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Effect of NaCl Saline Irrigation Water on Soil Salinity

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Abstract

Water scarcity and soil salinization are the two main common problems that affect the agricultural production in Jordan Valley, which is considered the main agricultural region in Jordan, where most areas are irrigated with saline irrigation water, particularly in the center and south region of the valley. This study was conducted to evaluate the impact of NaCl irrigation water on soil salinity in a short-term experiment. Durum wheat was planted in a field with nearly half dunum area in the central region of the valley on 29^{th} of December 2017 and harvested on the second of April 2018. Three salinity levels (S) (S1 2 (the control), S2 4, and S3 8 dS/m) with three irrigation amounts (R) of readily available water (RAW) (R1 120%RAW (control), R2 100%RAW, and R3 70% RAW) were used in the field experiment. Calcium, magnesium, and sodium concentration were measured once before planting and once after harvesting, soil electrical conductivity of saturated paste extract (ECe) and pH were measured every three weeks during the growing season. The results showed that the soil salinity in terms of (ECe) has increased gradually during the growing season, the final ECe has increased from an average of 0.96 ± 0.02 dS/m in the control to an average of 7.91 ± 0.48 dS/m in the most stressed treatment (S3R3) at 10 cm depth of the study area. Sodium adsorption ratio (SAR) has increased from 0.83 ± 0.03 in the control to 21.87 ± 2.41 in the most stressed treatment (S3R3), calcium, magnesium, and pH has decreased slightly when compared with the control.

Keywords: Jordan Valley, saline-sodic irrigation water, soil salinity and sodicity.

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أثر استخدام مياه الري القلوية على ملوحة التربة

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ملخص

تعد مشكلة توفر المياه و ملوحة التربة من أكثر المشاكل شيوعا في الأردن خاصة منطقة وادي الأردن الذي يعد عصب الأردن الزراعي، حيث تستخدم مياه مالحة نسبياً في الري خاصة في وسط وجنوب وادي الأردن، هذه الدراسة نفذت بهدف تقييم التغيرات في الملوحة لتربة حقل بمساحة نصف دونم تقريبا تقع في منطقة الأغوار الوسطى في وادي الأردن عند ري التربة بمياه مالحة نسبياً باستخدام كلوريد الصوديوم لمدة موسم واحد من زراعة القمح الصلب، ثلاثة مستويات من الملوحة مع ثلاثة مستويات من كمية مياه الري تم استخدامها في البحث، مستويات الملوحة كانت (2،4،8 ديسمينز/م) أما مستويات الري كانت (70%، 100%، 120%) من السعة الحقلية، تم قياس الملوحة ودرجة الحموضة كل ثلاثة أسابيع خلال الموسم، أما تراكيز بعض العناصر كالصوديوم والكالسيوم والمغنيسيوم فتم قياسها مرتين واحدة قبل الزراعة و الثانية بعد الحصاد، أظهرت الدراسة زيادة في الملوحة كمية الصوديوم عند معامل الري الأكثر ملوحة والأقل كمية ري، كما أثبتت الدراسة أن نوعية مياه الري الرديئة قد تؤدي لتراجع في خصائص التربة الكيميائية حتى لو تم استخدامها لموسم واحد فقط في منطقة غور الأردن.

1. Introduction

The process of increasing salt content in the soil to a limit that decreases crop productivity, causes environmental damage and lowers its economic value is known as soil salinization (Machado & Serralheiro, 2017). In irrigated areas, the formation of salt-affected soils is the most important process of land degradation. The extent to which salts accumulate in the soils is mainly related to irrigation water quality, type of irrigation system, different management practices, depth of groundwater if available, and the presence of drainage system (Läuchli & Grattan, 2007). Approximately 20% of cultivated land in the world, and 33% of irrigated land are salt-affected and currently are under degradation (Shrivastava and Kumar, 2014).

Soil salinity changes considerably with time and space because salinization results from both primary (natural) occurrence and secondary human-induced behaviour (Ammari et al., 2013). The primary cause comes from parent soil material, salt deposits, insufficient precipitation and other climate conditions that limit leaching ions from soil profile. Salinization is more frequent in arid and semi-arid regions where the high rate of water evaporation extremely exceeds precipitation rate, as it facilitates salts to accumulate, especially in the soil surface (Ekmekci et al., 2005). The secondary cause results from human activities, in particular inadequate irrigation practices and using low quality of irrigation water (Webber et al. 2010). In regions that suffer from water scarcity, treated wastewater is used as an alternative source of irrigation water. The use of low-quality water may lead to the accumulation of salts in the soil, since the leaching fraction is reduced and the salts in the irrigation water are not leached enough. Accumulation of salts also can occur as a result of prolonged use of fertilisers.

