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RESEARCH ARTICLE

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Cyclic use of saline and non-saline water to increase water use efficiency and soil sustainability on drip irrigated maize in a semi-arid region

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Abstract

Use of saline water for irrigation is a strategy to mitigate water shortage. The objective of this study was to investigate the impact of the cyclic and constant use of saline and non-saline water on drip irrigated maize yield and irrigation water use efficiency (IWUE). Nine field treatments were laid out based on alternative irrigation management of non-saline and saline water combinations. The treatments were: two salinity levels of 3.5 and 5.7 dS/m and freshwater (0.4 dS/m) application in every one, three and five saline water application (1:1, 3:1 and 5:1, respectively). Results showed that the 1:1 combination management was the best in terms of crop yield and IWUE. In this treatment, salt concentration at the end of growing season was not significantly changed compared to its initial condition. If off-season precipitation or leaching was available, the 3:1 and 5:1 treatments were appropriated. Highest and lowest values of IWUE were 15.3 and 8.7 kg/m^3 for the 1:1 management using water salinity of 3.5 dS/m and the treatment of constant irrigation with water salinity of 5.7 dS/m, respectively. Under low off-season precipitations, artificial leaching is essential for land sustainability in most treatments.

Additional key words: crop yield; soil salinity; leaching; drip irrigation; silage maize

Abbreviations used: DI (drip irrigation); DMRT (Duncan's multiple range test); EC (electric conductivity of saline water solution); EC_e (electrical conductivity of the saturation extract of the soil); $EC_{e\text{-threshold}}$ (average root zone salinity at which yield starts to decline); EC_{iw} (electrical conductivity of irrigation water); ET_c (crop evapotranspiration); ET_0 (reference evapotranspiration); F (fresh water); IRR_i (irrigation water applied for irrigation level i); IWUE (irrigation water use efficiency); K (purity degree of the salt); K_c (crop coefficient); K_s (salinity stress coefficient); K_y (yield response factor); LR (leaching requirement); RCBD (Randomized Complete Block Design); S1 (saline water at 3.5 dS/m salinity level); S2 (saline water at 5.7 dS/m salinity level); SAR (sodium adsorption ratio); SDI (subsurface drip irrigation); TDS (total dissolved salts in water); Y_{gd} (dryland yield); Y_{gi} (crop yield for irrigation level i).

Authors' contributions: Conceived and designed the experiments, analyzed the data, contributed reagents/materials/analysis tools, and wrote the paper: MH and HE. Performed the experiments: MH.

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Introduction

Sustainability of water resources is a critical issue as water demand for agricultural, industrial, and domestic purposes is rising (Provenzano *et al.*, 2013). FAO (2013) has indicated that about 60% more food will be needed to feed the 9.5 billion people in 2050. To supply water for agriculture, it is vital to achieve food security for the rapidly increasing global population (Singh, 2012). Sustainability of water resources largely depends on the proper management and efficient utilization of agricultural water (Fasakhodi *et al.*, 2010). Utilization of saline water for irrigation, as an alternative, is some way challenging. In fact, if used inappropriately, it can pose serious threats to agricultural sustainability and food security by creating salt buildup in the root zone (Tyagi, 2003). Conjunctive use of saline and fresh water for irrigation allows the utilization of poor quality surface water and/or groundwater resources with freshwater (Rhoades, 1987; Sharma & Rao, 1998; Crescimanno *et al.,* 2002; Datta & Jong, 2002; Yadav *et al.*, 2004; Kaur *et al.*, 2007). Blending and cyclic use are two options adopted when coordinating the use of water with different qualities (Rhoades *et al.*, 1992; Wichelns *et al.*, 2002; Hamilton *et al.*, 2007; Dudley *et al.*, 2008; Kulkarni, 2011). In the blending or mixing mode, the non-saline water can be mixed with saline water to be applied to the field, while the two water sources can be used alternately in the cyclic mode (Aslam & Prathapar, 2006; Singh, 2014).

Tscheschke *et al.* (1974) evaluated the use of saline water on trickle irrigation systems for tomato production. The results showed a profile of salt increasing from the trickle source outward, resulting in a gradual decrease in soil water potential. Naresh *et al.* (1993) evaluated cyclic and mixing use of saline and non-saline waters for wheat production. The results indicated cyclic treatment improved crop yield by 12% as compared with mixing treatment. Oron *et al.* (1999) investigated soil moisture and salinity distribution under subsurface drip irrigation (SDI) and conventional drip irrigation (DI) with saline water in a pear orchard. The results indicated that moisture and salinity distribution under SDI was better adjusted to the root pattern in the soil, in comparison with DI. Malash *et al.* (2005) investigated the effect of alternate and mixed fresh and saline water under drip and furrow systems on tomato yield and growth, in Nile Delta, Egypt. Mixed treatments had a higher crop growth and yield as compared with the alternate treatments. Moreover, tomato growth and yield were higher in alternate practice only with fresh water, whereas moderate saline irrigation for mixed treatment had the highest yield and growth. Hamdy *et al.* (2005) investigated the possibility of saline supplemental irrigation for rainfed wheat and barley during their sensitive stages of flowering and seed formation in a Mediterranean climate. In both cases, their results showed that crop yield increased under limited irrigation of brackish water. The limited amounts of added salts could be easily leached out even by modest off-season precipitations. Kang *et al.* (2010) evaluated effects of drip irrigation with saline water on waxy maize in North China Plain. The results showed that irrigation water use efficiency (IWUE) increased with the increase of irrigation water salinity, as long as salinity was lower than 10.9 dS/m. Huang *et al.* (2012) studied the impact of saline water irrigation on soils in northwest China. Soil salinity increased with saline irrigation water (7.03 dS/m) and slightly increased with brackish irrigation water (2.66 dS/m). No significant increase in soil salinity was observed under fresh water application. Rasouli *et al.* (2013) evaluated the effects of saline water irrigation in wheat-cultivated lands in Iran. The study revealed that rainfall distribution played a key role in creation of soil salinity profile during the growing season, and off-season winter rainfall was more effective in salt leaching than a similar amount of rainfall distributed throughout winter, spring, and autumn seasons. Li *et al.* (2015) investigated the effects of saline water irrigation on soil salinity and plant growth in the Taklimakan Desert in northwest of China. Saline water irrigation did not interfere with normal growth of adaptive plants (*Tamarix*, *Haloxylon* and *Calligonum*), which may be attributed to the plant adaptability to salinity stress through root morphology adjustment. Talebnejad & Sepaskhah (2015) investigated the influence of irrigation water salinity on growth and yield of quinoa (*Chenopodium quinoa* Willd) in lysimeters under greenhouse conditions. Results indicated that increased water salinity caused significant decrease in seed yield and dry matter. Arslan *et al.* (2015) reported the 50% yield reduction in chickpea, lentil, and faba bean occurred at salinity levels of 4.2, 4.4 and 5.2 dS/m, respectively. Faba bean was more tolerant crop to irrigation water salinity as compared to lentil and chickpea. Mguidiche *et al.* (2015) evidenced that for a potato crop cultivated in a sandy loam soil, frequent applications of irrigation water with an electrical conductivity of 4.0 dS/m, approximately replacing the potential crop transpiration did not affect crop yield if compared to the treatment using better quality water, despite the slightly higher salt concentration in the root volume.

Under water shortage condition, saline and fresh water resources may be simultaneously used for irrigation to improve water productivity and decrease gradual soil salinization if properly managed to insure sustainable agriculture. In this study, various managements of cyclic and constant use of saline and non-saline water were investigated under drip irrigation to increase maize yield and IWUE with minimum soil salinity build up. Additionally, the effects of off-season precipitations on moving salts in root zone were investigated. The information obtained from this study will be helpful for evaluating the potential of saline irrigation water in arid and semi-arid areas from an environmental and economic standpoint.

