistically different at 5 % probability level. W₁ = varzaneh wastewater (9 dS/m), W₂ = Isfahan university of technology's wastewater (1 dS/m), W₃ = blended wastewater (blending of W₁ and W₂ wastewaters with 1:1 ratio, 4.7 dS/m). LF₁ = 0 % leaching fraction, LF₂ = 15 % leaching fraction, LF₃ = 30 % leaching fraction

Table 5: Mean comparison of the effects of treatments on soil SAR ($p < 0.05$)

Soil depth	Irrigation water salinity/sodicity			Leaching fraction		
	W1	W2	W3	LF1	LF2	LF3
0-10 cm	23.33 a	2.30 c	16.67 b	16.61 ab	12.75 b	12.93 b
10-25 cm	10.16 a	2.69 b	7.64 a	5.59 a	6.53 a	8.02 a
25-40 cm	8.02 a	0.56 c	4.26 b	4.28 a	4.30 a	4.25 a

Note: The values followed by at least one same character are not statistically different at 5 % probability level. W₁ = varzaneh wastewater (9 dS/m), W₂ = Isfahan university of technology's wastewater (1 dS/m), W₃ = blended wastewater (blending of W₁ and W₂ wastewaters with 1:1 ratio, 4.7 dS/m). LF₁ = 0 % leaching fraction, LF₂ = 15 % leaching fraction, LF₃ = 30 % leaching fraction

Table 6: Mean comparison of the effects of treatments on soil potassium concentration meq L^{-1} ($p < 0.05$)

Soil depth	Irrigation water salinity/ potassium concentration			Leaching fraction		
	W1	W2	W3	LF1	LF2	LF3
0-10 cm	1.44 a	1.21 a	0.95 a	1.18 a	1.29 a	1.15 a
10-25 cm	1.51 a	1.07 a	1.58 a	1.28 a	1.52 a	1.36 a
25-40 cm	1.14 a	0.68 b	1.09 a	0.90 a	0.98 a	1.03 a

Note: The values followed by at least one same character are not statistically different at 5 % probability level. W₁ = varzaneh wastewater (9 dS/m), W₂ = Isfahan university of technology's wastewater (1 dS/m), W₃ = blended wastewater (blending of W₁ and W₂ wastewaters with 1:1 ratio, 4.7 dS/m). LF₁ = 0 % leaching fraction, LF₂ = 15 % leaching fraction, LF₃ = 30 % leaching fraction



and 25-40 cm. Leaching treatments significantly affected soil pH only at 10-25 cm soil depth. Results indicate that for W_2 as compared to W_1 and W_3 the soil pH at soil depth of 10-25 cm have more pH values.

Sodium adsorption ratio (SAR)

Different levels of irrigation water sodicity significantly affected sodium adsorption ratio (SAR) of the soil (Table 5). Leaching effects on soils SAR were significant only at soil depth of 0-10 cm. Irrigation water sodicity levels significantly increased soil SAR at all three soil depth. In comparison with W_1 treatment, the W_3 treatment caused 28 and 50 percent reduction in SAR at soil depths of 0-10 cm and 25-40 cm, respectively. So blending method can be used successfully to reduce soil sodicity impacts of sodic wastewater. This result is consistent with the results of Grattan *et al.* (2008). Two levels of leaching (15 and 30 percent leaching), caused 23 percent reduction of SAR at soil depth of 0-10 cm. Increasing leaching fraction from 15 to 30 percent did not significantly affect soil SAR. So, increasing leaching level is not recommended without using of calcium amendments. The leaching effects results correspond with results obtained by Chaganti *et al.* (2015). Results of interaction effects of the treatments on soil SAR are presented in Fig. 2. Interaction effects results show that application of the 15 and 30 percent leaching fraction for irrigation with W_3 wastewater significantly reduced soil SAR at the depth of 0-10 cm in comparison with W_1 treatments (with or without leaching application). As Chaganti *et al.* (2015) reported, effectiveness of leaching application has been observed even without any supplement.