Soil texture also influences soil salinization. High concentration of sodium ions in the soil causes soil dispersion which adversely affects soil physical properties such as soil drainage and aeration. Many of the countries in the Middle East have salinity and drought problems that affect their agricultural production such as Jordan, Syria and Lebanon. Jordan is considered among the most water stressed countries, and expected to have a long-term water crises (Hadadin et al., 2010). Agricultural sector in Jordan has the highest water consumption ratio that is used as irrigation water. More than 60% of Jordan agricultural products are grown in the Jordan Valley. The valley exhibits a very unique climate that allows growing crops in the winter season, mostly in the north of the Dead sea (AbuAisha, 2001), and it has a considerable contribution in national food requirements and international balance of payments in Jordan (Shammout et al., 2017).

Salinity of irrigated soils along the Jordan Valley is dramatically increasing since the natural floods are no longer available to wash the irrigated land and leach salts. In addition, high evaporative conditions, the lack of adequate drainage system and insufficient amount of rainfall for sufficient leaching contribute to additional salt accumulation (Miyamoto et al. 2005). The highest soil sodium content and Sodium Adsorption Ratio are found in the central region of the valley. About 75% of the top-soils are saline in the central valley because 96% of the farms in the valley use drip irrigation which causes a further accumulation of salts especially at the top soil layer as drip irrigation usually uses limited amount of water (Al-Zu'bi & Al-Kharabsheh, 2003). Using low irrigation water quality is common in the central valley and showed a pronounced increase in soil salinity at the central region from 2007 to 2013 ranged from 51%-63% (Ammari et al., 2013).

Many studies have been conducted to investigate the effect of irrigation water on soil quality, that include different aspects, either by comparing some soil quality parameters before and after irrigation, or by studying the difference between irrigated and non-irrigated fields. A four years study was conducted in Bari, Italy did not show any significant effect of saline and sodic irrigation water on soil chemical and physical properties when leaching requirement is considered. (Rietz & Hayness, 2003) indicated that a small increase in soil salinity has a high detrimental effect on microbial community. As demonstrated by numerous researchers a deterioration in soil quality would occur when soil is irrigated frequently with saline and sodic water, it will contain large amounts of sodium and salts (Thompson, 1991; Amézketa 1999; Tedeschi & Dell’Aquila 2005; Al-Zu’bi Y 2007; Huang et al., 2011; Askri et al., 2014).

In Jordan, the threat of water scarcity and soil salinization is expected to increase in the near future, thus more studies are needed to help farmers and decision makers to choose the best management practices. The objective of this study was to evaluate the impact of NaCl saline irrigation water on soil salinity during one growing season of durum wheat in the central Jordan Valley.

Materials and methods:

The experiment was conducted at the Agricultural Research Station in the central Jordan Valley (Damea) (32.08N, 35.58E), with a height of 218 below sea level (Fig. 1). Soil salinity has shown a pronounced increase from 2007 to 2013in this area ranged from 51%-63% (Al-Rjoub & Al-Samarrai, 2006). The soil type is Entisol with a fine loamy sand texture. The soil depth in the study area was 1.5 m with no drainage system. The experimental design was split plot randomised complete block design where three levels of salinity (S1 (2 dS/m), S2 (4 dS/m) and S3 (8 dS/m)) with three levels of water supply (R1 (120 % of RAW), R2 (100 % of RAW) and R3 (70 % of RAW)) based on Readily Available Water (RAW). RAW is the soil moisture held between field capacity and a nominated refill point for unrestricted growth, at which water can be easily absorbed by plant from the soil.