Material and methods

A field experiment for maize (*Zea mays* L.) production was carried out in 2012 at the Soil and Water

Research Center, University of Tehran, Karaj, which is located on 50°59´E and 35°48´N at an altitude of 1337 m above sea level. Karaj has a Mediterranean climate with annual precipitation of 265 mm. Total rainfall during the study was 20.5 mm, of which 20.1 mm occurred during the germination stage, before applying treatments). These rainfalls were subtracted from crop water requirements. Soil texture of the experimental field was mainly clay loam, characterized by a soil bulk density of 1.35 g/cm^3 and a gravel layer at depths greater than 60 cm. Other soil characteristics are shown in Table 1. The study crop was maize cv 'Single Cross 704' for fodder purpose. The crop was sown on July 14, 2012 and seeding was performed without any tillage, by using a direct planting machine (no tillage).

Nine field treatments were laid out in a Randomized Complete Block Design (RCBD) with three replications in 27 plots. In each plot, having dimensions of 2.85 m × 3 m, four maize rows were planted. An additional row of crop was planted beside the plots to remove marginal effect. A schematic layout of the experimental field is presented in Fig. 1. Irrigation water was distributed with a drip tape system; the main pipe was placed across the field and lateral pipes were branched to each plot. A small controlling valve was inserted in each plot to adjust irrigation inflow. The volume of water per plot was recorded using a volumetric flow meter. Irrigation discharge from emitters was 4.0 L/h at a pressure between 0.8 to 1.0 bar. The treatments are described in Table 2. Only one salinity level was constantly used for irrigation during the growing season in F, S1 and S2 treatments.

Water salinity levels of 3.5 and 5.7 dS/m were based on 25% and 50% reduction in maize yield, respectively (Allen *et al.,* 1998). After seeding, all treatments were irrigated to field capacity. From seeding until eight-leaf stage of maize, irrigation in each plot was based on soil moisture and crop water requirements.

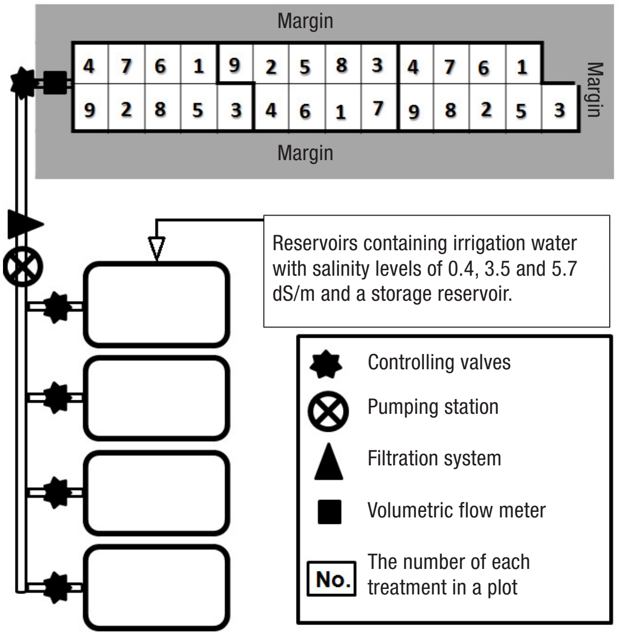

Figure 1. Schematic layout of the experimental field.

According to soil characteristics of the field and water requirements of maize, irrigation interval considered four days. Crop coefficient (K_c) of maize during initial, mid-season and the end of season stage were 0.3, 1.2 and 0.6 respectively (Allen *et al.,* 1998). Root depth of maize due to limited soil layer was determined 60 cm. The values of reference evapotranspiration (ET_0) during the growing season were calculated by CROPWAT 8.0 (Smith, 1992) using daily meteorological data. Due to reduction in evapotranspiration under salinity stress, a factor must be applied in crop evapotranspiration. Therefore, salinity stress coefficient (K_s) for maize was obtained according to Allen *et al.* (1998) as follows:

$$K_s = 1 - \frac{b}{K_y}\left(EC_e - EC_{e\ threshold}\right) \qquad [1]$$

Table 1. Soil properties determined at the upstream, middle and downstream parts of the experimental field.

Location	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture	Field capacity (volumetric percentage)	Initial salinity[1] (dS/m)
Upstream	0-20	36	36	28	Clay loam	34.6	2.31
	20-40	30	42	28	Clay loam	34.9	1.68
	40-60	36	34	30	Clay loam	37.3	1.92
Middle	0-20	36	36	28	Clay loam	34.6	2.22
	20-40	32	38	30	Clay loam	37.0	2.30
	40-60	32	34	34	Clay loam	37.3	1.89
Downstream	0-20	36	36	28	Clay loam	37.0	2.34
	20-40	36	36	28	Clay loam	34.6	1.31
	40-60	50	18	32	Sandy clay loam	34.6	2.52

[1] In term of electrical conductivity of the saturation extract of the soil (EC_e).

Table 2. Detailed description of the treatments when applying saline and non-saline irrigation water in 17 irrigation events during the maize growing season.

Treatment[1]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Irrigation water salinity (dS/m)																
F	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
S1	0.4	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
S2	0.4	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
1S1:1F	0.4	3.5	0.4	3.5	0.4	3.5	0.4	3.5	0.4	3.5	0.4	3.5	0.4	3.5	0.4	3.5	0.4
1S2:1F	0.4	5.7	0.4	5.7	0.4	5.7	0.4	5.7	0.4	5.7	0.4	5.7	0.4	5.7	0.4	5.7	0.4
3S1:1F	0.4	3.5	3.5	3.5	0.4	3.5	3.5	3.5	0.4	3.5	3.5	3.5	0.4	3.5	3.5	3.5	0.4
3S2:1F	0.4	5.7	5.7	5.7	0.4	5.7	5.7	5.7	0.4	5.7	5.7	5.7	0.4	5.7	5.7	5.7	0.4
5S1:1F	0.4	3.5	3.5	3.5	3.5	3.5	0.4	3.5	3.5	3.5	3.5	3.5	0.4	3.5	3.5	3.5	3.5
5S2:1F	0.4	5.7	5.7	5.7	5.7	5.7	0.4	5.7	5.7	5.7	5.7	5.7	0.4	5.7	5.7	5.7	5.7

[1] The letters of F, S1 and S2 are related to water salinity level of 0.4, 3.5 (light gray) and 5.7 (dark gray) dS/m, respectively, and the numbers before the letters indicate the application frequency.

where K_y is the yield response factor (1.25); b is the percentage reduction (7.4%) in crop yield per 1 dS/m increase in EC_e beyond $EC_{e\text{-threshold}}$; EC_e is electrical conductivity of the saturation extract of the soil (dS/m) at 25°C; and $EC_{e\text{-threshold}}$ is the average root zone salinity at which yield starts to decline (1.8 dS/m). The values above were obtained according to Allen *et al.* (1998) for maize. The values of K_s resulted equal to 0.8 and 0.6 for irrigation water salinity levels of 3.5 dS/m and 5.7 dS/m, respectively. These values were multiplied by ET_0 and crop coefficient to determine crop water requirement ($ET_c= K_s \times K_c \times ET_0$). The K_s coefficient was considered in this study because the plant biomass and subsequently the water requirement decreased under salinity stress. Obviously, without saline and water stress, K_s was equal to one. In this study, Eq. [2] was used to calculate the leaching requirement (LR) of non-saline irrigation water (Ayers & Westcot, 1985):

$$LR = \frac{EC_{iw}}{5EC_e - EC_{iw}} \quad [2]$$

where EC_{iw} is the electrical conductivity of irrigation water (dS/m). Leaching was only applied for non-saline irrigations. Because, in the contrary, the salts did not accumulate in the soil profile and theoretically there should not have been differences of soil salinity and crop yield between the treatments. Irrigation water was applied with a trickle system (tape) with emitters characterized by a flow rate of 4.0 L/h; the volume of water per plot was adjusted using a volumetric flow meter. To prepare saline water, industrial raw salt was dissolved in non-saline water and then the saline water was applied to the plots. The required salt for each treatments was calculated by the equation of TDS=640×K×EC (Smedema & Rycroft, 1983), where TDS is the total dissolved salts in water (mg/L), EC is the electric conductivity of saline water solution (dS/m), and K is the purity degree of the salt and was equal to 0.86. Some of the chemical properties of non-saline and saline water are shown in Table 3. Values of pH for saline and non-saline waters resulted of about 7.5, whereas the sodium adsorption ratio (SAR) increased with the electrical water conductivity.

