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Short communication

Infiltration of melting saline ice water in soil columns: Consequences on soil moisture and salt content

Zhigang Li [a,b], *Xiaojing Liu* [a,*], *Xiumei Zhang* [a], *Weiqiang Li* [a]

[a] *Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang, Hebei 050021, China*
[b] *Graduate University of Chinese Academy of Sciences, Beijing 100049, China*

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ABSTRACT

A soil column experiment was conducted to study the water and salt redistribution in a coastal saline soil under infiltration of saline ice meltwater. Four salinity levels (0, 5000, 10,000, and 15,000 mg l^{-1} diluted seawater) and three volumes (1800, 2700, and 3600 ml) of source water were used. The results indicated that the soil water content increased with the volume of applied ice. In the top soil layers, water content was higher under salt-free ice treatment than under saline ice treatments. In the deeper soil layers, however, the saline ice treatments showed higher water content than the salt-free ice treatment. While infiltration of meltwater reduced the salt content of the surface layer of all the treatments, the desalting depths of the saline ice treatments were greater than the desalting depth of the salt-free ice treatment. The results demonstrated that in the monsoon regions, saline soils could be improved through infiltration with meltwater of saline ice.

1. Introduction

Soil salinization is a major constraint for crop production in semi-arid and arid areas. Usually soil salinization is determined by the interaction of climate and groundwater. In the monsoon climatic regions, soil salt and water content vary seasonally because of the changes in evaporation, rainfall and temperature (Shi et al., 1986; Wang, 1993). Spring season is the salinization period because of high evaporation and low rainfall, summer season is the desalination period due to high rainfall, autumn season is the re-aggregation period due to reduced rainfall and increased evaporation, and winter season is the latent period due to the low temperature and evaporation. Additionally, saline soil areas usually have a shallow groundwater table with saline groundwater. The technologies often used for saline soil reclamation include draining out groundwater through pumping and canals, and leaching soil salts using rainfall and freshwater irrigation which is accompanied with the replacement of saline groundwater by rainwater or freshwater (Shi et al., 1986; Wang, 1993). Because of freshwater shortage, however, these technologies have limited applicability in the monsoon regions.

Irrigation with saline groundwater that contains adequate dissolved divalent cations such as Ca^{2+} is one way to leach and reclaim sodic and saline-sodic soils (Qadir et al., 2001). One major problem with this method is the inadequate amount of divalent cations, particularly Ca^{2+}, in the water that usually requires the application of gypsum. Other limitations of this technique are the difficulties in collection and conveyance of saline water and collection and disposition of drainage water

* *Corresponding author*. Tel.: +86 311 85871748; fax: +86 311 85815093.
E-mail address: xjliu@ms.sjziam.ac.cn (X. Liu).

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Table 1 – Chemical properties of the soil sample before the infiltration experiment

Soil salt content (% of dry soil weight)	
pH	8.0
$K^+ + Na^+$	1.50
Mg^{2+}	0.13
Ca^{2+}	0.09
Cl^-	2.13
SO_4^{2-}	0.95
HCO_3^-	0.02
Total salt content	4.80

(Qadir et al., 2001), and the need for excessive freshwater to leach the desorbed Na^+ from the root zone. Water desalination by natural freezing has been used for a long time (Fournier et al., 1974). Shi et al. (2002) tried to get low salinity (and even fresh) water from the Bohai sea ice through natural freezing in winter and thawing in spring. They considered this method might provide a solution to the water shortage problem of that area. Due to the high cost and technical difficulties, however, it is difficult to utilize desalinized water directly to agriculture by natural freezing.

Based on the above studies, we hypothesize that saline soils may be improved by irrigation with water from melting saline ice. In the monsoon regions with cold winter (e.g., northern China), saline groundwater is used for irrigation in winter, which will be frozen to ice. The saline ice melts gradually in spring. Since meltwater at initial thawing stages contains more salts, infiltration of late-melted freshwater would wash out the deposited salts and create a desalinized soil surface layer. Therefore, the objective of this experiment was to investigate the changes in soil salt and water contents under infiltration of saline ice meltwater and elucidate the possible mechanisms of soil desalination by freezing saline water irrigation.

