Shahid Chamran University of Ahvaz

Irrigation Sciences and Engineering (JISE)
Vol. 45, No. 2, Summer 2022, p. 99-108

Original Paper

Journal homepage: https://jise.scu.ac.ir

Evaluating the Performance of salt Leaching in Frozen Saline Soils

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ARTICLE INFO

Artlcle history:
Received: 24 May 2021
Revised: 5 November 2021
Accepted: 8 November 2021

Keywords:
Saline water; Saline soil; Soil columns.

TO CITE THIS ARTICLE:

Zare, H., Khaledian, M., Shabanpour, M., Malekpour, A. (2022). 'Evaluating the Performance of salt Leaching in Frozen Saline Soils', Irrigation Sciences and Engineering, 45(2), pp. 99-108.

Abstract

The movement of water and solutes have received the attention of many scientific researchers over the past few years. Saline soils contain a high content of salt that is deposited in micropores. Therefore, it is necessary to leaching these soils during a time period when winter ice melting occurs due to the splitting of micropores affected by expansion and contraction resulting from the freezing and melting of water in the soil. The present research studies some different salt leaching methods on soil samples collected from Nazarabad region, Iran in 2016. Two types of saline and conventional water of the region and three different volumes of water in both continuous and alternate modes were used under frozen and non-frozen conditions. The results showed that frozen treatments that were irrigated continuously with conventional water of the region had the best performance as compared to other studied treatments, being feasible during winter in the studied region.

Introduction

Soil salinity is major stress limiting crop yield in the both arid and semi-arid regions (Sundha et al. 2020). It is likely to further aggravate with climate change, being characterized increase in temperature and changing pattern of rainfall. The increase in temperature will raise crop evapotranspiration and thus more salt-load in arid and semi-arid regions, threatening farm productivity (Ahmad et al., 2016).

The use of saline water facilitates salt accumulation in the root zone, leading to reduced crop production and low soil fertility (Tedeschi and Aquila 2005). Able to prevent water absorption and nutrient elements, soil salinity (sodium salinity) is considered to be one of the major problems associated with growing crops that hampers their growth (Kaya et al. 2001; Liu et al. 2020). To correct saline soils through proper irrigation and efficient drainage systems, leaching is one of the best and most practical methods for salt leaching, which, of course, depends on the quantity and quality of applied water. However, it cannot be guaranteed that the stability of the physical and chemical conditions of saline and sodic soils will be maintained (Mostafazadeh-Fard 2008). Increasing sodium salinity in soil solution leads to the degradation of aggregates, deflocculation, swelling and scattering of clay particles, trapping and porosity reduction, low soil permeability, and low soil hydraulic conductivity (Bennett et al. 2019; Dang et al. 2018).

Table 1- Some physicochemical characteristics of soil at sampling location, Nazarabad city

Soil ECe (dS/m)	Water EC (dS/m)	Ks (cm/hr)	ρ_s (gr/cm^3)	ρ_b (gr/cm^3)	Porosity (%)
3.45	0.8	2.8	2.39	1.34	43

The basis for modifying sodic soils is to replace exchangeable sodium with calcium. In this respect, sodium is removed from the root zone or soil profile. The results of studies by some researchers such as Kay and Vandenbygaart (2002), Puget et al. (2000), and Tejada et al. (2006) showed that bulk density decreased using organic matter. The researchers found that the organic matter acted as a cementing agent and was essential for particles to coalesce together to form resinous aggregates. In addition to organic matter (Wong et al. 2009; Fa-Hu and Keren 2009), gypsum (Mitchell et al. 2000), and sulfuric acid (Amezketa et al. 2005; Sadiq et al. 2007) are modifiers used to correct sodic and saline soils. In addition, some researchers have corrected saline and sodic soils through leaching so far (Anapali et al. 2001; Akhtar et al. 2003; Ammari et al. 2008). Saline-sodic soils that contain calcium are widespread in the arid and semi-arid regions of the world. Under these conditions, $CaCO_3$ available in soil slowly dissolves and provides calcium for the reform process (Choudhary et al., 2011).

In this background, we hypothesized that the conjunctive use of different quality of irrigation water, different volumes of irrigation water, and continuous and alternate modes with frozen and non-frozen waters could affect saline soil leaching and should be considered in soil reclamation projects. Therefore, this laboratory study was accomplished to compare and evaluate the reclamation potential of those leaching treatments. Those treatments were not applied together in previous researches, especially frozen and non-frozen irrigation waters were considered for the first time here for salt leaching. So, the aim of the present study is the evaluation of different salt leaching methods and different volumes of water with both continuous and alternate modes under frozen and non-frozen conditions.