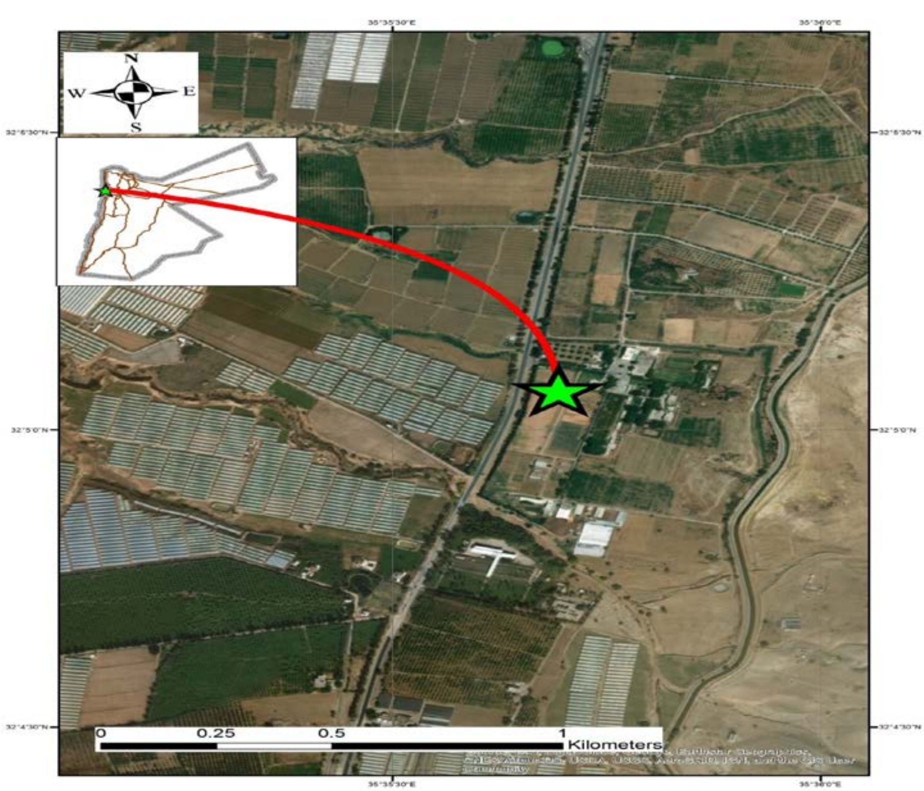


Figure 1. Map of the study area

Um Qais durum wheat cultivar was planted on 29/12/2017 using drip irrigation system. Each plot has an area of 9 m^2, the area was divided into four blocks, in each block a factorial combinations of the two factors: three salinity levels with three water amounts levels were made to form the nine treatments (S1R1, S1R2, S1R3, S2R1, S2R2, S2R3, S3R1, S3R2 and S3R3) in one block (Fig. 2). In this paper those nine treatments are given the letters (A, B, C, D, E, F, G, .H, and I), respectively. Each treatment was replicated four times with a total number of 36 plots (3x3m) in an area of 456.5 m^2.

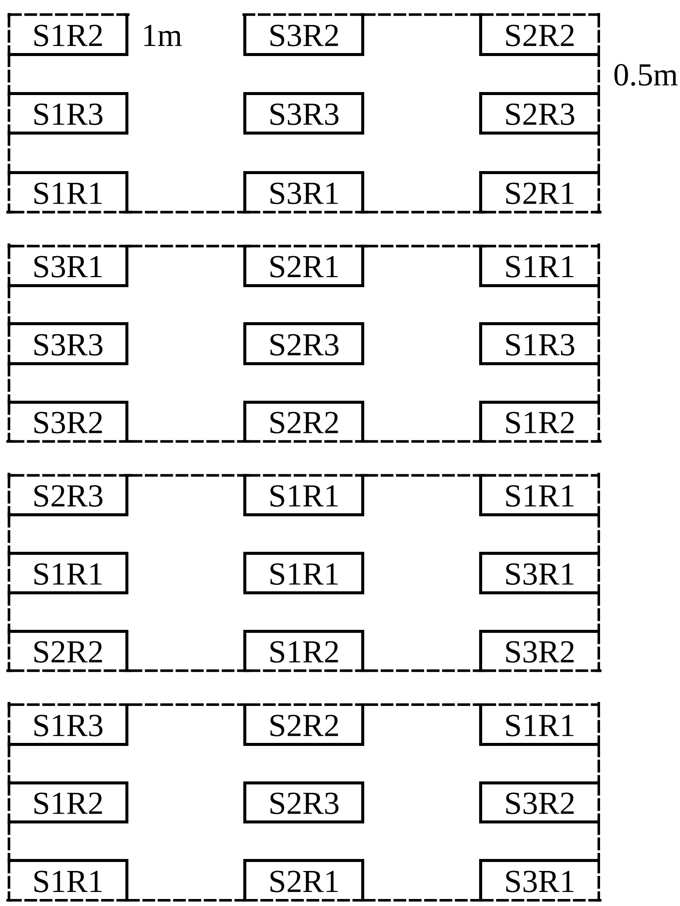


Figure 2: Field experiment layout

The RAW was applied when the measured soil moisture reached the critical soil moisture which is defined as the fraction of total available soil water between field capacity and wilting point that is readily available for crop transpiration. The management allowable depletion (MAD) was assumed to be 0.5 based on Allen et al. recommendation for durum wheat (1998). RAW was calculated using the following formula:

$$RAW = MAD\ (FC - PWP)z \qquad (1)$$

Where (FC) is field capacity, (PWP) is permanent wilting point, and z is root depth in mm. When soil water content reaches the critical level then irrigation water should be applied to reach the field capacity. The critical soil water content can be found as follows:

$$The\ Critical\ soil\ moisture = FC - MAD(FC - PWP) \qquad (2)$$

The irrigation scheduling for the nine treatments of field experiment is illustrated in Table 1, regarding that the rainfall during the growing season was 77 mm and the average temperature was nearly 23ºC.