Twenty-one days after sowing (almost four leaves stage), salinity stress was applied. Totally, 17 irrigation events during the growing season were applied and finally the crop was harvested at dough stage of grains on October 4th.

To determine soil salinity distribution, soil samples were collected five times for the first three treatments (F, S1 and S2) and six times for the rest (1S1:1F, 1S2:1F, 3S1:1F, 3S2:1F, 5S1:1F and 5S2:1F). Soil was collected at depths of 20, 40 and 60 cm and at distances of 0, 15 and 30 cm from the irrigation source (lateral pipe). After

Table 3. Chemical properties of non-saline and saline water irrigation.

Water	EC (dS/m)	pH	K^+ (mg/L)	Na^+ (meq/L)	Ca^{2+}+Mg^{2+} (meq/L)	Cl^- (mg/L)	SAR[1]
Non-saline	0.4	7.47	1.9	1.4	12.6	72	1.05
Saline (3.5 dS/m)	3.5	7.47	2.8	31.4	12.7	1349	12.45
Saline (5.7 dS/m)	5.7	7.45	3.2	57.4	12.9	2293	22.60

[1] SAR: sodium adsorption ratio.

Table 4. Soil sampling days (black circles) during the growing season for each treatment.

Treatment	Jul. 13 [1]	Aug. 21 [2]	Aug. 25 [3]	Aug. 29 [4]	Sep. 2 [5]	Sep. 6 [6]	Sep. 14 [7]	Sep. 18 [8]	Oct. 4 [9]	Dec. 4 [10]
F	●	●	●			●			●	●
S1	●	●	●			●			●	●
S2	●	●	●			●	●		●	●
1S1:1F	●			●	●		●	●	●	●
1S2:1F	●			●	●		●	●	●	●
3S1:1F	●			●	●		●	●	●	●
3S2:1F	●			●	●		●	●	●	●
5S1:1F	●	●	●				●	●	●	●
5S2:1F	●	●	●				●	●	●	●

[1]: initial condition of the field. [2]: before 7th irrigation. [3]: after 7th irrigation. [4]: before 9th irrigation. [5]: after 9th irrigation. [6]: before 11th irrigation. [7]: before 13th irrigation. [8]: after 13th irrigation. [9]: after 17th irrigation. [10]: before the second cultivation.

soil sampling, the holes were filled with the same soil in order to minimize changes in the distribution of water and solutes in the soil. Table 4 indicates soil sampling days during the growing season for each treatment. Totally, more than 400 soil samples were collected to measure the EC_e. These sampling days during the growing season varied among treatments, because the irrigation dates were different. The soil sampling was approximately carried out in the middle of each plot to minimize the effect of lateral salt and water movement on soil salinity profile among different plots.

The latter soil samples were collected two months after the last irrigation to determine soil salinity distribution after off-season precipitations. During these two months (October and November) rainfalls in the area resulted of 23.7 and 70.5 mm, respectively. In this study, IWUE was used to compare the treatments (Bos, 1979):

$$\mathrm{IWUE} = \frac{Y_{gi} - Y_{gd}}{\mathrm{IRR}_i} \quad [3]$$

where Y_{gi} is crop yield (kg) for irrigation level i, Y_{gd} is the dryland yield (kg; actually, the crop yield without irrigation) and IRR_i is the irrigation water applied (m^3)

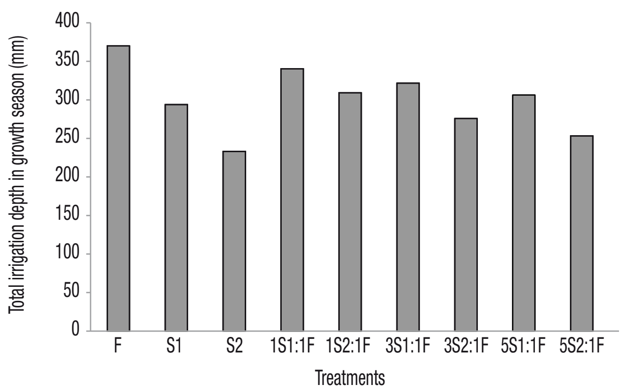

Figure 2. Total irrigation depth in the growing season for each treatment.

for irrigation level i. Since the biomass is important in forage maize, in this study IWUE was calculated based on total wet weight (biomass). In Eq. [3], Y_{gd} was assumed equal to zero (it is often zero in many arid and semi-arid regions such as the studied area).

Duncan's multiple range test (DMRT) was used for comparing the average crop yield and IWUE at 0.05 statistical level (Duncan, 1955).

Results and discussion

Applied irrigation water

The total irrigation depth for each treatment is shown in Fig. 2. Considering the application of K_s coefficient to evaluate ET_c, the amount of applied water resulted lower in saline irrigation treatments. The justification of this seems that when the plants are faced to salinity stress, their water requirements are restricted and consequently irrigation doses have to be reduced. The lowest seasonal irrigation water was distributed in the S2 treatment (233 mm), whereas the highest in F treatment (370 mm).

Soil salinity analysis

Soil salinity profiles during the growing season for the various treatments are shown in Fig. 3. Minor changes in soil salinity occurred at the end of the growing season if compared to the initial condition, at the beginning of the growing season, in F treatment. Due to continuous use of non-saline water in S1 and S2 treatments as consequence of the continuous use of saline water, salt accumulation in the soil profile was observed at the end of the growing season. Moreover, in treatments with saline water, as a result of lower amount of irrigation water, the wetting front was closer to the irrigation line and the amount of salts