Materials and methods

The soil was obtained from one of the orchards in Nazarabad, Iran. This has a problem of salinity. It was sampled from different area points of the orchard at a 0-0.3 m depth. The soil ECe was measured with a conductivity meter with a Jenway model (UK) in a saturation extract of soil (Rhoades, 1996), and K_s in soil was determined by the falling head test according to soil sampling and methods of analysis using a ELE device model (UK) (Carter and Gregorich 2008). Soil texture was determined by the hydrometric method (Gee and Or, 2002, being clay loam. Dry bulk density with cylinder method Klute, (1986) and particle density of the soil with picnometric method (Flint and Flint, 2002) were also measured (Table 1).

In this research, columns made of PVC characterized by a height of 0.3 m and an inner diameter of 0.1 m along with a funnel attached to the end of the column to convey drain water into a sample container for leaching were constructed. To fill the columns, the 0.3 m height of the soil column was divided into three 0.1 m sections, and each 0.1 m section reached the soil bulk density equivalent to field conditions by two shots with a weight of 326 g, measured with a Sartorius scale with an accuracy of 0.001 g (USA). After filling the soil columns, irrigation and the leaching process were carried out according to the type of treatments, at the lower end of which an appropriate filter was inserted to prevent fine particles from passing through. A container was designed and installed at the end of the column to observe and direct drainage and collect drains. A filter paper was placed on the soil surface to prevent soil compaction and structure disturbance of soil surface while adding water. It should be noted that any upward movement of water (evaporation) during the experiment was prevented by covering the soil surface (Delbari et al. 2012). This test was carried out with two types of water, three different volumes of water, and continuous and alternate modes with frozen and non-frozen waters. Saline water and conventional water were the typical types of water in the region, which contained an equivalent amount of salinity at the time of leaching. Three different volumes of water included one, three, and five times the soil pore volume. The experiment was done in continuous and alternate modes in frozen and non-frozen water conditions. In the continuous mode, irrigation in the non-frozen water condition was applied continuously and, in the frozen water mode, the water required for all three volumes and the soil column froze simultaneously. In the alternate mode, irrigation in the non-frozen mode was applied through several steps: in the case of the volume one time the soil pore volume, irrigation was done similar to that in the continuous mode; however, for the volume three and five times the soil pore volume, irrigation interval lasted 48 hours. Furthermore, in the alternate mode under the frozen condition, in the case of the volume one time the soil pore volume, water and soil column froze together, whereas, for the volume three and five times the soil pore volume, the first water volume and the soil column froze together and the rest of water volumes froze separately. Further, a day after the drainage of water from the bottom of the soil column, the other water volumes that froze separately in the freezer were applied to the soil surface at an interval of 48 hours. All treatments were replicated three times. At the end of each treatment, soil salinity was measured. It should be noted that the ambient temperature of the laboratory was kept almost constant during the experiment using the heating/cooling system. During the experiment, the amount and electrical conductivity of the drain water (EC) from the soil column were also measured (Office of Standard and Technical Criteria 2002). The irrigation during the experiment was done in the following manner; first, initial irrigation began to increase the soil moisture content by saturation using saline water and conventional water of the region, used for leaching in both modes of frozen and non-frozen waters. Saline water was prepared using laboratory-based $CaCl_2$ to reach EC=3.45 dS m^{-1}, equal to soil ECe before leaching. $CaCl_2$ was used to replace Na with Ca in soil. Then, the freezing phenomenon occurred in frozen treatments, which was followed by the occurrence of the melting phenomenon and water drainage. Finally, after initial irrigation, another irrigation was carried out with conventional water in the region for three to five pore water treatments in the continuous and alternate modes for both frozen and non-frozen treatments. For the sake of the purpose of this study, aiming to perform soil leaching, in order to reach the salinity level of water in the area, laboratory-based NaCl was used; in addition, to supply water for irrigation, distilled water was used. Considering that all the events that occurred during the experiment resulted from the presence of sodium salt and not anything else, distilled water was used in this study to simplify the problem. A total of 72 experimental units (72 = two types of water × two continuous and intermittent modes × two frozen and non-frozen conditions × three volumes of water × three replications) were considered according to available options. However, since the alternate and continuous modes of irrigation water treatments are similar in form, the number of treatments decreased to 60 units to expedite the experiment and reduce the cost. ANOVA for analysis of variance and Duncan method for mean comparison were used with SPSS20 software package. To compare two treatments e.g. frozen and non-frozen conditions, paired samples t test was employed.