Table 1. Irrigation scheduling for the field experiment.

Date **R3 (70 %)**	**R1 (120 %)**	**R2 (100 %)**	
15-Feb	70	57	40
03-Mar	70	57	40
14-Mar	70	57	40
24-Mar	70	57	40
01-Apr	70	57	40
Total (mm)	350	285	200

Soil chemical and physical properties were first determined on 20/12/ 2017 after dividing the area into four blocks. Samples for initial conditions were taken once at two depths (10 and 30 cm) from each block. Soil texture was measured using the pipette method (Gardner, 1965). The bulk density was measured using the core method (Blake, 1965). The field capacity and permanent welting point were determined using the ceramic plate method (Gardner, 1965).

Soil soluble potassium and sodium were measured by flame photometer (Jenway Research PFP7/C). The cation exchange capacity was determined by sodium acetate method (Chapman, 1965). Other ions (chloride, calcium, magnesium and bicarbonate) were measured by titration according to the methods illustrated by (Rhoades et al., 1999). Phosphorus was determined by Olsen method (Olsen, 1965), total nitrogen by Kjeldahl method (Bremner, 1965). It was found that the electrical conductivity of the saturated soil extract (ECe) and pH are the two valuable measures to assess soil chemical conditions (Smith and Doran, 1996), therefore soil salinity and pH were measured frequently by taking samples from the two central blocks, nine locations were determined for the soil samples to represent the nine plots of each block, the total locations number was eighteen, four depths were taken from each location (10,30,50 and 70 cm) every three weeks during the growing season of the durum wheat, the method used to determine soil salinity was the saturated soil extract (Rhoades et al., 1999).
A pH and EC meters of type BP3001 were used each time.

Sodium adsorption ratio (SAR) is a preferred measure of sodicity (Marchuk & Rengasamy, 2011), and known as a good index of structural stability (Oliver et al., 2013). It is defined as the ratio between the amount of sodium ions in soil solution considering its dispersion effect with the amount of calcium and magnesium ions considering their flocculation effect on soil. Measurements were taken from the soil water extract and calculated as follows:

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

Soil chemical and physical properties are shown in Table 2.

Table (2) Soil chemical and physical properties in the Jordan Valley experiments (initial conditions before planting). (CEC) is the cation exchange capacity of the soil.

a. Soil chemical properties	
Cl (ppm)	0.33 ± 0.05
Na (ppm)	41.98 ± 6.52
K (ppm)	54.55 ± 0.04
Ca (ppm)	120 ± 0.65
P (ppm)	42 ± 4.10
Mg (ppm)	105.6 ± 1.24
Organic C (%)	0.23 ± 0.01
N (%)	0.5 ± 0.05
CEC (cmol/kg)	18.6 ± 0.48
SAR	0.83 ± 0.02
ECe (dS/m)	4 ± 0.23
pH	8 ± 0.09
b. Soil Physical properties	
Clay (%)	16 ± 0.48
Sand (%)	73 ± 0.65
Silt (%)	10 ± 0.55
Field capacity (FC) (cm^3/cm^3)	0.186 ± 0.01
Permanent welting point (PWP) (cm^3/cm^3)	0.09 ± 0.01
Saturated water content(cm^3/cm^3)	0.38 ± 0.02
Bulk density (g/cm^3)	1.58 ± 0.11

Soil soluble amounts of magnesium, calcium and sodium were measured again at the end of the growing season with SAR, with ECe and pH to compare the soil initial and final chemical conditions. The durum wheat was harvested on 2/4/2018, the total amount of the applied irrigation water for the whole field experiment was 90.18 m^3 and was distributed as 37.8, 30.78 and 21.6 m^3 for R1, R2 and R3, respectively. 1.6 and 3.5 kg/m^3 NaCl was added to each tank for S2 and S3 treatments, respectively. The electrical conductivity was measured frequently before and after irrigation. The weight of NaCl was estimated in both experiments according to Rani and Sharma (2015) methods. Some chemical properties of the irrigation water are shown in Table 3.

Table (3) Some chemical properties of irrigation water for the treatments of field (a) and greenhouse experiment,

	Ca meq/l	Mg meq/l	Na meq/l	SAR	pH	EC_{iw} (dS/m)
(A, B, C)	6.52 ± 2.30	4.11 ± 0.48	12.03 ± 0.910	5.22± 0.050	7.81 ± 1.50	2.01 ± 0.32
(D, E, F)	5.35 ± 2.11	4.31 ± 0.47	71.29 ± 2.230	32.44 ± 1.13	7.79 ± 0.41	4.01 ± 0.64
(G, H, I)	5.33 ± 2.10	4.23 ± 0.47	162.95 ± 3.71	74.53 ± 3.10	7.77 ± 0.45	7.98 ± 1.52

ANOVA was calculated using the general linear model (GLM) procedure of the Statistical Analysis System (NCSS), version 12 (NCSS Statistical Software, Kaysville). Differences were considered significant at $\alpha = 0.05$. The analysis was used in the results was one-way ANOVA except for Table 5. Two-way ANOVA was used to study the interaction between salinity and deficit irrigation. The two samples t-test for unequal variances was used to determine the significant changes in the results with the control treatment α = 0.05.