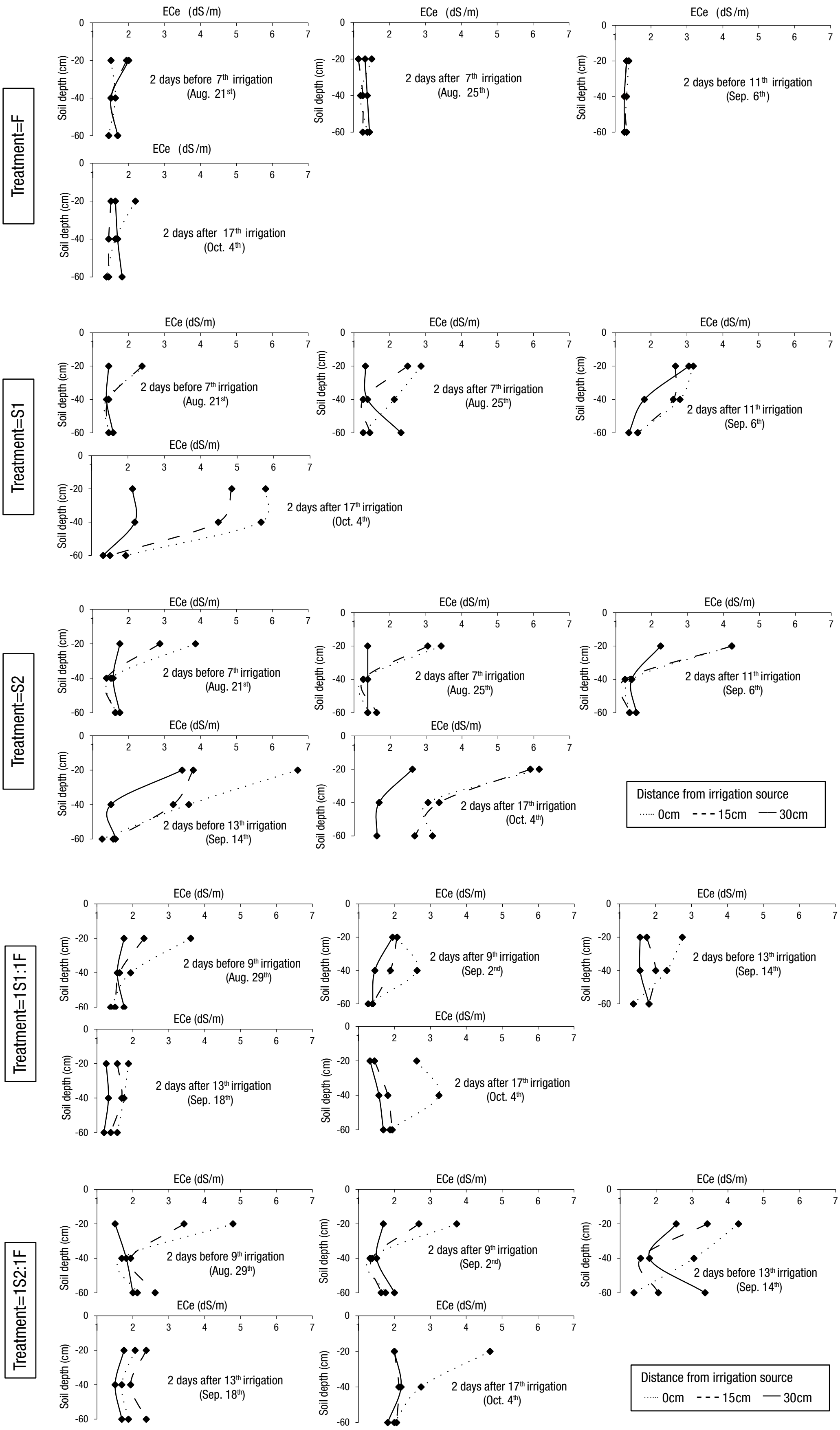

Figure 3. Soil salinity profiles at depths of 20, 40, 60 cm and at distances of 0, 15, 30 cm from irrigation line during the growing season for the nine treatments.

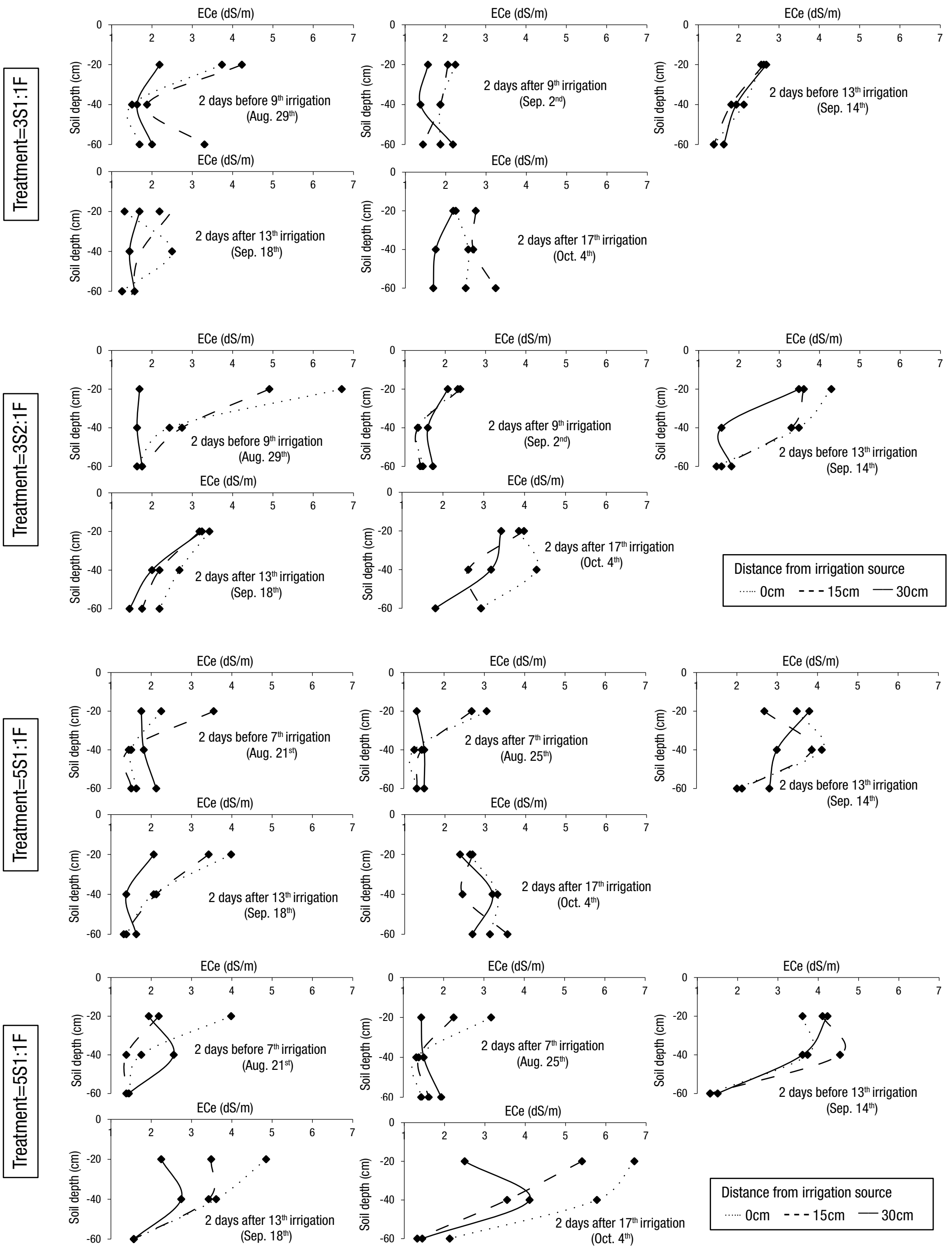

Figure 3. *(Cont.)* Soil salinity profiles at depths of 20, 40, 60 cm and at distances of 0, 15, 30 cm from irrigation line during the growing season for the nine treatments.

accumulated at a distance of 30 cm resulted lower than that accumulated at distances of 0 and 15 cm from the pipe. Due to water uptake and soil evaporation, salt accumulation was generally higher at the soil surface and close by the plants (irrigation line) (Fig. 3).

When non-saline water were applied (F treatment), the changes of soil salinity with depth were negligible (Fig. 3). On the contrary, in S1 and S2 treatments, due to salt accumulation at soil surface, the distribution of soil salinity with depth at different distances from the source showed an abrupt slope. As seen in Fig. 3, dotted lines (at irrigation line) compared to solid and dashed lines (distances of 15 and 30 cm from irrigation lines, respectively) generally had a higher slope.

Irrigation with non-saline water after saline water irrigation caused reduction in soil salinity in the 1S1:1F, 1S2:1F, 3S1:1F, 3S2:1F, 5S1:1F and 5S2:1F treatments (cyclic treatments). Soil salinity reduction, due to irrigation with non-saline water, was higher at irrigation line (Fig. 3). Soil salinity reductions after non-saline irrigation in the 1S1:1F treatment were lower than the 1S2:1F treatment, due to the concentration of applied water that determined the sudden changes and the abrupt slopes, as shown in Fig. 3. This is also true for the 3:1 and 5:1 treatments. It could be said that non-saline irrigation after irrigations with higher water salinity level (5.7 dS/m) produced more salt movement in the soil profile compared to less water salinity level (3.5 dS/m). This was also related to the difference between the higher volume of non-saline irrigation water and the lower volume of high saline (5.7 dS/m) irrigation water.