A number of comparative criteria are presented here for comparing salt concentrations of drain water, based on which this study is determined to choose the best performing treatment of all studied treatments and the corresponding salinity output.

1. If the final yield of EC shows a high number in volume, then it becomes certain that a greater salinity volume has been taken out as compared to similar replicas and the opposing treatment. For instance, if a treatment is frozen, the opposing treatment will be non-frozen with the same level of

pore water, salinity level, and irrigation mode.
2. Soil washing can be done more efficiently and properly if there is a greater volume of water necessary for irrigation. As a result, the lower final yield of EC shows that the leaching performance of treatments with a higher water volume (e.g., 5PV compared to 3PV and 1PV) has been satisfactory.
3. To make a comparison between treatments of saline water and conventional water in the region, it is quite normal for the final yield of saline-water treatment EC to be higher than that of conventional water treatment. Therefore, it becomes clear that the high salinity level of drain water in saline-water treatment is not a thoroughly convincing reason for leaching and, thus, the final decision about choosing the better treatment performance should be made by comparing the EC_e, such that the lower the salinity level of the soil is, the better the treatment performance will be.
4. At the end of comparisons, a mean comparison of the treatments should be made by SPSS software.

Results and discussion

According to Table (2), based on the criteria previously used for comparing concentrations and Criterion 1, frozen treatments have outperformed non-frozen treatments. On the other hand, according to Criterion 2, the treatments with 5 pore water volumes have outperformed those with 3 and 1 pore water volumes. Based on the statistical comparison, frozen treatments have a better yield than non-frozen treatments in 3 and 5 pore volumes of water. It should be noted that in the treatment of 1 pore volume of water, the data are discarded and are not used in statistical comparisons due to a large number of errors, but are available in the data list. The findings of this research regarding frozen and non frozen water are consistent with previous studies following Delbari et al (2012) and Jalali and Ranjbar (2009). Unfortunately, no references were found for the use of frozen water for leaching during the literature review phase.

According to Table 3, based on the criteria used for the comparison of concentrations and criterion 3, frozen treatments have outperformed non-frozen treatments. It is now clear that treatments that have been continuously irrigated have shown better performance. Based on the statistical comparison, it can be seen that frozen treatments have a better yield than non-frozen treatments in either 3 pore volumes of water or 5 pore volumes of water. Further, the continuously irrigated treatments have produced better leaching. The best treatment according the statistical comparison is F5CC treatment (Table 3). According to Cote et al (2000) and Rajabzadeh et al (2009), the efficiency of alternate leaching is higher than that of continuous method due to unsaturated conditions and the passage of water through fine pores. Although similar to the results of the present study, depending on the soil conditions, the opposite result may be obtained (Nielsen and Biggar, 1962; Kolahchi and Jalali, 2007; Rajabzadeh et al. 2009; Behbahani Zadeh Rezaeyan et al. 2016).

Table 2- Comparison of final salt output concentration in treatments by Duncan method

Treatments	Pore volume of water		
	1 PV	3PV	5PV*
FCC	71.6	3.367^{c}	1.767^{e}
FCS	79.1	4.933^{a}	2.467^{d}
FAC	-	3.300^{c}	3.133^{c}
FAS	-	4.100^{b}	4.067^{b}
NFCC	29.46	1.833^{e}	1.133^{f}
NFCS	48.10	2.000^{de}	1.233^{f}
NFAC	-	1.967^{e}	1.067^{f}
NFAS	-	2.100^{e}	1.233^{f}

* pore volumes of water
F: frozen; C: continuous; C: common, S: salty; A: alternate; NF: non-frozen

Table 3- Comparison of the average salt concentration in soil after leaching in different treatments by Duncan method

Treatments	Pore volume of water		
	1 PV	3PV	5PV*
FCC	0.662[cdefg]	0.574[g]	0.480[h]
FCS	0.756[abc]	0.594[g]	0.577[g]
FAC	-	0.655[defg]	0.664[cdefg]
FAS	-	0.702[cde]	0.746[bcd]
NFCC	0.8[ab]	0.694[cdef]	0.605[fg]
NFCS	14.19 (not considered)	0.8[a]	0.662[cdef]
NFAC	-	0.724[cde]	0.605[fg]
NFAS	-	0.600[fg]	0.650[efg]