3. Results

The relationship between salinity levels and irrigation amounts is illustrated in Table 4. The relative high soil salinity was observed in R3 (70% RAW) for the three salinity treatments S1, S2 and S3. There was a significant increase of ECe in S1 (the control) from an average of 1.41 ± 0.15 dS/m when the irrigation level was R1 (120% RAW) to an average of 2.23 ± 0.30 dS/m (S1) when irrigation level was R3 (70% raw). The soil salinity in S2 treatments increased gradually from 2.18 ± 0.31 dS/m, then 2.9 ±0.36 dS/m to a statistically significant increase of 3.15 ±0.42 dS/m, in R1 (120% RAW), R2 (100% RAW) and R3 (70% RAW) respectively. The increase in soil salinity was most noticeable in S3, where the average soil salinity changed from 3.77 ± 0.54 dS/m, 4.41 ± 0.83 dS/m, and 4.52 ± 0.77 dS/m for R1, R2 and R3 respectively, although statistically there was insignificant among S3 when compared to the control of R1 (120%). The two samples t-test of unequal variances was used to compare the mean of the treatments with the mean of the control (α = 0.05).

Table (4) The mean electrical conductivity of the three salinity levels in field (S1, S2 and S3) with respect to the three irrigation levels (R1, R2 and R3).†

Treatments	R1 120%	R2 100%	R3 70%
S1 (2 dS/m)	1.41 ± 0.15 (A)	1.58 ± 0.23 (B)	2.23 ± 0.30 (C)*
S2 (4 dS/m)	2.18 ± 0.31 (D)	2.9 ±0.36 (E)	3.15 ±0.42 (F)*
S3 (8 dS/m)	3.77 ± 0.54 (G)	4.41 ± 0.83 (H)	4.52 ± 0.77 (I)

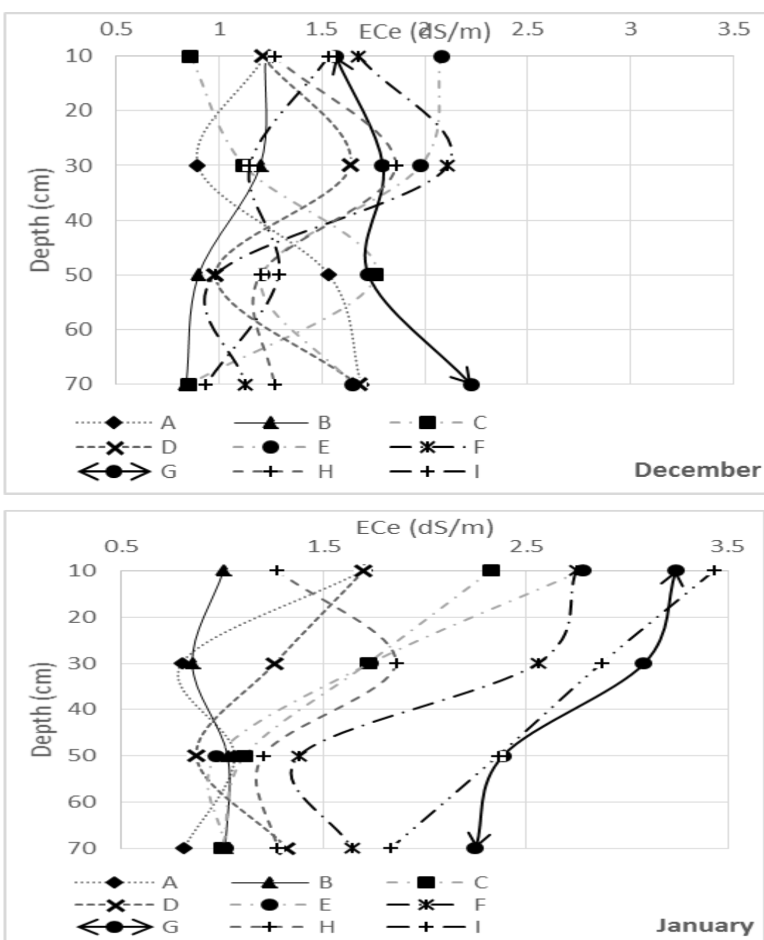
† The letter next to each value represents the treatment symbol in the field experiment. The star symbol * means that the treatment showed a significant result compared with the control using two samples t-test of unequal variances.