The average soil salinity of nine samples was calculated for each treatment and the changes were plotted during different days of the growing season (Fig. 4). The results showed that in the 1:1 treatment, average soil salinity at the end of the growing season compared with the initial soil salinity did not show difference (decreased 1.0% in the 1S1:1F treatment and increased 17.9% in the 1S2:1F treatment as seen at the right top of Fig. 4). Therefore, the 1S1:1F and 1S2:1F treatments are proper for land sustainability. Obviously, 1S1:1F is the most appropriate treatment under the presence of both salinity levels. However, amount and frequency of non-saline water to remove salts from soil profile were not adequate in the 3S2:1F and 5S2:1F treatments, for which it was observed the salt accumulation in the soil profile at the end of growing season with increments of soil salinity of 39.0% and 46.2%, respectively. Therefore off-season precipitation or leaching is necessary for the 3S2:1F and 5S2:1F treatments to reduce soil salinity for the following cultivation. Otherwise, increased soil salinity might pose serious problems during the successive years. Non-saline irrigations between saline irrigations removed the salts from the soil profile in 3S1:1F and 5S1:1F treatments and lower salt accumulation was observed at the end of the growing season if compared to S1 treatment. In other words, the soil salinity increased by 17.9% and 31.6% in 3S1:1F and 5S1:1F treatments, respectively, while this increase was 40.7% in S1 treatment. It means that with four non-saline irrigations in 3S1:1F treatment and two non-saline irrigations in 5S1:1F treatment throughout the growing season, the soil salinity was reduced by 22.8% and 9.1%, respectively, compared to S1 treatment. The results also showed that only in the F and 1S1:1F treatments the soil salinity was tolerable for maize germination at the end of the growing season (Fig. 4). Consequently, the maize production would be faced with salinity problem in most of the studied treat-

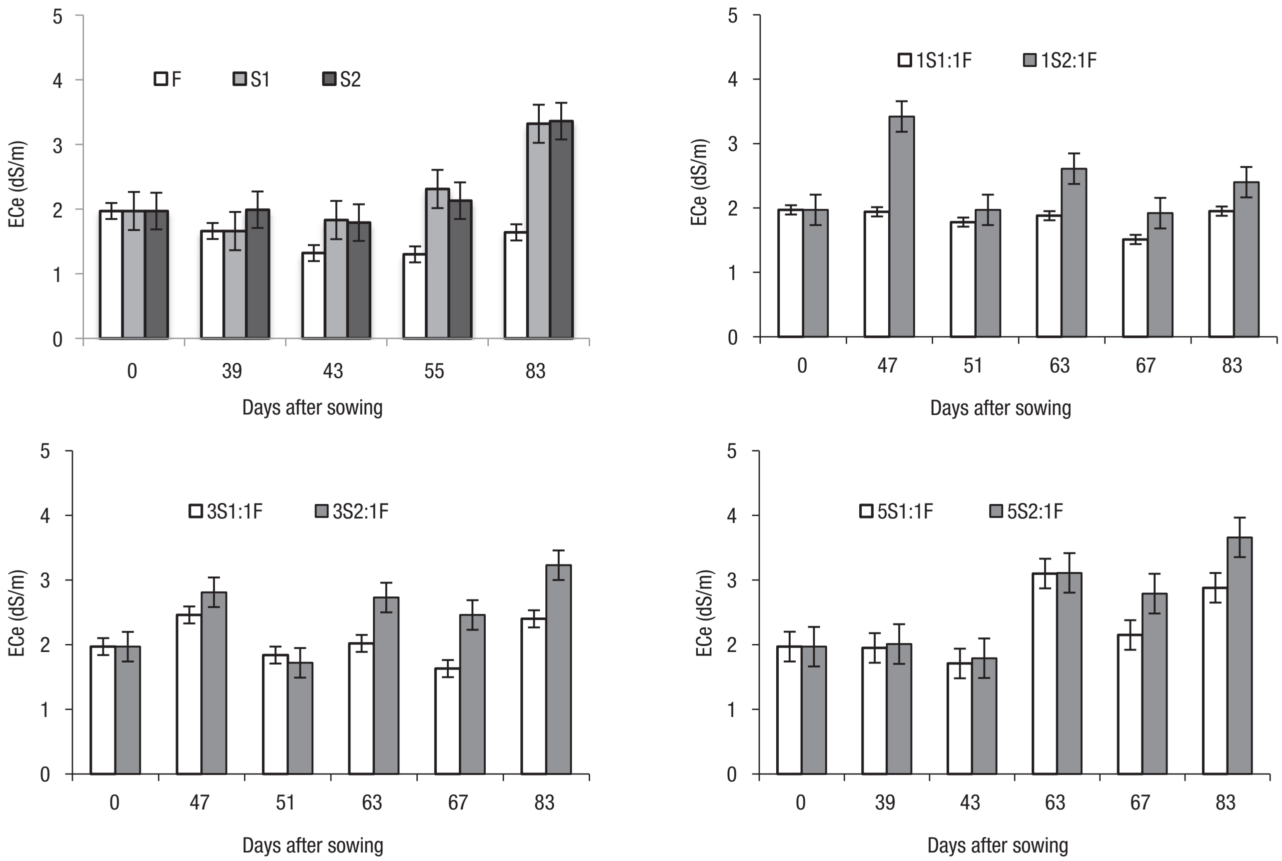

Figure 4. Soil salinity changes for average of nine samples during the growing season for all treatments.

ments without any off-season precipitation or artificial leaching.

The temporal variations of average soil salinity, determined by considering the samples collected at the three soil depths and at the distance of 0 cm, 15 cm and 30 cm from irrigation line, are plotted for all treatments from Fig. 5 to Fig. 7. The results showed that generally salt accumulation did not occur at distances of 15 and 30 cm from irrigation line, at the end of the growing season (especially at 30 cm). This circumstance indicated that the wetting front in trickle irrigation had fewer advances and was concentrated around the plant.

Tscheschke *et al.* (1974) reported that the salts accumulated on the borders of active root zone, in which soil water potential decreased, under greenhouse condition for tomato production with loamy sand soil. It seems that four days irrigation frequency in this study and daily irrigation in Tscheschke's study was the reason for this different result. However, Yazar *et al.* (2003) stated that soil salinity increases with increasing of irrigation water salinity and salt distribution profile under saline irrigation follows the distribution pattern typical of trickle irrigation (bulb shape), with maximum EC_e occurring at the soil surface. Amer (2010) also reported that salt accumulation in the soil profile increased with increasing irrigation water salinity. Li *et al.* (2015) showed that soil salts significantly accumulated at the soil surface (crust and 0–10 cm soil layers) when using saline water for irrigation, but the soil salinization did not increase at the 40– 60 cm soil depth where abundant lateral roots were found and extended horizontally.

Impact of off-season precipitations on soil salinity distribution

The purpose of collecting soil sampling two months later than the last irrigation was to find if the soil salinity was tolerable for second crop season or not. Hence, the sampling was only carried out close to the position of irrigation line, at depths of 20, 40 and 60 cm, where the highest salt accumulation was observed, and then compared with the corresponding samples collected after