* pore volume water
F: frozen; C: continuous; C: common, S: salty; A: alternate; NF: non-frozen

As the amount of irrigation water increased, the amount of salt released from the soil column also increased nonlinearly as in a downward trend. That is, the amount of the extracted salt in the treatment with the 5 pore volumes of water was higher than that in the 3 pore volumes of water treatment, but not directly, since, in the early stages of leaching, the salts available in the macropores were removed and, then, the salts were slowly taken out of the micropores by the addition of the irrigation water. The findings of the current research are consistent with the results of Behbahani Zadeh Rezaeyan et al (2016). The salt in the micropores was not entirely leached as it was stuck at the bottom of the aggregates, which is the reason why the salt cannot be entirely removed by simply increasing irrigation water. Paired sample t test was used for comparing the treatments. First, saline treatments were compared in frozen and non-frozen treatments. Table 3 reports the significance or insignificance of the existing differences. It is clear that frozen continuous saline treatment (FCS) showed better performance. Then, continuous conventional treatments (FCC) were compared. It was determined that, under frozen treatments, continuously irrigated treatments with conventional water showed better performance. In the next comparison, frozen and non-frozen alternate saline treatments were compared, which revealed that frozen alternate saline irrigation treatments (FAS) had a better yield than non-frozen saline irrigation treatments (NFAS).

The FAC treatment performed better. Accordingly, the treatments had almost the same function; however, given that the conventional alternate freezing treatment (FAC) in 3 and 1 pore volumes of water had a lower salt content in the soil, this treatment was selected to make a general comparison with the type of frozen treatment that received continuous conventional irrigation (FCC). The comparison of the graphs showed that frozen treatments outperformed non-frozen treatments. Further to that, it is evident that the treatments that were tested continuously performed better than the alternate treatments. The later results are inconsistent with previous studies following cote et al. (2000) and Rajabzadeh et al. (2009). According to ECe, the treatments that were irrigated with saline water did not perform well. Therefore, the addition of calcium salt ($CaCl_2$) did not have effect on leaching.

It was assumed that, at the end of leaching, the salt concentration of the soil surface would be balanced by the electrical conductivity (EC) of irrigation water and that the concentration of the saline soil at the end of the column would be equal to the drain water concentration at the final moment of the leaching procedure. Accordingly, the general pattern of the state of salt in the soil at three points was drawn. According to the comparison of the graphs in Figures 1-4, it is now clear that the pattern of salt concentration in soil profile (assuming the existence of lower salt concentration along the soil profile) in NFCC treatments is better than that of other treatments, such that NF5CC treatment is slightly better than other treatments (Figure 2). However, since three data have been used to draw the profiles, it cannot be definitely concluded that NF5CC treatment is better than other treatments, because, according to Table 3, F5CC treatment performed the maximum amount of salt leaching. In addition, the measured ECe value associated with the 15-cm soil depth can be considered as the average ECe soil profile and, as is clear from Table 3, the treatment of F5CC can be claimed to be the best treatment.