Potassium (K+)

Different levels of irrigation water salinity or its potassium concentrations (K) had significant effect on soil potassium concentration at depth of 25-40 cm (Table 6). Leaching levels did not have significant impact on soil potassium concentration. The potassium concentration effect on soil physical properties related to soil's clay minerals may cause reduction in soil hydraulic conductivity (Arienzo *et al.*, 2012). Because of low accumulation of potassium in soil profile, potassium concentration did not affect soil hydraulic conductivity.

Growth components of corn

Dry weight yield

As shown in Table 7, the increase in irrigation water salinity causes significant decrease in corn dry yield. The least corn yield was obtained with W_1 (9 dS/m) treatment. This result is similar with results obtained by Wan *et al.* (2010) and Mostafazadeh-Fard *et al.* (2009). Mean comparison of corn biomasses (dry yield) indicates that W_3

treatment significantly increased corn dry yield in comparison with W_1 treatment. Therefore, it can be concluded that blending of saline wastewater with non-saline wastewater can be an effective way in order to improve dry weight yield of corn plant. Results of leaching effects on corn dry yield show that 15 and 30 percent leaching increased corn biomass about 19 and 66 percent, respectively. Leaching can be an effective way to increase corn dry yield for irrigation with saline and sodic wastewaters. Mostafazadeh-Fard *et al.* (2009) and Heidarpour *et al.* (2009) have reported similar results for irrigation of winter wheat with saline drainage water. Results of interaction effects of the treatments (Table 8) show that application of 15 and 30 percent leaching fraction increased corn dry yield for irrigation with all of three wastewaters in comparison with treatments without leaching application but only the 30 percent leaching effect was statistically significant. Irrigation with the W_3 wastewater (blended wastewater) without leaching application significantly increased corn dry yield, in comparison with W_1 wastewater treatment with 0 and 15 percent leaching application. Plant yield prediction based on prevailing soil condition is truly important. Maas and Hoffman (1977) presented a liner equation between plant yield and ECe but specific-ion impacts should be considered too. A linear regression was developed between corn relative yields (Yr) and ECe. In addition, another linear regression was developed between relative yield (Yr) and sodium adsorption ratio (SAR) of soil saturated extract paste. Regression analysis showed more variation for Yr and SARe ($R^2=0.82$) than Yr and ECe ($R^2=0.74$). These results are presented in Figs. 3 and 4. It can be concluded that for situations when corn is irrigated by sodic water and soil SAR is moderate or soil is sodic, it will be better to predict corn yield base on prevailing sodicity level of the soil instead of salinity level.

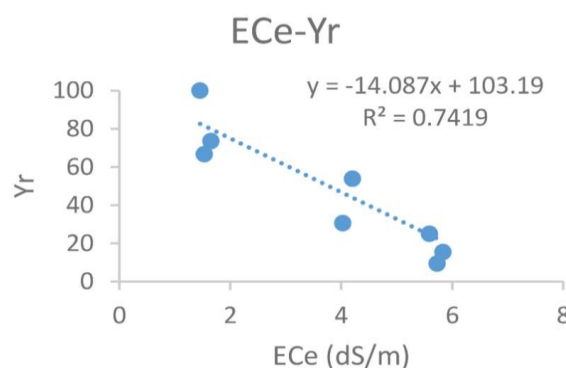


Figure 3: Linear relationship between soil ECe and forage corn relative yield



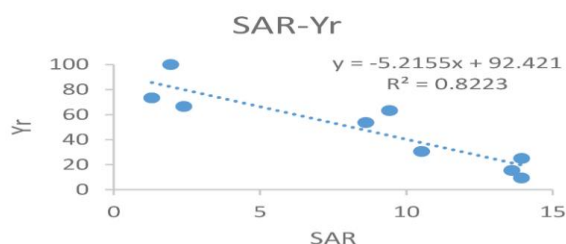


Figure 4: Linear relationship between soil SAR and forage corn relative yield

Plant Fresh Biomass

Irrigation water salinities and leaching fractions significantly affected plant wet yield (Table 7). A

significant reduction of plant wet weight has been observed as consequences of increasing irrigation water salinity. Irrigating with W_3 water (blending treatment) significantly increased corn wet yield in comparison with W_1 treatment. The 15 and 30 percent leaching fractions, significantly increased corn wet weight about 26 and 54 percent, respectively. Results of interaction effects of treatments (Table 8) show that application of the 15 and 30 percent leaching for irrigation with W_3 wastewater significantly increased corn wet weight in comparison with W_1 treatments (with or without leaching application). Results of interaction effects of treatments show that the 30 percent leaching application for irrigation with all of three wastewaters significantly increased plant wet weight in comparison with treatments, which leaching was not