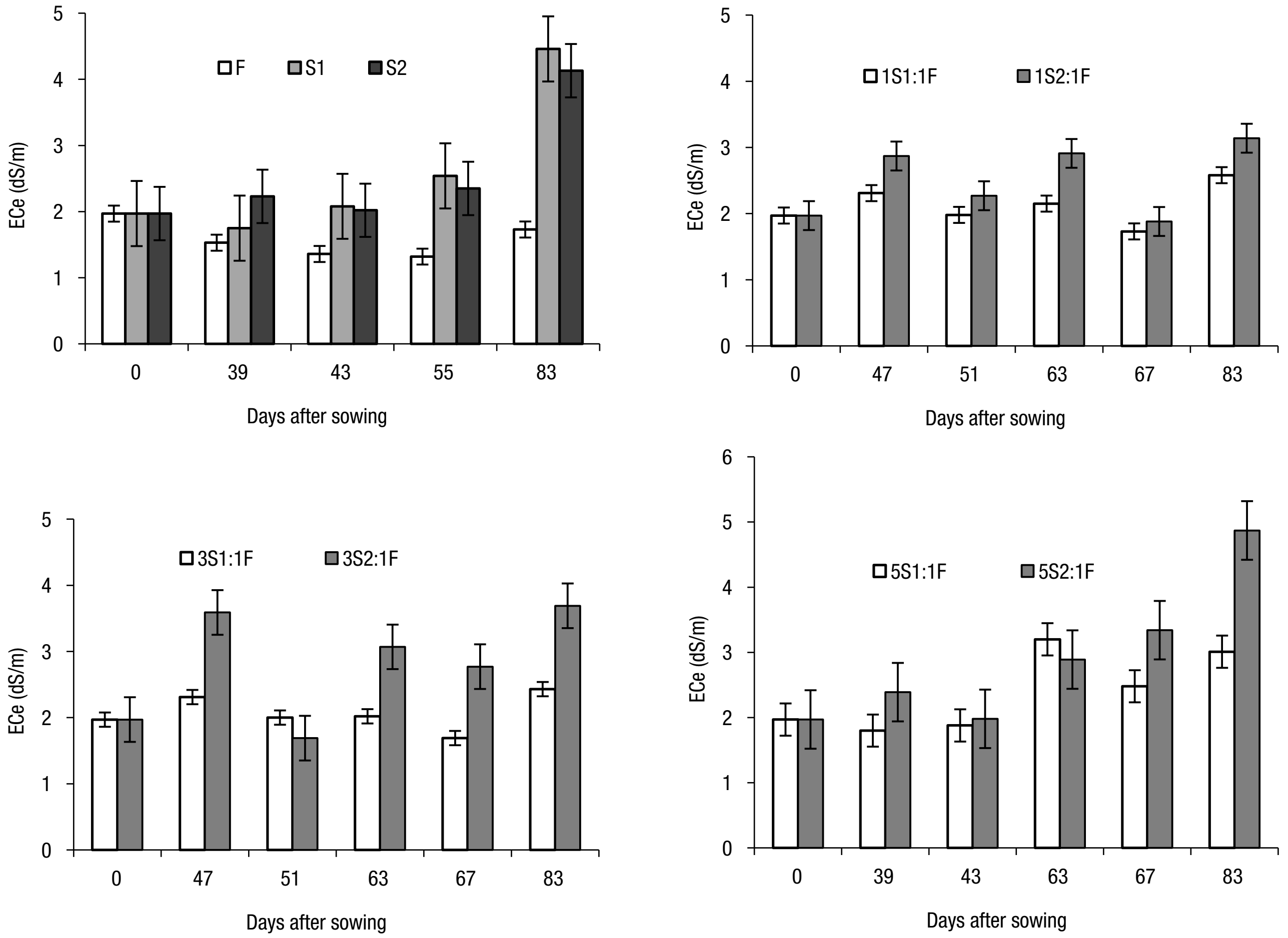

Figure 5. Soil salinity changes for average of three depth samples on irrigation line during the different days in the growing season for all treatments.

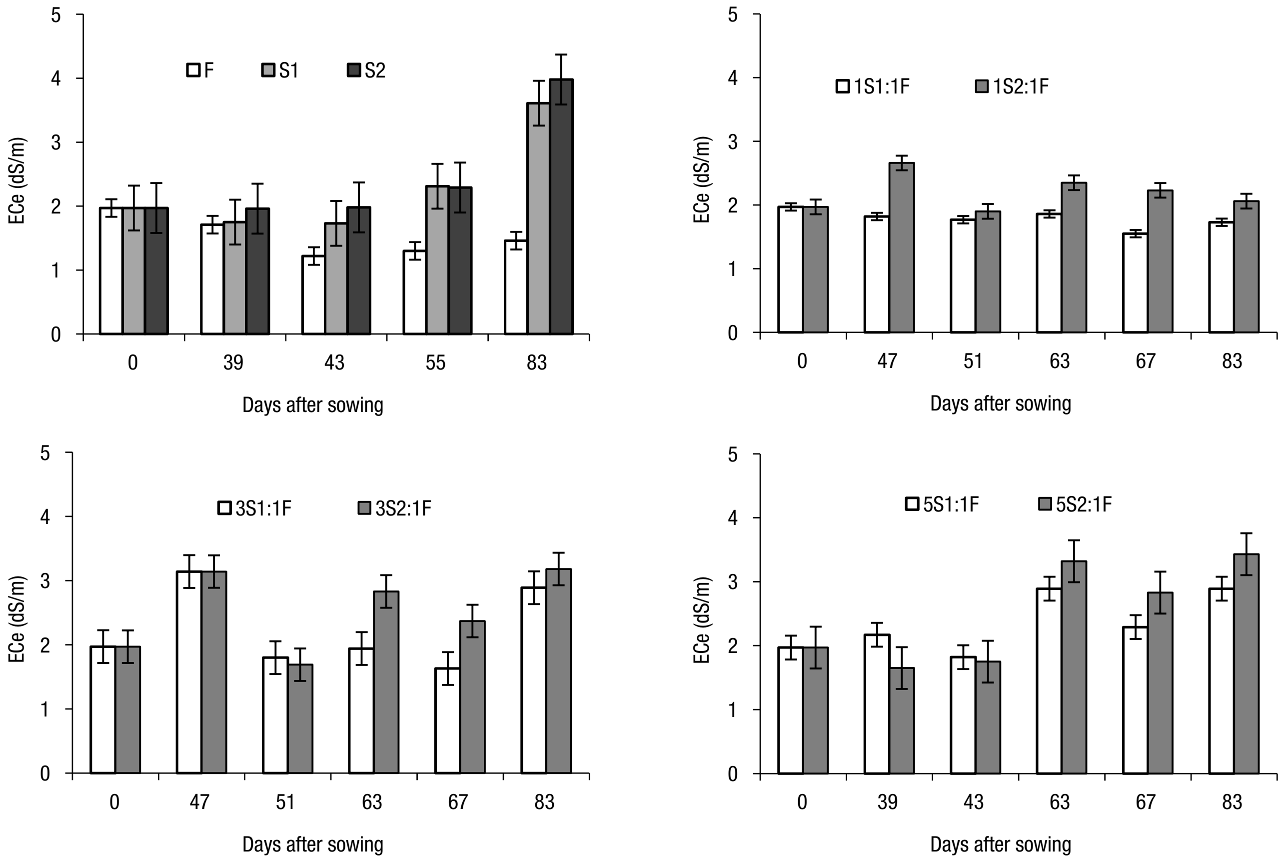

Figure 6. Soil salinity changes for average of three depth samples at distance of 15 cm from irrigation line during the different days in the growing season for all treatments.

the last irrigation. The soil salinity profiles on irrigation line in the two days after the last irrigation (Oct. 4th) and after off-season precipitations (Dec. 4th) for all treatments are shown in Fig. 8. The pattern of rainfall depths from Oct. 4th to Dec. 4th are shown in Fig. 9.

After off-season precipitations, soil salinity generally decreased at 20 cm depth and increased at 40-cm depth. This means that in most treatments the salts accumulated in the soil surface were slightly displaced, reaching the depth of 40 cm. Although the amount and distribution of water from precipitations were not able to move salts below 60 cm soil depth, it was effective to reduce salinity of the soil surface, ensuring the possibility of a second crop season, because the soil salinity level at soil surface is important at the early stages of plant growth. In addition, winter rainfalls could move the wetting front to deeper depths and reduce soil salinity. Monteleone & Libutti (2012) irrigated silty loam soil columns to simulate fall-winter rainfalls. Irrigation was done every day for 15 days under drip irrigation with discharge of 1 L/h. A total of 70% of the salts were removed from 0-30 cm soil layer. Moreover, 43-60 and 54-70% of the salts remained at depths of 40 and 60 cm, respectively. Off-season precipitations naturally play a very important role in salts leaching and justify the use of saline water for some treatments. This is true when the soil is well drained and salts can move below the root zone or out of the soil profile. In absence of drainage or in soils with an impermeable soil layer, off-season rainfall could determine the groundwater rise and, at the same time, the rise of salt concentration at the soil surface.

Crop yield

Mean comparisons by Duncan test showed that although F treatment had the highest crop yield based on biomass (56.2 t/ha), there was no significant difference between this treatment and 1S1:1F, 1S2:1F, 3S1:1F and 5S1:1F treatments (Fig. 10).