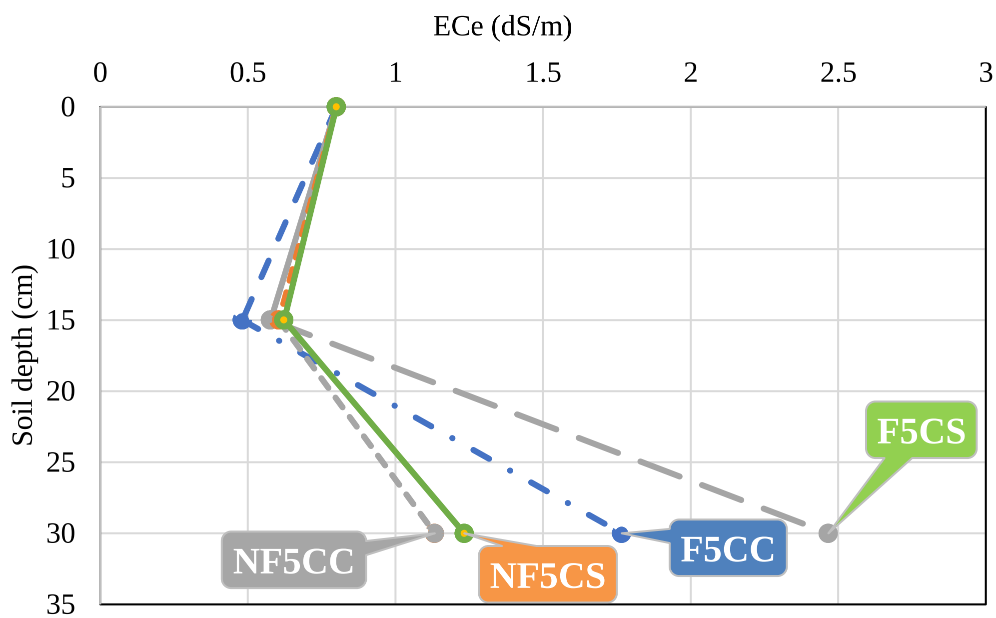

Fig. 1- Salt concentration profiles in soil after leaching for continuous treatments with 5 pore volumes of water (F: frozen; C: continuous; C: common, S: salty; A: alternate; N: non-frozen)

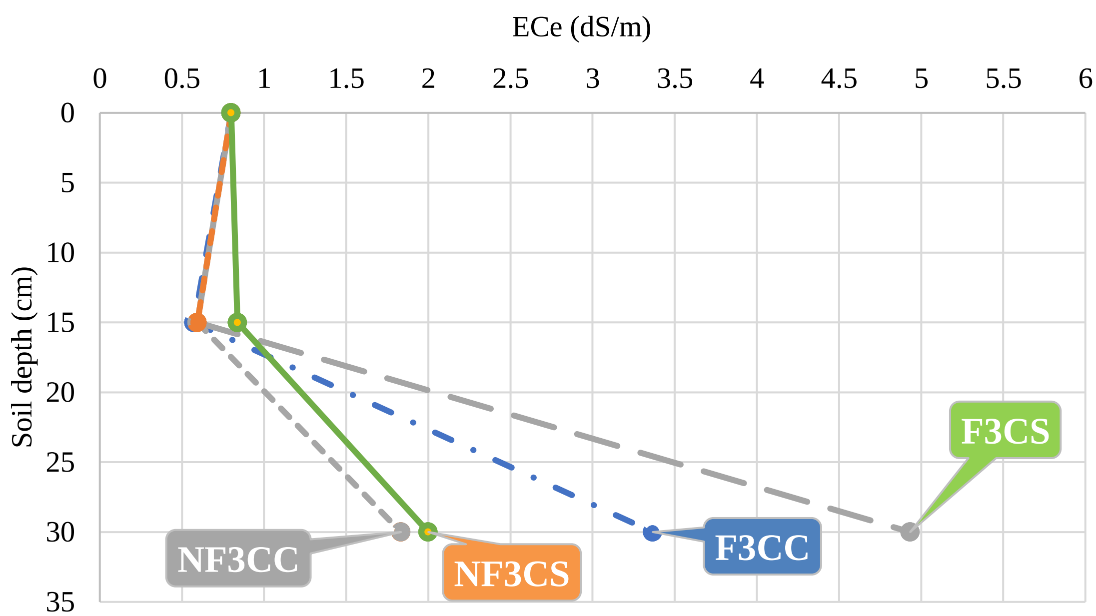

Fig. 2- Salt concentration profiles in soils after leaching for continuous treatments with 3 pore volumes of water (F: frozen; C: continuous; C: common, S: salty; A: alternate; N: non-frozen)

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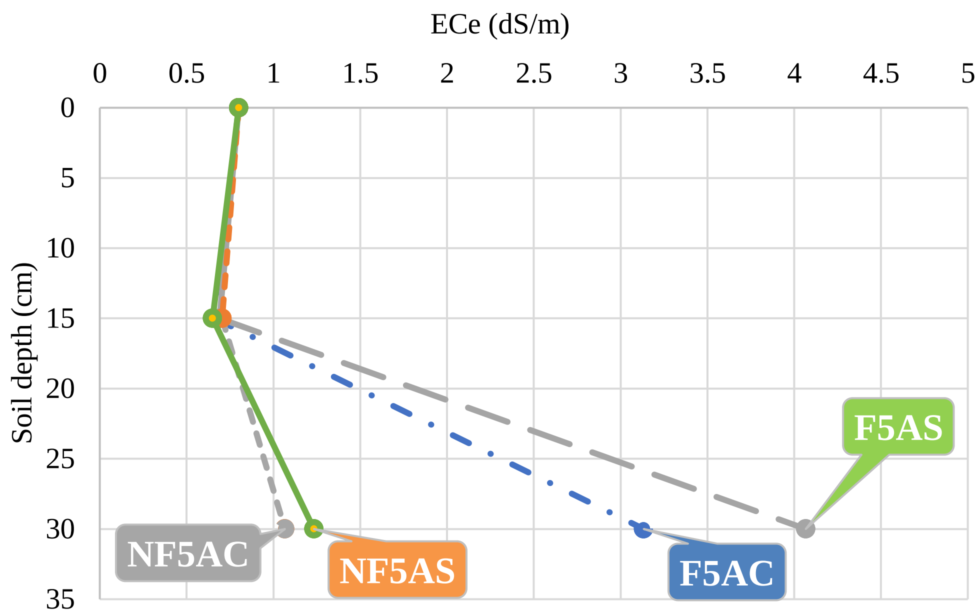

