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Artificial Macropores with Sandy Fillings Enhance Desalinization and Increase Plant Biomass in Two Contrasting Salt-Affected Soils

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Abstract: Salt accumulation in topsoil is a widespread restricting factor that limits agricultural production and threatens food security in arid and semi-arid regions. However, whether this upward enrichment was suppressed by macropores was less documented. Therefore, artificial macropores with sandy fillings (AMSF) method was proposed in this study. Soil column experiments showed a significant improvement of saturated hydraulic conductivity (*Ks*) by more than 260% under artificial macropore treatment. Freshwater irrigation was conducted to monitor the short-term water and salt movement. This research aimed at evaluating the potential benefit of AMSF method on soil desalinization in coastal farmland of northern China. The results demonstrated that downward movement of soil water was stimulated in AMSF method, accordingly, washing more salt ions out of top rooting zone. Particularly, 10 cm or more macropore depth treatments of AMSF method enhanced total desalinization by 52.1% to 176.6% in 0–30 cm soil layer, in comparison to the control group without macropore. Subsequent observations for alfalfa showed higher biomass by 20.8% under 15 cm macropore depth. The results here provided an exploration demonstration to pursue these studies with the ultimate goal of optimizing application strategies for amendment in coastal salt-affected lands of northern China.

Keywords: macropores; sandy fillings; infiltration; soil desalinization; freshwater irrigation

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1. Introduction

Soil salinization is a global widespread problem, which would limit agricultural production and threaten food security dramatically in arid and semi-arid regions [1,2]. According to statistics, salt-affected soils account for approximately 25% of the total land area, widely distributing in over 100 countries around the world [3].

Salt accumulation has detrimental influence on soil physicochemical properties and crop growth as well. This upward movement of salt is caused by the combined influence of groundwater transport, soil evapotranspiration and other water input. The groundwater which contains soluble salt tends to transport via capillary rise to upper soil layer due to continuous evapotranspiration [4]. Simultaneously, liquid water also moves up to compensate for the water loss, and thereby, salt accumulates and precipitates in topsoil. The solid salt may also occupy the pore between soil particles and thereby weaken soil porosity. More importantly, the vast majority of crops' roots concentrate in the top 0 to 30 cm soil layer [5], so it is of great importance to ensure an acceptable salt conditions in the topsoil for realizing regional agro-ecological value.

Macropores are continuous pores with over 0.05 mm diameter, which naturally exist in the form of root channels, wormholes, or soil aggregate gaps. The irregular structure makes it complicated and difficult to conduct accurate infiltration simulation [6]. However, macropores have been considered as a key element to support water flow because they usually work as a water pathway that preferentially delivers solutions into deeper layer [7,8].

More importantly, preferential flow under saturated condition tends to be dominated via macropores due to gravity [9]. This provides an important evidence of macropores for promoting soil infiltration. Therefore, artificial macropores were introduced into degraded lands for improving solute transport and bioremediation [10,11]. Aeration, another type of macropore, was tested to promote root penetration and soil environment in grass land [12,13]. Despite the positive paradigm in soil remediation, artificial macropores are merely a suboptimal option for exploiting ill-drained fields, as the empty macropore structure is difficult to maintain due to the collapse and clogging. Mori et al. [10] protected the macroporous structure by filling glass fibers, and doubled plant biomass was surveyed one year later. However, the enhanced infiltration may result from the capillary force which was produced by fibrous material.

In China, more than 36 million ha degraded lands are suffering from salt toxicity, among which coastal saline soils occupy significant proportion. Generally, coastal saline soils are vulnerable to climatic changes because of the intrusion from marine water and poor drainage capacity [14,15]. In this study, a novel solution was proposed to alleviate salt accumulation of coastal saline farmland. Specifically, we designed artificial macropores with sandy fillings (AMSF) method to determine how they contribute to water migration in saline soils, based on our hypothesis that if coastal lands with poor drainage capacity could be improved, it would be helpful in stimulating water downward transport, reducing salt accumulation, as well as thereby achieving an acceptable farmland. Therefore, column experiments were carried out to compare the drainage capacity of artificial macropore under different salinized levels; irrigation experiments with freshwater were conducted to monitor the water and salt movement, and alfalfa (*Medicago sativa* L.) was sown to observe plant growth.