The results showed that for every 1 dS/m increase of irrigation water salinity in F, S1 and S2 treatments, the crop yield decreased by 10.3%. Bassil & Kaffka (2002) stated that increasing salinity in soil and irrigation water would reduce safflower biomass. Similar results were found for maize production in this study. Emdad & Fardad (2000) appointed that water salinity

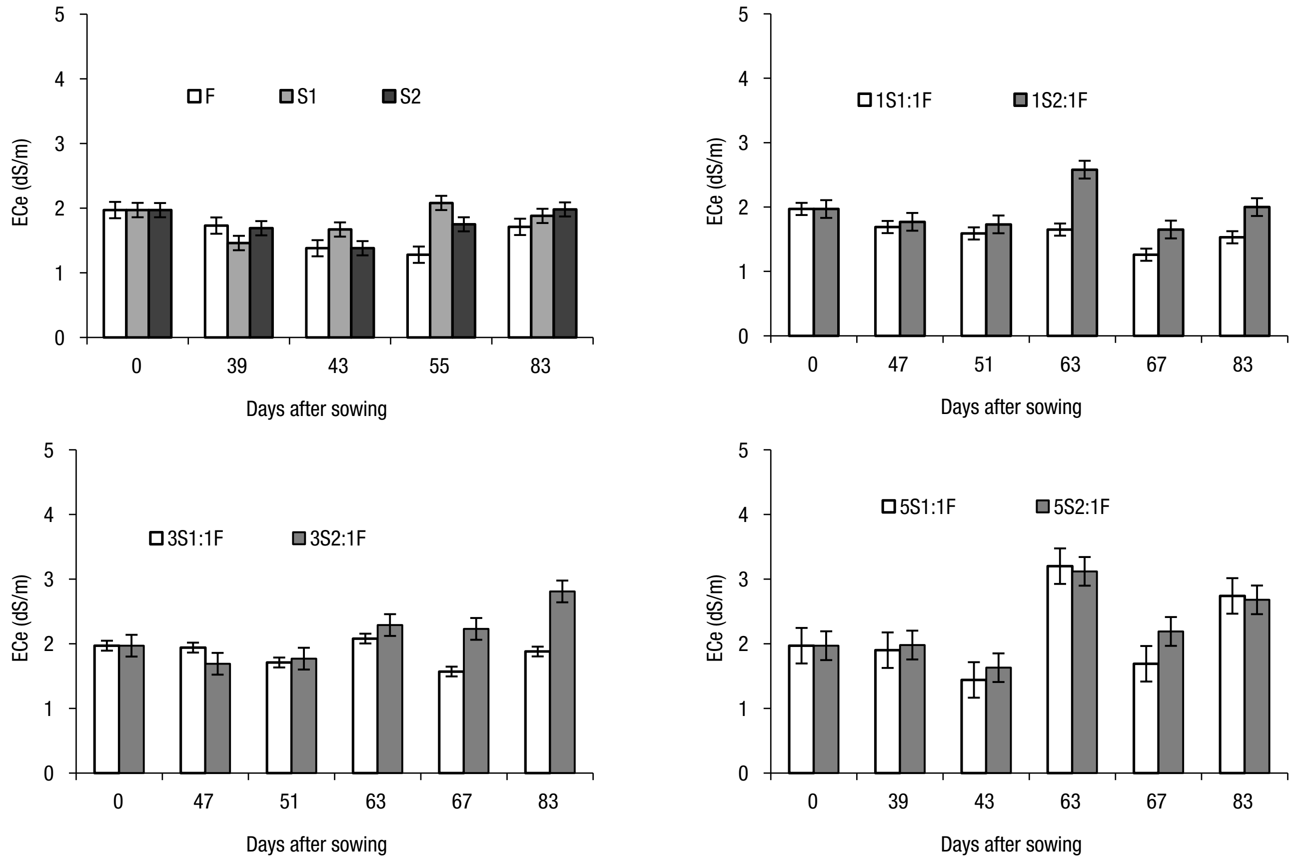

Figure 7. Soil salinity changes for average of three depth samples at distance of 30 cm from irrigation line during the different days in the growing season for all treatments.

of 4, 6 and 8 dS/m reduced maize yield about 17%, 34% and 49%, respectively, as compared with non-saline irrigation water treatment. Wan *et al.* (2010) reported that cucumber fruit yield decreased by 5.7 and 10.8% for 1 dS/m increase of irrigation water salinity and soil salinity, respectively. Kang *et al.* (2010) also stated that the decreasing rate of the fresh ear yield for every 1 dS/m increase in salinity of irrigation water was about 0.4–3.3% for waxy maize.

Naresh *et al.* (1993) concluded that higher production of wheat could be achieved with cyclic use of non-saline and saline waters when non-saline water was applied at the initial stages (pre-irrigation and/first post-sowing irrigation). Liaghat & Esmaili (2003) indicated there was no significant difference between the 1:1 and mixed treatments in dry matter of grain maize. Malash *et al.* (2005) stated that the mixed management gave higher growth and yield than cyclic management for tomato production. Zarei *et al.* (2007) reported that 1:1 management provided better conditions for shallow-root plants but mixed management was more suitable for deep-root plants. In the present study, S1 (a mixing of saline (5.7 dS/m) and non-saline (0.4 dS/m) waters) and 1S2:1F treatments could be considered as a cyclic management of the above saline and non-saline waters. The results showed that the biomass yield for S1 treatment (mixing management) was 20% higher than 1S2:1F treatment (cyclic or alternative management).

Irrigation water use efficiency

In terms of IWUE, only S2 treatment showed a significant difference if compared to the other treatments (Fig. 10). In this study, despite the reduction of total fresh weight (biomass) due to irrigation with saline water, IWUE was not considerably decreased for all treatments, except S2 treatment. In fact, both the crop yield (numerator of the Eq. [3]) and crop water requirement (denominator of Eq. [3]) decreased with a similar ratio. However, the reduction of crop yield was too much in S2 treatment and this ratio was not similar. As a consequence, IWUE decreased under high saline irrigation water application.

Ben-Asher *et al.* (2006) used three salinity levels (1.8, 3.3 and 4.8 dS/m) of saline water to irrigate grapevine and stated that salinity had no effect on IWUE. Wan *et al.* (2007) also reported that using saline water with electrical conductivity ranging between 1.1 and 4.9 dS/m on tomato, caused increase in IWUE as water