Table 7: Mean comparison of the effects of treatments on corn growth components ($p < 0.05$)

	Irrigation water salinity			Leaching fraction		
	W1	W2	W3	LF1	LF2	LF3
Dry Weight (g)	19.45 c	58.70 a	41.69 b	31.11 b	37.04 b	51.69 a
Wet Weight (g)	31.54 c	77.81 a	61.10 b	44.87 c	56.49 b	69.10 a
IWUE (kg/ha.mm)	6.66 c	20.68 a	14.64 b	12.23 a	13.29 ab	16.46 b
Stem Diameter (mm)	10.96 c	15.91 a	14.35 b	10.70 b	14.85 a	15.66 a
Stem Height (cm)	24.68 c	67.36 a	37.13 b	31.68 c	45.25 b	52.24 a
Leaf area (cm ²)	50.54 c	89.10 a	61.58 b	51.78 c	63.67 b	85.76 a
Root Volume (mm ³)	7.49 b	29.06 a	17.04 b	14.16 a	17.17 a	22.27 a

Note: The values followed by at least one same character are not statistically different at 5 % probability level. W_1 = varzaneh wastewater (9 dS/m), W_2 = Isfahan university of technology's wastewater (1 dS/m), W_3 = blended wastewater (blending of W_1 and W_2 wastewaters with 1:1 ratio, 4/7 dS/m). LF_1 = 0 % leaching fraction, LF_2 = 15 % leaching fraction, LF_3 = 30 % leaching fraction

Table 8: Mean comparison of the interaction effects of treatments on growth components of corn ($p < 0.05$)

Treatments	EC(dS/m)	Corn Growth Components						
		Dry Weight (g)	Wet Weight (g)	IWUE (kg/ha.mm)	Stem Diameter (mm)	Stem Height (cm)	Leaf area (cm ²)	Root Volume (mm ³)
W1LF1	9	10.56 e	20.54 f	4.17 f	5.68 g	11.24 e	27.03 e	6.16 c
W1LF2	9	15.22 de	29.21 ef	5.45 ef	13.75 de	24.57 d	53.63 d	8.82 bc
W1LF3	9	32.56 cd	44.87 de	10.35 de	13.45 e	38.24 c	70.97 bcd	7.49 c
W2LF1	1	49.56 bc	65.87 bc	19.46 ab	15.30 bcd	57.57 b	74.27 bc	11.16 ab
W2LF2	1	55.33 ab	75.37 ab	19.88 ab	14.24 cde	71.28 a	79.70 b	21.53 bc
W2LF3	1	71.22 a	92.21 a	22.71 a	18.17 a	73.24 a	113.33 a	40.49 a
W3LF1	4.7	33.22 c	48.21 cd	13.35 cd	11.12 f	26.24 d	54.03 d	11.15 bc
W3LF2	4.7	40.56 bc	64.87 bc	14.54 bcd	16.54 b	39.91 c	57.70 cd	21.16 bc
W3LF3	4.7	51.22 b	70.21 b	16.32 bc	15.37 bc	45.24 c	73.00 bc	18.82 bc

Note: The values followed by at least one same character are not statistically different at 5 % probability level. W_1 = varzaneh wastewater (9 dS/m), W_2 = Isfahan university of technology's wastewater (1 dS/m), W_3 = blended wastewater (blending of W_1 and W_2 wastewaters with 1:1 ratio, 4.7 dS/m). LF_1 = 0 % leaching fraction, LF_2 = 15 % leaching fraction, LF_3 = 30 % leaching fraction



applied.