2. Materials and methods

A saline soil sample was taken from the coastal area of Haixing County of Hebei Province, China. Soil analysis indicated that the soil was a fine clay and its salt content was 4.8% (Table 1). The soil sample was air-dried (with water content of 0.02 g g^{-1}), ground, sieved on a 2-mm sieve, and then packed into PVC cylinders (diameter: 16 cm; height: 100 cm). In order to take soil samples, pre-drilled holes were provided along the wall of PVC cylinders in a 5-cm interval. The holes were blocked with rubber stoppers during the experiment. To obtain a homogeneous soil bulk density (1.3 g cm^{-3}), column filling was accomplished in 10-cm thick sections till the height of 80 cm was reached. A 5-cm thick filter layer was put at the bottom of soil columns.

Saline water of four salinity levels (0, 5000, 10,000, 15,000 mg salt l^{-1}) was obtained by diluting seawater with distilled water. For each salinity level, three volumes of 1800, 2700, and 3600 ml, corresponding to irrigation rates of 90, 135 and 180 mm, respectively, were applied. Table 2 lists the contents of different ions in the source water. The source water was frozen at −14 °C in a refrigerator for 24 h. At the start of the experiment, the ice was put on the surface of the soil columns at room temperature of 25 °C. After about 27 h, the ice was melted completely and all water infiltrated into the soil. When ponded water disappeared from the soil surface, soil samples were collected from the holes on the wall at depths of 5, 10, 15, 20, 30, 40, 55 and 70 cm.

Gravimetric soil water content was determined by the oven-drying method. Soil water soluble salts were extracted using a 1:5 soil:water suspension and the contents of cations and anions were determined by the methods of Lao (1988). The total salt content was calculated as the sum of cations and anions.

3. Results and discussion

The soil water content and infiltration depth increased with the increase in applied ice volume, and there were interactions between salinity level and volume of applied water (Fig. 1). For the low volume treatment (1800 ml), the four salinity levels showed similar soil water content (0.27–0.28 g g^{-1}) in the 0–10 cm soil layer. With further increase in soil depth, however, soil water content was higher in the saline ice treatments than in the salt-free ice treatment. For the medium (2700 ml) and high volume (3600 ml) treatments, the soil water content in the upper layers was reduced with increasing ice salinity, but increased with increasing ice salinity in the deeper layers. At 5-cm depth, soil water content was 0.34 g g^{-1} in salt-free source water treatment and 0.28–0.30 g g^{-1} in saline source water treatments for the 2700 ml, while it was 0.42 g g^{-1} in salt-free source water treatment and 0.30–0.34 g g^{-1} in saline source water treatments for the 3600 ml. At 55 cm, soil water content of the high volume (3600 ml) treatment was 0.16–0.21 g g^{-1} for saline ice treatments, while it was still at the initial value of 0.02 g g^{-1} for salt-free ice treatment. These results indicate that soil columns treated with saline water may have higher hydraulic conductivity than that treated with low salinity water and fresh water. Reeve and Bower (1960) reported that the hydraulic conductivity of a sandy loam soil irrigated with hyper-saline water diluted with various amount of river water, decreased with increasing dilution level. Even for non-saline soils, irrigation with saline water resulted in reduced hydraulic conductivity with rainwater (Minhas and Sharma, 1986). The reduction in soil hydraulic conductivity under low salinity and fresh water treatments is due to the

Table 2 – Ion content in the source water (mg l^{-1})

Source water salinity	$K^+ + Na^+$	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
5000	1680	170	60	2700	380	20
10,000	3360	330	110	5390	760	40
15,000	5050	500	170	8090	1140	50