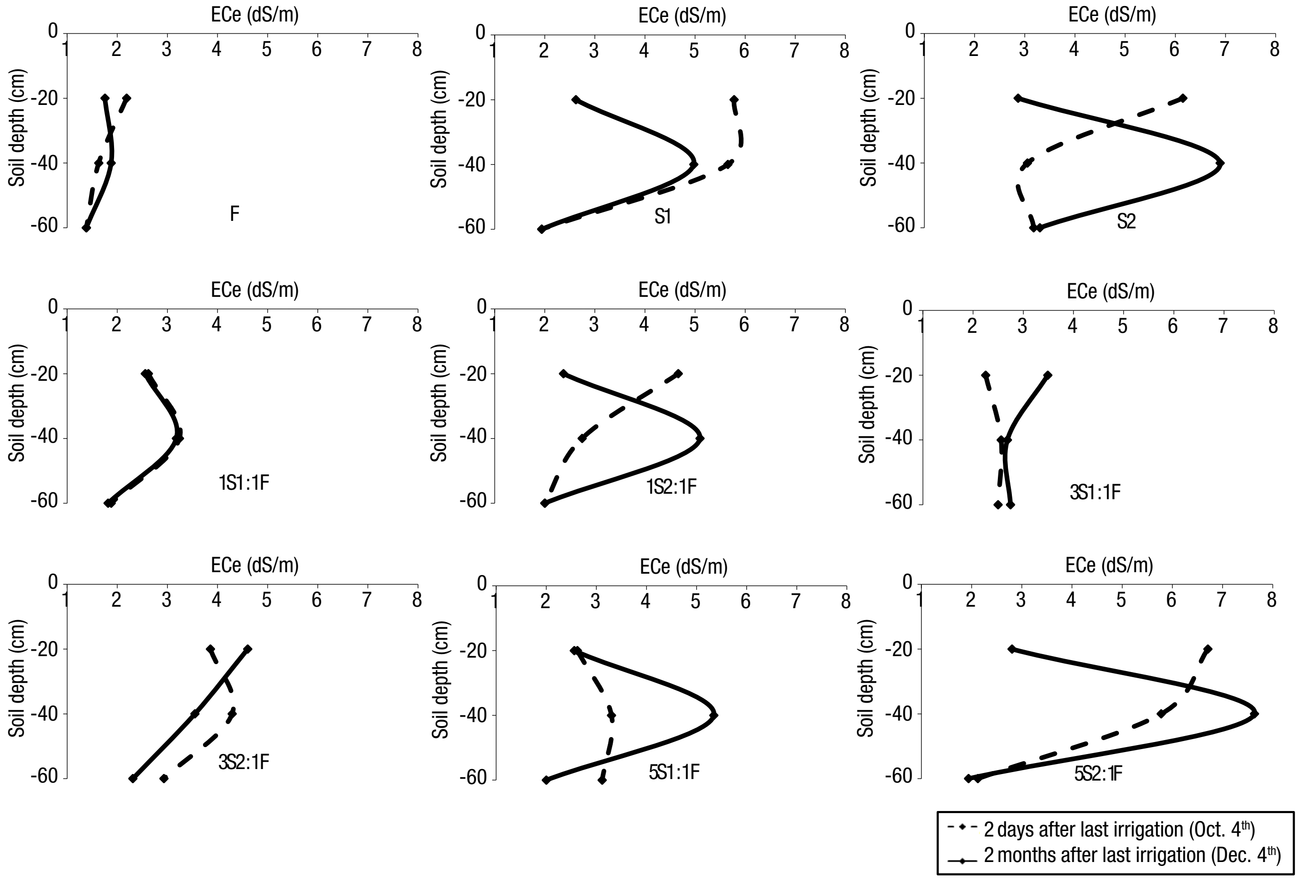

Figure 8. Soil salinity profiles on irrigation line in the two days after the last irrigation and two months after that for all treatments.

salinity increased. Chen *et al.* (2009) indicated that with every 1 dS/m increase in irrigation water salinity, oleic sunflower yield decreased by 1.8% while IWUE increased. Kang *et al.* (2010) stated that IWUE increased with increasing irrigation water salinity provided that salinity level was less than 10.9 dS/m.

Conclusions

In irrigation management using saline water for crop production, salt build up in the root zone and crop yield reduction must be simultaneously considered. In this study we investigated the impacts of the combined use

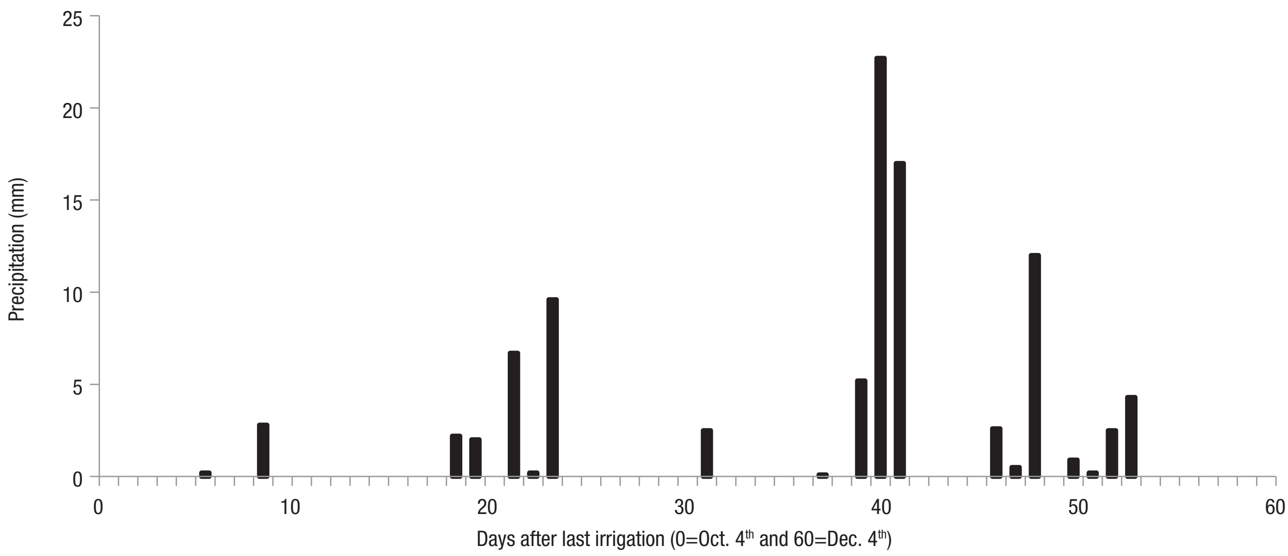

Figure 9. Rainfall amounts from the last irrigation day (October 4th) until two months after that (December 4th).

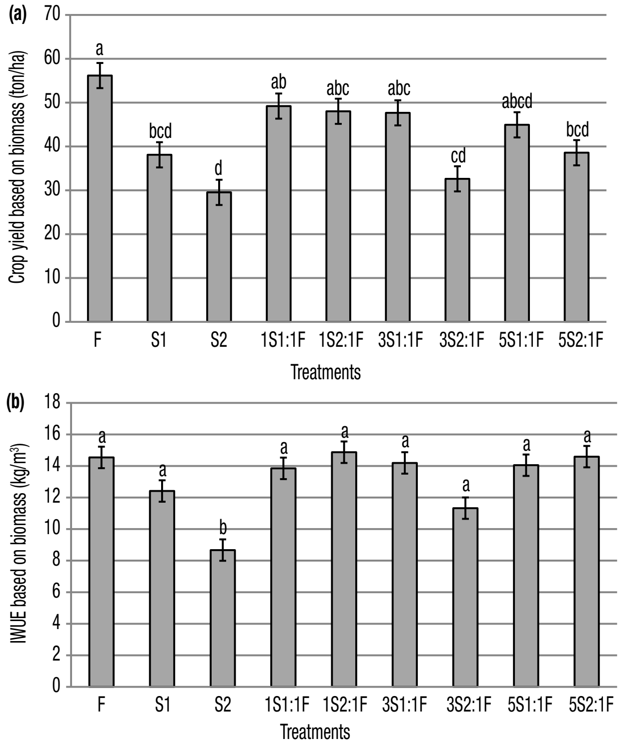

Figure 10. Values of (a) crop yield (based on biomass) and (b) irrigation water use efficiency (IWUE) for all treatments. Treatments with same letters had no significant difference at 5% level according to Duncan test.

of saline and fresh irrigation water on maize yield and soil salinity, as well as the effects of off-season precipitations on moving salts in root-zone. The results showed that increasing irrigation water salinity determined a decrease of the amount of applied water due to reduction in vegetation canopy and evapotranspiration, even if salt accumulation and leaching requirement increased. After application of non-saline water in cyclic treatments, soil salinity decreased especially close to irrigation line that was more influenced by the source of irrigation water. The higher the distance from irrigation line, the lower soil salinity. Soil salinity at 20 cm depth was often higher than at depths of 40 and 60 cm. Even with the use of saline water in 1:1 treatments, salt accumulation in the root zone did not occur at the end of the growing season. Despite the reduction in crop yield due to irrigation with saline water, the reduction of IWUE was generally not significant.

This study indicates that the cyclic use of saline and non-saline water can increase IWUE with a little reduction in crop yield compared to constant use of saline water for irrigation during the maize growing season. Off-season precipitations are effective to reduce salinity of soil surface, ensuring the possibility of a second crop season and justify the use of saline water for most treatments.

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