Irrigation water use efficiency (IWUE)

Irrigation water salinity significantly effected IWUE based on mean comparison results presented in Table 7. As irrigation water salinity increased, IWUE significantly decreased. The W_3 wastewater (blending treatment) significantly increased IWUE in comparison with W_1 wastewater. The 15 and 30 percent leaching caused 8 and 35 percent increase in IWUE, respectively, which only the 30 percent leaching effect was significant. It can be concluded that mixing wastewater and leaching can successfully improve the salinity condition. Results of treatments interaction effects (Table 8) show that irrigation with W_3 wastewater without leaching application significantly increased IWUE of plant in comparison with W_1 wastewater treatment with 0 and 15 percent leaching application. Interaction effects results also show that there was no significant difference between effects of irrigation with W_3 wastewater with the 15 and 30 percent leaching application and irrigation with W_2 (1 dS/m) wastewater with 0 and 15 percent leaching application.

Stem diameter

As shown in Table 7, irrigation water salinity and leaching significantly affected plant stem diameter. Same as the other plant components, increase of irrigation water salinity significantly reduced corn stem diameter. W_3 treatment increased stem diameter significantly in comparison with W_1 treatment. Increasing leaching from 0 to 15 percent, significantly increased stem diameter. However, no significant difference between 15 and 30 percent leaching effects has been observed. Results of the treatments interaction effects (Table 8) show that increasing level of leaching from 15 to 30 percent reduced corn stem diameter for irrigation with saline wastewaters (W_1 and W_3) but this effect was not statistically significant. In addition, interaction results show that application of the 15 and 30 percent leaching for irrigation with W_1 and W_3 wastewaters significantly increased plant stem diameter in comparison treatments, where no leaching was applied.

Stem height

As shown in the Table 7, irrigation water salinity and leaching fraction had significant impacts on stem height. Irrigation water salinity significantly reduced stem height and leaching significantly increased stem height. In addition, increase of stem height was observed for irrigation with W_3 treatment in comparison with W_1 treatment. Results of treatments interaction effects show that the application 15 and 30 percent leaching significantly increased corn stem height in comparison with treatments,

which no leaching was applied. However, only for irrigation with W_1 wastewater the 15 and 30 percent leaching effects was statistically significant in comparison with each other. In addition, interaction results show that there was no significant difference between effects of irrigation with W_1 wastewater with the 30 percent leaching application and irrigation with W_3 wastewater with 15 and 30 percent leaching application.

Leaf area

As shown in the Table 7, irrigation water salinity and leaching fraction had significant effects on corn leaf area which this result is consistent with the results of Mostafazadeh-Fard *et al.* (2009), Amer (2010) and Heakal *et al.* (1990). Same as the other plant components, increase of irrigation water salinity significantly reduced leaf area and increase of leaching significantly increased leaf area. In comparison with W_1 treatment, W_3 treatment significantly increased plant leaf area. The 15 and 30 percent leaching significantly increased leaf area about 23 and 66 percent, respectively. Therefore, it can be concluded that leaching can be a successful way to improve leaf area of forage corn plant. Results of interaction effects of the treatments (Table 8) show that the 15 percent leaching application significantly increased leaf area only for irrigation with saline-sodic wastewater (W_1). The 30 percent leaching application significantly increased leaf area for all of three wastewaters used in this experiment. Results of interaction effects also show that there was no difference between effects of the 30 percent leaching application for irrigation with W_1 (9 dS/m) wastewater and 15 percent leaching application for irrigation with W_2 (1 dS/m) wastewater.

Root volume

Root volume as an indicator of plant growth, should be evaluated. As shown in Table 7, irrigation water salinity and leaching significantly affected root volume. Same as the other plant components increase of irrigation water salinity reduced root volume and increase of leaching increased root volume. In comparison with W_1 treatment, W_3 treatment did not significantly affect corn root volume. The 15 and 30 percent leaching caused 21 and 57 percent increment in root volume respectively. Interaction effects of treatments results (Table 8), indicates that only the application of 30 percent leaching for irrigation with W_3 wastewater significantly affected corn root volume in comparison with other experimental treatment.