Fig. 3- Salt concentration profiles in soil after leaching for alternate treatments with 5 pore volumes of water (F: frozen; C: continuous; C: common, S: salty; A: alternate; N: non-frozen)

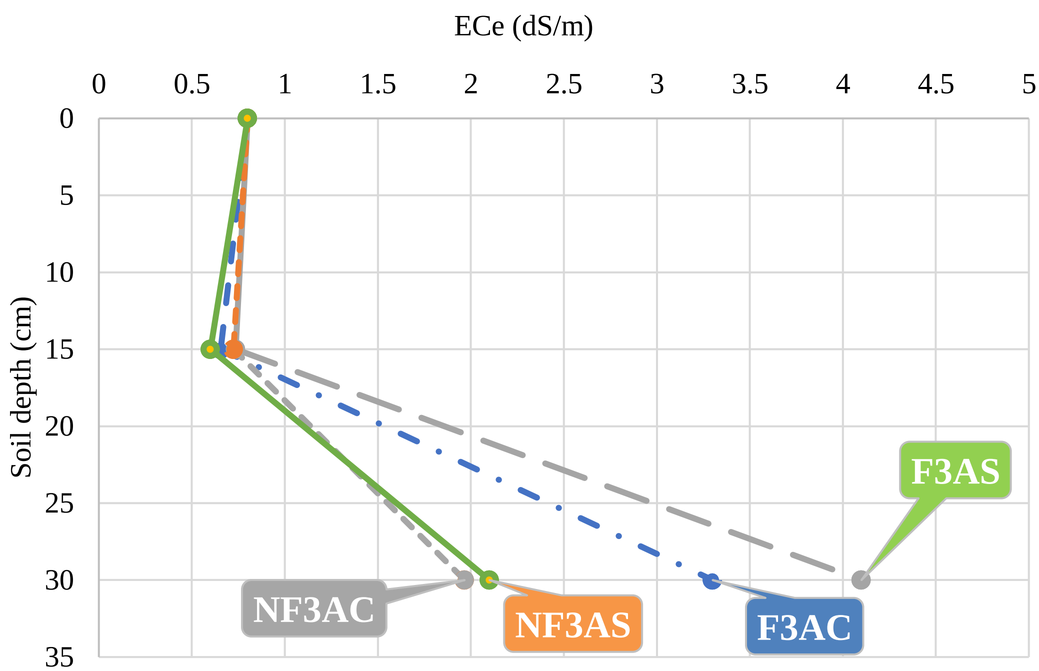

Fig. 4- Salt concentration profiles in soil after leaching for alternate treatments with 3 pore volumes of water (F: frozen; C: continuous; C: common, S: salty; A: alternate; N: non-frozen)

Conclusion

The goal of the present study is the assessment of some different methods for saline soil leaching. In this laboratory study, frozen irrigation water was used for soil leaching for the first time compared with non-frozen irrigation water. The results showed that all studied treatment could reduce soil ECe. So, this soil has a relevant potential for soil reclamation. An increase in the volume of irrigation water results in an increase in the leached salt, and the amount of salt leaching from the whole soil profile in the frozen treatments is higher than that of the non-frozen treatments. The amount of salt leaching from the whole soil profile in continuous treatments is more than that in alternate treatments. In brief, it can be concluded that frozen treatments that were irrigated continuously with conventional water of the region (FCC) showed better performance than other treatments. The management which is feasible during winter in the region. In the end, it should be noted that the addition of $CaCl_2$ in the soil is not recommended for correcting the studied soil. Motivated by the experience gained throughout this research and given the importance of leaching in regions with saline and alkaline soils, this study recommends conducting salt leaching at field scale at a proper temperature in the winter.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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