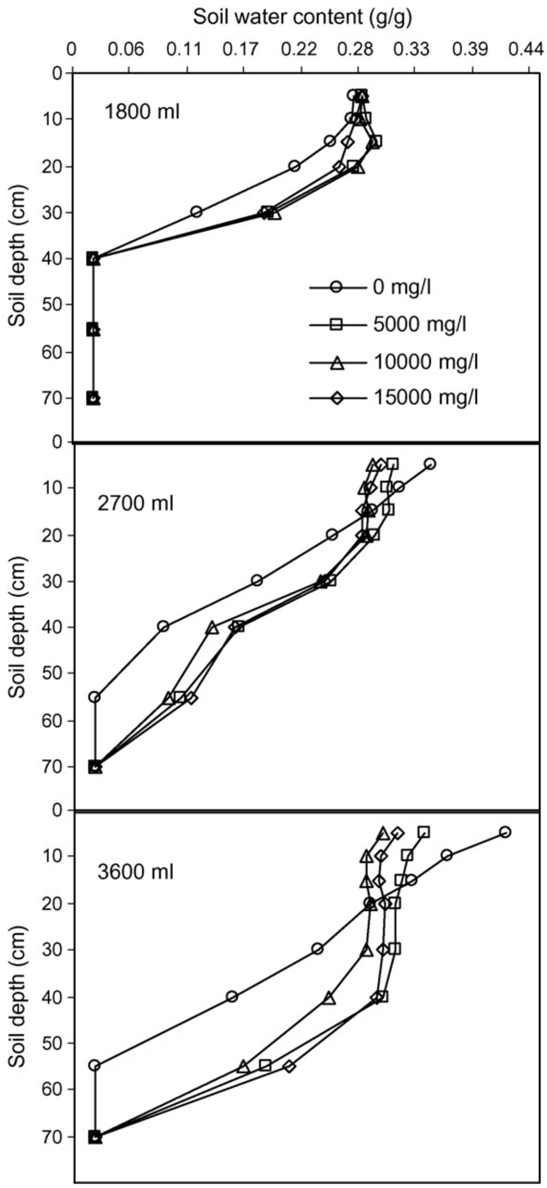

Fig. 1 – Soil water content after the infiltration of saline ice meltwater.

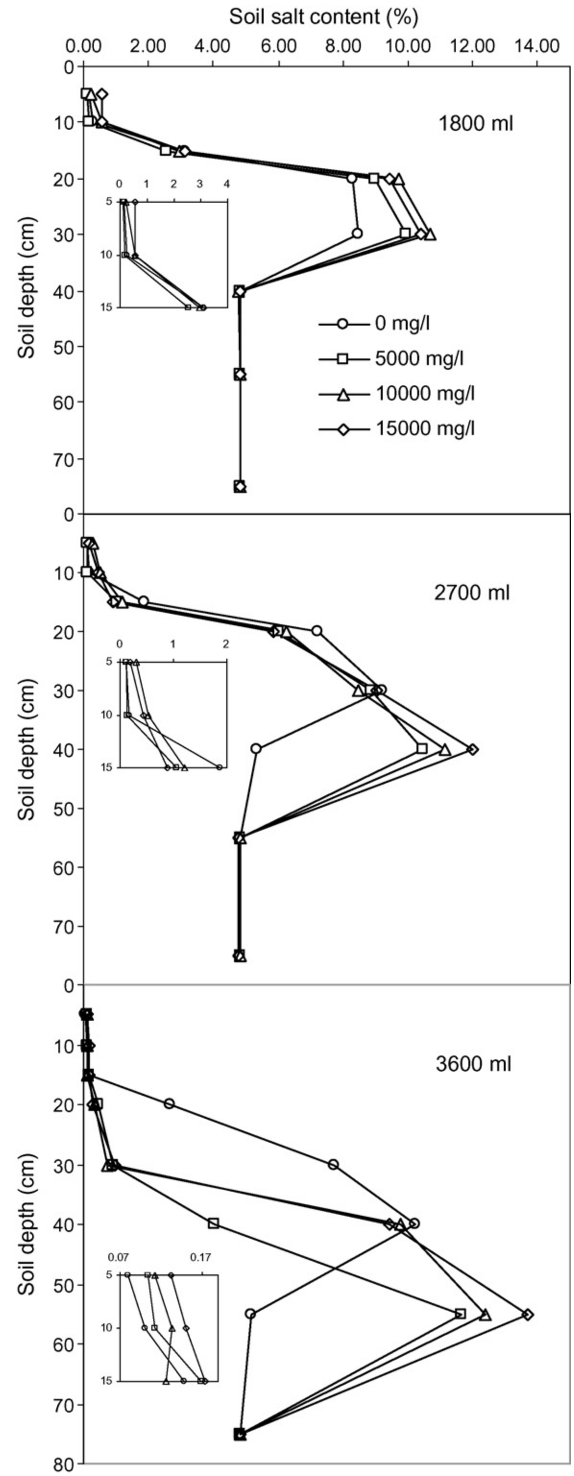

Fig. 2 – Soil salt content after the infiltration of saline ice meltwater. The insets depict the soil salt content in the 0–15 cm soil layer.