Conclusion

The effects of different types of municipal wastewaters as irrigation water and leaching on soil chemical properties and corn yield were studied. Results showed that increasing



of leaching fraction effectively reduced soil salinity but its effect on soil SAR was not statistically significant. Application of the 30 percent leaching fraction significantly reduced soil salinity accumulation at 0-10 cm depth only for irrigation with saline-sodic wastewater. The 15 and 30 percent leaching fraction significantly affected corn dry weight yield, stem diameter, stem height and leaf area but only the 30 percent leaching application significantly affected corn dry biomass and IWUE (Irrigation Water Use Efficiency). By blending of non-saline or non-sodic wastewater and saline-sodic wastewater with 1:1 ratio in order to use it for irrigation in combination with leaching application, high corn production can be achieved without significant difference in comparison with non-saline or non-sodic wastewater irrigation. The significance result of this study is production of corn plant even in condition that salinity and sodicity of irrigation water are beyond threshold value of plant. These results can be considered as a solution in areas which water scarcity is main problem of agricultural systems of the region. The results obtained in this study needed to be extrapolated by further field experiments to be realistic but the general trend of results of this study can be a clue for future investigation.

Acknowledgment

This study was financially supported by Isfahan University of Technology, which is appreciated. Special thanks to Prof. Afuyni and Prof. Haj Abbasi, faculty members of Soil Science Department at Isfahan University of Technology, for their great comments.

References

- Lal, K., P.S. Minhas and R.K. Yadav. 2015. Long-term impact of wastewater irrigation and nutrient rates II. Nutrient balance, nitrate leaching and soil properties under peri-urban cropping systems. *Agricultural Water Management* 156: 110-117.
- Amer, K.H. 2010. Corn crop response under managing different irrigation and salinity levels. *Agricultural Water Management* 97: 1553-1563.
- Anonymous. 2013. Corn production in Iran. Retrieved from <http://www.indexmundi.com/>
- Arienzo, M., E.W. Christen, N.S. Jayawardane and W.C. Quayle. 2012. The relative effects of sodium and potassium on soil hydraulic conductivity and implications for winery wastewater management. *Geoderma* 173: 303-310.
- Ayers, R.S. and D.W. Westcot. 1985. Water quality for agriculture. FAO Irrigation and drainage paper 29 Rev. 1. Food and Agricultural Organization. Rome.
- Bame, I.B., J.C. Hughes, L.W. Titshall and C.A. Buckley. 2014. The effect of irrigation with anaerobic baffled reactor effluent on nutrient availability, soil properties and maize growth. *Agricultural Water Management* 134: 50-59.
- Batziaka, V., K. Fytianos and E. Voudrias. 2008. Leaching of nitrogen, phosphorus, TOC and COD from the biosolids of the municipal wastewater treatment plant of Thessaloniki. *Environmental Monitoring and Assessment* 140: 331-338.
- Bedbabis, S., B. Ben Rouina, M. Boukhris and G. Ferrara. 2014. Effect of irrigation with treated wastewater on soil chemical properties and infiltration rate. *Journal of Environmental Management* 133: 45-50.
- Bedbabis, S., D. Trigui, C. Ben Ahmed, M.L. Clodoveo, S. Camposeo, G.A. Vivaldi and B. Ben Rouina. 2015. Long-terms effects of irrigation with treated municipal wastewater on soil, yield and olive oil quality. *Agricultural Water Management* 160: 14-21.
- Ben Ahmed, C., S. Magdich, B. Ben Rouina, M. Boukhris and F. Ben Abdullah, 2012. Saline water irrigation effects on soil salinity distribution and some physiological responses of field grown Chemlali olive. *Journal of Environmental Management* 113: 538-544.
- Blum, J., A.J. Melfi, C.R. Montes and T.M. Gomes. 2013. Nitrogen and phosphorus leaching in a tropical Brazilian soil cropped with sugarcane and irrigated with treated sewage effluent. *Agricultural Water Management* 117: 115-122.
- Chaganti, V.N. and D.M. Crohn. 2015. Evaluating the relative contribution of physiochemical and biological factors in ameliorating a saline-sodic soil amended with composts and biochar and leached with reclaimed water. *Geoderma* 259: 45-55.
- Chaganti, V.N., D.M. Crohn and J. Šimůnek. 2015. Leaching and reclamation of a biochar and compost amended saline-sodic soil with moderate SAR reclaimed water. *Agricultural Water Management* 158: 255-265.
- Chang, D. and Z. Ma. 2012. Wastewater reclamation and reuse in Beijing: Influence factors and policy implications. *Desalination* 297: 72-78.
- Chen, W., S. Lu, W. Jiao, M. Wang and A.C. Chang. 2013. Reclaimed water: A safe irrigation water source?. *Environmental Development* 8: 74-83.
- Choudhary, O.P., B.S. Ghuman, A.S. Josan and M.S. Bajwa. 2006. Effect of alternating irrigation with sodic and non-sodic waters on soil properties and sunflower yield. *Agricultural Water Management* 85: 151-156.
- Eck, H.V. 1984. Irrigated corns yield response to nitrogen and water. *Agronomy Journal* 76: 421-428.
- Magesana, G.N., C. D.A. MacLay. and V.V. Lal. 1998. Nitrate leaching from a free-draining volcanic soil irrigated with municipal sewage effluent in New Zealand. *Agriculture, Ecosystems and Environment* 70: 181-187.