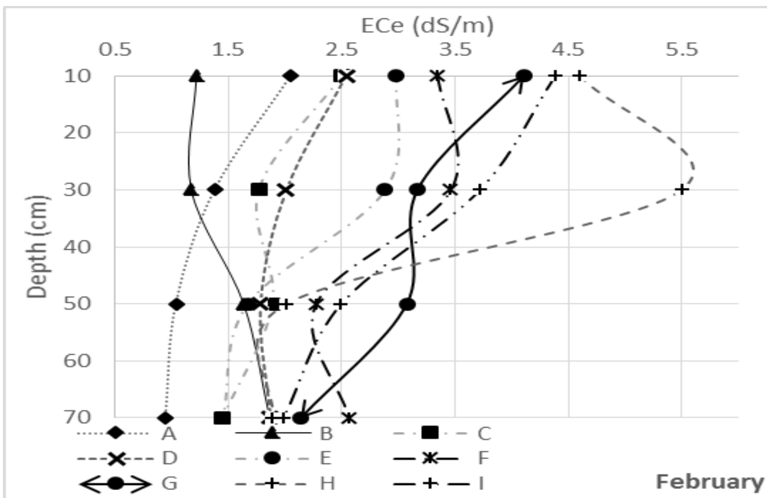
Analysis of variance (ANOVA) was calculated considering the two independent factors, salinity levels (S1, S2, and S3), and irrigation water treatments (R1, R2, and R3). The significance of the two factors on soil salinity are illustrated by Fisher test (F) and probability value (P). The irrigation water salinity (R) showed a significant impact on soil salinity while irrigation levels were insignificant, and the interaction between the two factors in the field experiment was weak (Table 5).

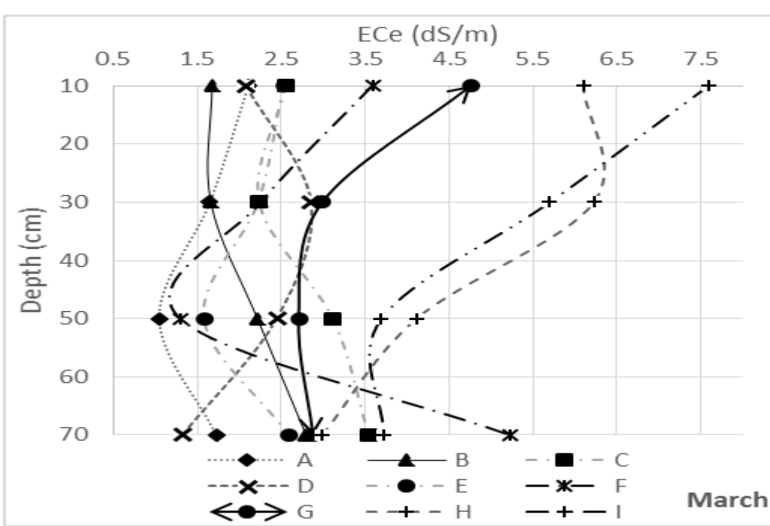
Table (5) Two-way ANOVA considering the three salinity levels with the three irrigation levels in field experiment

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	94.59	2	47.296954	19.82709	9.8E-08	3.109311
Columns	10.92	2	5.4590419	2.288454	0.107945	3.109311
Interaction	1.21	4	0.3031328	0.127075	0.972231	2.484441
Within	193.22	81	2.385471			

The changes in soil salinity in the four depths (10, 30, 50, and 70 cm) each month during the growing season for the nine treatments are illustrated in Fig. 3. In December, the soil salinity values showed an insignificant changes within the different layers and between the treatments using one way ANOVA analysis the p-value was more than 0.05. On 25/12/2017, soil salinity at 10 cm for A (the control) was very close to other treatments with values of 1.22, 0.89, 1.53 and 1.69 dS/m for the depths 10, 30, 50, and 70 cm, respectively. In January, all the values were less than 3 dS/m except in (G) treatment, ECe was 3.24 and 3.1 dS/m for the depths 10 and 30 cm, respectively, although the ANOVA analysis showed that the significant changes within the four layers in soil salinity starts in January ($P<0.05$). In February, the increase in soil salinity was obvious at two depths (10 and 30 cm) for treatments F, G, H and I. In March, there was a dramatic increase in soil salinity for the most stressed treatments (H) and (I) near the surface, ECe was 3.59, 4.76, 6.1, and 7.6 dS/m at 10 cm for F, G, H and I treatments, respectively. The deepest layers (50 and 70 cm) didn't record any values higher than 4 dS/m except the treatment H, at which the ECe was 4.11 dS/m at 50 cm depth, ANOVA showed that in March the significant value was the highest with p = 0.00084, The accumulation of salts continued in April. The salinity concentrated in the first 40 cm depth, soil salinity was 6.49, 6.23, 7.65, and 7.9 dS/m for the treatments F, G, H, and I, respectively at 10 cm depth, ANOVA showed a significant difference in soil salinity between soil layers P-value = 0.01413. The control (A) in April didn't show any soil salinity higher than 2 dS/m in the four depths.