processes of swelling (especially in clayey soils), dispersion, and movement of clay particles that results in pore blockage in coarser soils (Frenkel et al., 1978; Pupisky and Shainberg, 1979; Shainberg et al., 1981a,b). In the present study, the infiltration of saline meltwater was more complicated because infiltration of saline water during ice melting followed the order of excessive high salinity water, high salinity water, moderate salinity water, low salinity water, and fresh water. The replacement of Na^+ in soils by divalent ions (e.g., Ca^{2+}) in earlier melted saline water prevents clay dispersion and preserves soil structure and permeability (Luthin, 1978; Shainberg and Singer, 1990). As a result, the soil columns under saline ice treatments show higher infiltration rate than the corresponding soil columns under salt-free ice treatment.

The difference in infiltration rate and depth under various treatments influences the movement and redistribution of salts in the soil columns. Salt leaching depth was increased with the increase of applied ice volume (Fig. 2). With 1800-ml saline ice treatment, the desalting depth was similar among the four salinity levels. Under the 2700 and 3600-ml saline ice treatments, however, desalting depth was increased with increasing ice salinity (Fig. 2). The desalting rate of 0–20 cm soil

Table 3 – Desalting rate in the 0–20 cm soil layer after infiltration with saline ice meltwater

Treatment (ml)	Desalting rate in 0–20 cm soil layer (%)			
	0 mg l^{-1}	5000 mg l^{-1}	10,000 mg l^{-1}	15,000 mg l^{-1}
1800	38.3	38.5	29.7	28.6
2700	51.1	61.7	56.7	61.5
3600	84.3	95.7	96.2	96.3

layer, calculated as the percentage of salinity difference between measurements before and after infiltration experiment, is presented in Table 3. With 1800-ml ice volume, the salt-free and 5000 mg l^{-1} treatments showed higher desalting rates than the 10,000 and 15,000 mg l^{-1} treatments. For ice volumes of 2700 and 3600 ml, however, the salt-free treatment reduced desalting rate comparing to the other three treatments (Table 3). It has been shown that irrigation with high salinity water followed by leaching with fresh water is one way to reclaim sodic soils (Qadir et al., 2001). In the present study, the melting of saline ice possibly accompanies two processes: infiltration of earlier saline meltwater that leads to replacement of Na^+ by divalent cations in the saline meltwater, and leaching of ions by low salinity or even fresh water melted at later time. More salts from the surface soil layer were leached when greater amount of saline ice was applied.

4. Conclusions and remarks

The objective of this work was to investigate the changes in soil water and salt contents under infiltration of saline ice meltwater. Soil water content increased with ice application volume. Comparing the different treatments, water content was higher in the salt-free ice treatment than in saline ice treatments in the top soil layers, but the trend was reversed in deeper soil layers. For both saline ice and salt-free ice treatments, salt content in the top soil layers was reduced, and the desalting depth was greater in the saline ice treatments than in the salt-free ice treatment. These preliminary results indicated that infiltration of saline ice meltwater is beneficial for saline soil reclamation, and application of high volume of saline ice is recommended on the field. Two mechanisms may explain the impact of saline ice meltwater on the dynamics of soil salts. First, divalent cations in saline meltwater replace Na^+ at the early drainage period. Secondly, the salts are leached down by melted fresh water at later drainage period.

The process of saline water infiltration into soil is affected by many factors, such as soil salinity (or sodicity), sodium adsorption ratio, texture, and organic matter content (Frenkel et al., 1978; Pupisky and Shainberg, 1979; Shainberg et al., 1981a, b; Minhas and Sharma, 1986). In cold regions, soil salinization can be controlled by freezing and thawing process (Zhang and Wang, 2001; Zhang et al., 2005; Wang, 1993). During the freezing process, salt accumulation in the frozen soil layer is caused by the temperature difference between soil layers, which induces the redistribution of water and salts in the soil profile. The frozen layer may become salinized due to high evaporation rates during the thawing process in spring (Zhang and Wang, 2001). Under this condition, the saline ice from freezing saline water irrigation in winter will influence the freezing and thawing process, which may increase soil temperature in winter, similar to increase in ground temperature under concrete or snow cover (Li et al., 2001; Ling and Zhang, 2007). Further laboratory and/or field studies are required to quantify the mechanisms of freezing and thawing of saline water on soil desalinization.

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