- Gengmao, Z., S.K. Mehta and L. Zhaopu. 2010. Use of saline aquaculture wastewater to irrigate salt-tolerant Jerusalem artichoke and sunflower in semiarid coastal zones of China. *Agricultural Water Management* 97: 1987-1993.
- Estefan, G. and J.R. Rolf Sommer. 2013. *Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North Africa region*.
- Grattan, S.R., S.E. Benes, D.W. Peters and F. Diaz. 2008. Feasibility of Irrigating Pickleweed (. Torr) with Hyper-saline Drainage Water. *Journal of Environment Quality* 37: S-149.
- Grattan, S.R., F.J. Díaz, F. Pedrero and G.A. Vivaldi. 2015. Assessing the suitability of saline wastewaters for irrigation of Citrus spp.: Emphasis on boron and specific-ion interactions. *Agricultural Water Management* 157: 48-58.
- Grattan, S.R., J.D. Oster, S.R. Kaffka and M.C. Shannon, 2000. Reuse of Saline-Sodic Drainage Water for Irrigation. In *Watershed Management and Operations Management* p. 1-9.
- Heakal, M.S., A.S. Modaihsh, A.S. Mashhady and A.I. Metwally. 1990. Combined effects of leaching fraction, salinity, and potassium content of waters on growth and water-use efficiency of wheat and barley. *Plant and Soil* 125: 177-184.
- Heidarpour, M., B. Mostafazadeh-Fard, J. Abedi Koupai and R. Malekian. 2007. The effects of treated wastewater on soil chemical properties using subsurface and surface irrigation methods. *Agricultural Water Management* 90: 87-94.
- Heidarpour, M., B. Mostafazadeh-Fard, A. Arzani, A. Aghakhani and M. Feizi. 2009. Effects of Irrigation Water Salinity and Leaching Fraction on Yield and Evapotranspiration in Spring Wheat. *Communications in Soil Science and Plant Analysis* 40: 2521-2535.
- Jalali, M., H. Merikhpour, M.J. Kaledhonkar and S.E.A.T.M. Van Der Zee. 2008. Effects of wastewater irrigation on soil sodicity and nutrient leaching in calcareous soils. *Agricultural Water Management* 95: 143-153.
- Kang, Y., M. Chen and S. Wan. 2010. Effects of drip irrigation with saline water on waxy maize (*Zea mays* L. var. ceratina Kulesh) in North China Plain. *Agricultural Water Management* 97: 1303-1309.
- Katerji, N. 2003. Comparison of corn yield response to plant water stress caused by salinity and by drought. *Agricultural Water Management* 65: 95-101.
- Keller, J., and R.D. Bliesner, 1990. *Sprinkle and trickle irrigation*. New York (USA) Van Nostrand Reinhold.
- Kirkham, M.B.B. 2005. *Principles of soil and plant water relations*. Retrieved from http://books.google.com.br/books/about/Principles_of_Soil_and_Plant_Water_Relations.html?id=NUcoZNPQEEC&pgis=1
- Li, C., J. Lei, Y. Zhao, X. Xu and S. Li. 2015. Effect of saline water irrigation on soil development and plant growth in the Taklimakan Desert Highway shelterbelt. *Soil and Tillage Research* 146: 99-107.
- Maas, E.V. and G.J. Hoffman. 1976. ICASALS, 1977. Crop salt tolerance [expressed as the decrease in yield]: evaluation of existing data. *International Conference on Managing Saline Water for Irrigation, Planning for the Future*. Lubbock. Tex. (USA).
- Marchuk, A.G. and P. Rengasamy. 2010. Cation ratio of soil structural stability (CROSS). In *19th World Congress of Soil Science*. pp. 5981-5983.
- Marofi, S., M. Shakarami, G. Rahimi and F. Ershadfat. 2015. Effect of wastewater and compost on leaching nutrients of soil column under basil cultivation. *Agricultural Water Management* 158: 266-276.
- Mohammad Rusan, M.J., S. Hinnawi and L. Rousan. 2007. Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. *Desalination* 215: 143-152.
- Mostafazadeh-Fard, B., H. Mansouri, S.F. Mousavi and M. Feizi. 2009. Effects of different levels of irrigation water salinity and leaching on yield and yield components of wheat in an arid region. *Journal of Irrigation and Drainage Engineering* 135: 32-38.
- Murtaza, G., A. Ghafoor, and M. Qadir. 2006. Irrigation and soil management strategies for using saline-sodic water in a cotton-wheat rotation. *Agricultural Water Management*. 81: 98-114.
- Musick, J.T., A., and D.A. Duseek. 1980. Irrigation corn yield response to water. *Transaction ASAE*, 23: 92-98.
- Oster, J. D., and S. R. Grattan. 2002. Drainage water reuse. *Irrigation and Drainage Systems*, 16: 297-310.
- Page, A.L., A. Ayanaba, M.S. Baram, G.W. Barrett, W.G. Boggess, A. Chang. T.E. Long. 1996. Use of reclaimed water and sludge in food crop production. *National Research Council*.
- Payero, J.O., D.D. Tarkalson, S. Irmak, D. Davison and J.L. Petersen. 2008. Effect of irrigation amounts applied with subsurface drip irrigation on corn evapotranspiration, yield, water use efficiency, and dry matter production in a semiarid climate. *Agricultural Water Management* 95: 895-908.
- Qadir, M and J. Oster. 2004. Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. *Science of The Total Environment* 323: 1-19.
- Qadir, M., A.S. Qureshi and S.A.M. Cheraghi. 2008. Extent and characterisation of salt-affected soils in Iran and strategies for their amelioration and management. *Land Degradation and Development* 19: 214-227.