ECe (dS/m)
0.5 1.5 2.5 3.5 4.5 5.5
Depth (cm)
10 20 30 40 50 60 70
A B C D E F G H I
February


ECe (dS/m)
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5
Depth (cm)
10 20 30 40 50 60 70
A B C D E F G H I
March

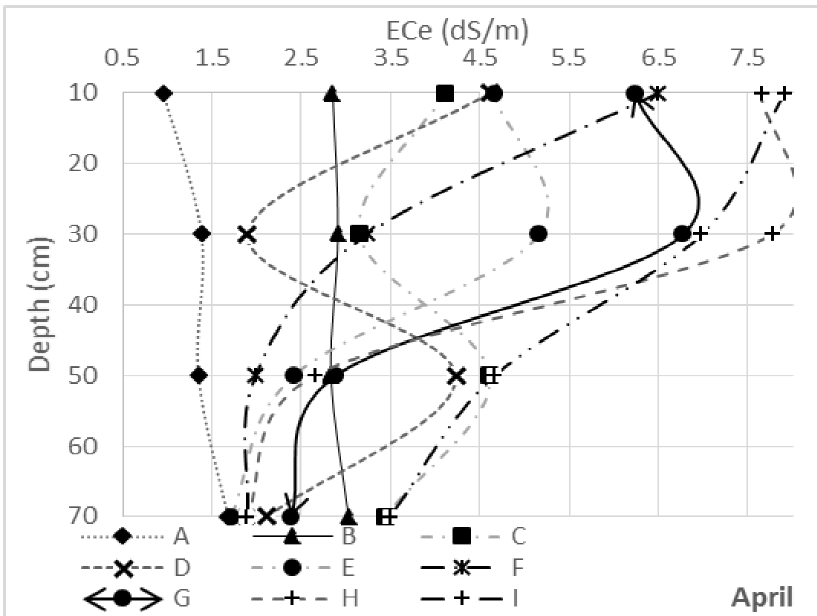


Figure 3. The changes in soil salinity at each month of the growing season, considering the depths (10, 30, 50, and 70 cm) for the nine treatments of field experiment (A, B, C, D, E, F, G, H, and I).

The final soil chemical properties were taken on 7/4/2018 (Table 6). The concentration of magnesium and calcium ions decreased gradually from the control (A) with 6.1 ± 0.76 meq/l to 5.55 ± 0.12 in (I), using ANOVA showed that both has significant changes between the nine treatments (P-value < 0.05). The significance difference in calcium was in all treatments compared to the control when using two samples t-test of unequal variances ($\alpha = 0.05$). The sodium ions concentration increased considerably among the nine treatments. It was 2.05 ± 0.05, 10.3 ± 0.31 and 12.22 ± 0.78 meq/l for A, B and C respectively, while it was 10.23 ± 0.73, 40.9 ± 2.73 and 51.53 ± 5.21 meq/l for G, H and I treatments, respectively, the P-value in ANOVA was very small for sodium concentration (P-value = 5.43017E-27), the highly significant changes was also shown in SAR, with very small P- value (1.09407E-29) using one way ANOVA. SAR increased from 0.83 ± 0.03 in A (control) to 17.28 ± 1.82 and 21.87 ± 2.41 for treatments H and I, respectively. There was no significant change in pH, while the ECe changed significantly from 0.96 ± 0.02 dS/m at control (A) to 7.65 ± 0.28 and 7.91 ± 0.48 dS/m for treatments H and I, respectively.

Table (6) The final soil chemical properties in field (a) and greenhouse (b) experiments.