Accordingly, the objective of this study was to create artificial macropores which filled with sandy material, to evaluate its potential benefits for salt-affected soils, and to thereby enhance soil infiltration, improve leach of topsoil with salt accumulation, and increase plant biomass.

2. Materials and Methods

2.1. Field Experimental Site and Soils

From June to August in 2016, field experiments were conducted at Shiji Tianyuan Agricultural Machinery Cooperative (38°46′ N, 117°13′ E), located in Zhongtang town, Binhai district, Tianjin, China. The site is located in a warm and semi-humid region with a continental monsoon climate. Average annual temperature is 12.3 °C with 211 frost-free days. Average annual rainfall is 570 mm, which mostly falls between June and September.

In field plots, soil was classified as coastal solonchak, in accordance with Chinese grading standards of salinization. Two levels of salinized soil (mild and severe salinization) were selected. The soil chemical properties in top 30 cm were showed in Table 1.

2.2. Design of Artificial Macropore with Sandy Fillings

Previous studies have verified the advantage of artificial macropores in delivering solutes into deeper profile [16]. In this study, we attempted to improve surface desalinization for bare saline soils using artificial macropores (Figure 1). The artificial macropores were designed with following properties:(1) The artificial vertical boreholes with different depth were made to mimic macropore structure. (2) The fine sand particles, sandy material, were incorporated into artificial macropore to stabilize the structure. (3) The sandy particles generated a water pathway that delivered solution into deeper layer.

Meanwhile, we prepared sandy materials from sand dune outside the experimental sites. The texture was classified as fine sand, and its preparation steps were as follows: the sand sample was passed through a 1 mm sieve to separate gravel, then passed through 0.25- and 0.05-mm sieve in turn, and finally mixed with 30% of medium and coarse sand (0.25 to 1 mm), and 70% of fine sand (0.05 to 0.25 mm) according to the USDA classification. Those cohesive particles with a size of less than 0.05 mm were removed. In this study, the upper apex of the filled material was 1 cm above the ground in order to relieve the clog or encrustation from soil particles during flooding [16]. In addition, the sands filled into holes cannot contain salt.

Table 1. Basic soil characteristics prior to the initiation of field experiments.

Soil Properties	Salinity Levels of Experimental Soil	
	Mild Salinization	Severe Salinization
Soil texture		
Sand (0.02~2 mm, %)	14.9	10.6
Silt (0.002~0.02 mm, %)	64.8	61.0
Clay (<0.002 mm, %)	20.3	28.4
Soil physical properties		
Bulk density (g cm^{-3})	1.31	1.39
Total porosity (%)	48.6	46.5
Field capacity (%, by weight)	24.7	28.4
Soil chemical properties		
Electrical conductivity (1:5 soil to water, dS m^{-1})	0.56	2.04
Salt content (g kg^{-1})	1.95	7.08
pH	8.11	8.34
Organic matter (g kg^{-1})	17.9	10.4
Available nitrogen (mg kg^{-1})	55.6	64.5
Available phosphorus (mg kg^{-1})	12.1	31.4
Available potassium (mg kg^{-1})	97.8	63.2

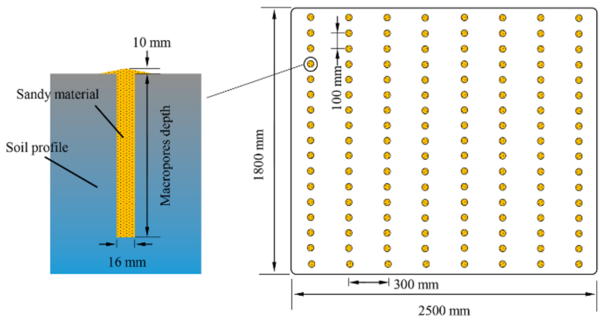

Figure 1. Schematic representation of artificial macropores with sandy fillings (AMSF) method.

2.3. Field Irrigation Experiments

Three different macropores depths (5, 10 and 15 cm) were introduced in these experiments. The treatment without artificial macropore (0 cm depth treatment) was adopted as the control group. Three replicate plots were carried out for two salinization levels and four macropore treatments (twenty-four plots totally).