- Seckler, D., R. Barker and U. Amarasinghe. 1999. Water Scarcity in the Twenty-first Century. *International Journal of Water Resources Development* 15: 29-42.
- Shahabfar, A., A. Ghulam, and J. Eitzinger. 2012. Drought monitoring in Iran using the perpendicular drought indices. *International Journal of Applied Earth Observation and Geoinformation* 18: 119-127.
- Shainberg, I. and J. Letey. 1984. Response of sodic soils to saline conditions. *Hilgardia* 52: 1-57.
- Sou/Dakouré, M.Y., A. Mermoud, H. Yacouba and P. Boivin, 2013. Impacts of irrigation with industrial treated wastewater on soil properties. *Geoderma* 200: 31-39.
- Steduto, P., J.M. Faurès, J. Hoogeveen, J. Winpenny. and J. Burke. 2012. *Coping with water scarcity: an action framework for agriculture and food security*. Food and Agriculture Organization of the United Nations Rome, Italy.
- Wan, S., Y. Kang, D. Wang and S. Liu. 2010. Effect of saline water on cucumber (*Cucumis sativus* L.) yield and water use under drip irrigation in North China. *Agricultural Water Management* 98: 105-113.
- Zhang, C.Y., S. Zhang, M.Y. Yin, L.N. Ma, Z. He, and Z. Ning. 2013. Nitrogen isotope studies of nitrate contamination of the thick vadose zones in the wastewater-irrigated area. *Environmental Earth Sciences* 68: 1475-1483.