Treatment	Ca meq/l	Mg meq/l	Na meq/l	SAR	ECe	pH
A	6.1 ± 0.76	6.1 ± 0.75	2.05 ± 0.05	0.83 ± 0.03	0.96 ± 0.02	8.01 ± 0.03
B	6.25 ± 0.73*	6.25 ± 0.70	10.3 ± 0.31*	4.12 ± 0.03*	2.85 ± 0.03*	8.05 ± 0.03
C	6.34 ± 0.45*	5.98 ± 0.43	12.22 ± 0.78*	4.92 ± 0.12*	4.11 ± 0.03*	8.00 ± 0.01
D	5.51 ± 0.32*	5.4 ± 0.32*	14.21 ± 0.87*	6.08 ± 0.12*	4.61 ± .06*	7.89 ± 0.02
E	5.56 ± 0.37*	5.5 ± 0.31*	20.49 ± 1.20*	8.74 ± 0.75*	4.65 ± 0.04*	8.00 ± 0.01
F	5.6 ± 0.22*	5.6 ± 0.21*	11.36 ± 0.77*	4.80 ± 0.35 *	6.49 ± 0.05*	7.81 ± 0.05
G	5.59 ± 0.12*	5.57 ± 0.13*	10.23 ± 0.73*	4.33 ± 0.08*	6.23 ± 0.15*	7.89 ± 0.05
H	5.6 ± 0.11*	5.6 ± 0.12*	40.9 ± 2.73*	17.28 ± 1.82*	7.65 ± 0.28*	8.01 ± 0.02
I	5.55 ± 0.12*	5.54 ± 0.12*	51.53 ± 5.21*	21.87 ± 2.41*	7.91 ± 0.48*	7.86 ± 0.05

***** The star symbol * means that the treatment showed a significant result compared with the control using two samples t-test of unequal variances.

4. Discussion

The accumulation of salts in the soil in this experiment may be explained by several reasons, such as low quality irrigation water, inadequate management practices and climate conditions, in addition of the insufficient amount of irrigation that reduces the ability of the soil to leach salts and causes further accumulation of salts. This could explain results of Table 4 where the accumulation of salts was significant in R3 treatments (the lowest irrigation amount).

According to the Two-way ANOVA (Table 5), three hypothesis can be discussed, the impact of salinity levels on soil salinity, the impact of irrigation water amounts on soil salinity, and the impact of the interaction between salinity levels and irrigation amounts on soil salinity. The results showed that the water salinity level has the highest impact on soil salinity, particularly when irrigated with 8 dS/m saline water, while irrigation water has insignificant effect, and the interaction between the two factors was insignificant too.

The accumulation of salts in the field during the growing season didn’t exceed the average of 4.51 dS/m for the 80 cm depth, even in the most stressed treatment (I). This can be explained by the short growing season in the field due to the hot climate in Jordan Valley. Such a short growing season limited the effect of the irrigation water on salinizing the soil. Also, the type of soil texture affects the rate of salinization. Loamy sand, the soil texture of the study area has a high proportion of sand particles that do not allow for much accumulation of salts unlike clay particles (Singh & Chatrath, 2001).

The accumulation of salts was noticed to be near the surface. In the field, most of the layers with 50 and 70 cm depth stayed non-saline, this was mostly noticed in April. The climate condition at Jordan Valley is expected to play the major role in this, where the rainfall was less than 80 mm for the whole season. The temperature started a rapid increase from the mid of February, the salt is expected to be near the surface as the rate of evaporation exceeds the rate of rainfall. According to Fig. 3 the difference between the treatments in soil salinity started to be obvious in March, and recorded as statistically significant from February. This can be explained by two reasons, the frequent irrigation in March and the high evaporative condition due to the increase in temperature, this was in a good agreement with (Bajwa et al., 1992), (Hamam & Negim 2014), & (Bedbabis et al., 2014).

Even though the experiment was conducted in a short term for one growing season of durum wheat but there was a deterioration in the soil chemical properties, sodium concentration, SAR, and ECe increased significantly, while the magnesium and calcium concentration decreased. There was no significant change in pH. The significant decrease in calcium and magnesium was noticed at the end of the growing season mainly because of the plant uptake and the effect of sodium accumulation (Munns, 2002). The high increase in sodium concentration in soil from the applied irrigation water increased the SAR for (H and I) treatments to be above 13, the high SAR indicated that the soil became sodic according to the increase of sodium in relative with calcium and magnesium in soil. The soil salinity was above 4 dS/m in H and I treatments, accordingly a saline sodic soil was formed in the most stressed treatments H and I after one wheat growing season of NaCl irrigation water in Jordan Valley. The increase in soil salinity and sodicity when a sodic irrigation water is used was also observed by Ashraf et al. (2017) in a short-term experiment.

5. Conclusion

Saline irrigation water concentration has a great effect on soil salinity and sodicity. Also, the unique climate condition of Jordan Valley is assumed to play an essential role in affecting the level of deterioration of soil salinity and sodicity when irrigated with NaCl saline water even for one season. A 70% RAW (R3) can still be suitable to be used with a moderate saline irrigation water as this treatment did not increase soil salinity and pH significantly during the growing season for S1 and S2. The impact of saline and sodic irrigation water on soil salinity should be conducted in other locations at the valley to establish a long- and short-term management plan to limit the increase in salt affected soil in Jordan, and keep sufficient agricultural productivity for the valley in the future.

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