The vegetation was removed, and the surface was leveled prior to the experiment. Plots were 40 cm apart. Each plot was 2.5 m long and 1.8 m wide, around which 0.6 m depth plastic film was buried, and 15 cm high ridge was built to avoid lateral flow. Then total treatments were randomly separated, different deep artificial macropores were installed with 10 cm apart in a row, and the row distance was 30 cm (Figure 1). After that, freshwater was applied to reduce the salt interference from irrigation water, and the chemical properties are shown in Table 2. According to local irrigation practice, we introduced flood irrigation for each plot under 1200 m^3 ha^{-1}, i.e., 0.54 m^3 per plot.

Table 2. Chemical properties of irrigation water.

Mineralization (g L^{-1})	Total Salt (g kg^{-1})	HCO_3^- (g L^{-1})	Cl^- (g L^{-1})	SO_4^{2-} (g L^{-1})	Ca^{2+} (g L^{-1})	Mg^{2+} (g L^{-1})	Na^+ (g L^{-1})	K^+ (g L^{-1})
0.192	0.250	0.116	0.039	0.010	0.024	0.048	0.009	0.004

2.4. Sampling and Measurements

Soil samples were collected after 5, 10, 15, 20 and 25 days of irrigation, i.e., the duration of monitoring period was 25 days, referring to the research method of Li et al. [17]. More specifically, in each plot, soil samples were collected at 0~5 cm, 5~10 cm, 10~15 cm, 15~20 cm, 20~30 cm, 30~40 cm, 40~50 cm, and 50~60 cm depth. The metal ring samplers with 52 mm high and 70 mm in diameter were used to collect undisturbed soils. These ring samplers were hammered into the designed profile after the upper soils were collected and removed. No rainfall events were observed during the entire sampling period.

Undisturbed soils were randomly sampled to measure water content and bulk density based on oven drying method. Disturbed samples were collected with soil auger for salt determination. In addition, the macropores areas filled with sand were not included.

Soil moisture storage was estimated following the procedure described by He et al. [18]:

$$W = 10\sum_{i=1}^{n} \theta_{gi}\rho_{si}z_i/\rho_{\rm w} \tag{1}$$

where W is soil moisture storage, mm; θ_{gi} is soil gravimetric water content of i soil layer, g g^{-1}; ρ_{si} is soil bulk density of i soil layer, g cm^{-3}; z_i is thickness of i soil layer, cm; $\rho_{\rm w}$ is density of water, g cm^{-3}.

The air-dried soil samples were pulverized and then passed through a 2 mm mesh sieve, while visible roots, pebbles and aggregates larger than 2 mm were screened out. Soil electrical conductivity was measured in a soil: water suspension (1:5) using an EC meter (DDS-11A, Shang Hai Yoke Instrument Co., Ltd., Shanghai City, China), and the soil salt content was calculated by an empirical equation, as described by Du et al. [19]:

$$Y = 3.471Ec + 0.015 \ldots$$

where Y is soil salt content, g kg^{-1}; Ec is conductivity of soil extract at 25 °C, mS cm^{-1}.

Soil salt storage was described as be the mass per unit area:

$$S = 10\sum_{i=1}^{n} y_i\rho_{si}z_i, \tag{2}$$

where S is soil salt storage, g m^{-2}; y_i is soil salt content of i soil layer, g kg^{-1}; ρ_{si} is soil bulk density of i soil layer, g cm^{-3}; z_i is thickness of i soil layer, cm.

2.5. Aboveground Plant Biomass

After soil sampling, i.e., on the 26th day after irrigation, alfalfa (*Medicago sativa* L.) was planted manually at a rate of 15 kg ha^{-1}. Alfalfa seeds were drilled at a depth of 30 mm and a row spacing of 30 cm. Chemical fertilizers (N-P_2O_5-K_2O) were utilized simultaneously 40–50 mm below the seeds, to supply 85 kg ha^{-1} N, 45 kg ha^{-1} P, and 40 kg ha^{-1} K. Then for all treatments, each plot was irrigated at an equal rate of 450 m^3 hm^{-2} biweekly until the late August. Moreover, plant protection was applied when needed based on the traditional agronomic management. Aboveground plant biomass was sampled at random from a 1 m^2 location in each plot. The plant samples were dried at 65 °C for 48 h and then weighed.

2.6. Laboratory Experiments for Soil Columns

In this section, we sampled the undisturbed soil with 52 mm high and 70 mm in diameter from 10 to 20 cm deep layer of experimental lands. A stainless pipe with 6 mm diameter was applied to created artificial macropores from the soil column center. The air-dried soil samples from the same depth were pulverized and sieved, and then, cohesive particles less than 0.05 mm were removed. Finally, the remaining sand particles were incorporated into the gap, and the same amount was applied to obtain a consistent bulk density with soil column.

In addition, column samples without artificial macropore were introduced as control. Each treatment was replicated three times under two salinized levels. All the soil columns were saturated from bottom with capillary rise for 30 h. The saturated hydraulic conductivity (*K*s) was measured with the constant head method [20] by a permeameter (TST-55, Nanjing Soil Instrument Co., Ltd., Nanjing City, China).

2.7. Statistical Analysis

The Statistical Product and Service Solutions (SPSS) analytical software package was used for all of the statistical analyses. Mean values were calculated for each of the measurements, and analysis of variance (ANOVA) was performed to the data sets to assess the treatment effects on the measured variables. When ANOVA indicated a significant *f*-value, multiple comparisons of mean values were made on the basis of the least significant difference (*LSD*).

3. Results

3.1. Saturated Hydraulic Conductivity of Soil Columns

As presented in Figure 2, saturated hydraulic conductivity (*K*s) was measured under two initial soil conditions. In comparison to the control group without macropore, AMSF method increased *K*s by 268% ($p = 0.05$) in mild salinization condition, and by 309% ($p = 0.05$) in severe salinization condition. The results indicated an improvement for AMSF method on drainage capacity in soils. This could be explained by the replacement of cohesive particle, so that continuous macropores were generated between sand particles. Thus, water could be delivered preferentially into deeper soil layers through pores.

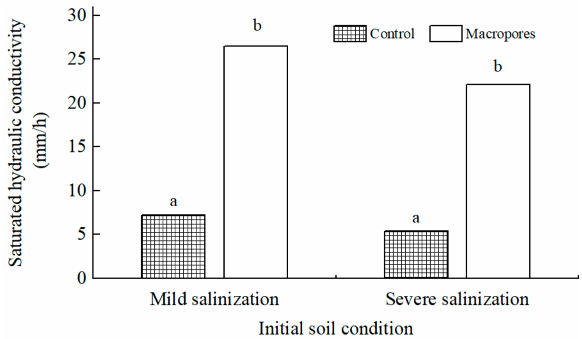

Figure 2. Saturated hydraulic conductivity (*K*s) as affected by macropore treatment under two initial soil conditions. Control: soil columns without macropore treatment. Macropores: artificial macropores with sandy fillings (AMSF) treatment.

3.2. Water Storage

Figure 3 compares the mean water storage in 0 to 30 cm soil layer under two salinization levels, which was calculated within 25 days after irrigation. Gradually, mean water storage tended to decrease gradually from 125.7 mm to 76.4 mm with the passage of time. Meanwhile, mean values under severe salinization treatment were 2.2% to 8.6% higher than that of mild salinization condition.

For both initial salinization levels, there appeared to be a trend of decrease in mean water storage with the increasing of macropores depth (Figure 4). An overall decrease in stored water by 13.1% to 14.2% ($p = 0.05$) was observed for 15 cm macropores depth treatment, as compared to the control group without macropore.

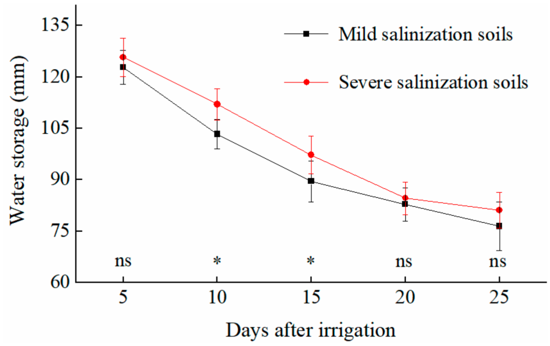

Figure 3. Mean water storage at top 30 cm under different salinization conditions without artificial macropores. Label "ns" means values within the same sampling time are not significantly different, and label "*" means values within the same sampling time are significantly different ($p = 0.05$).

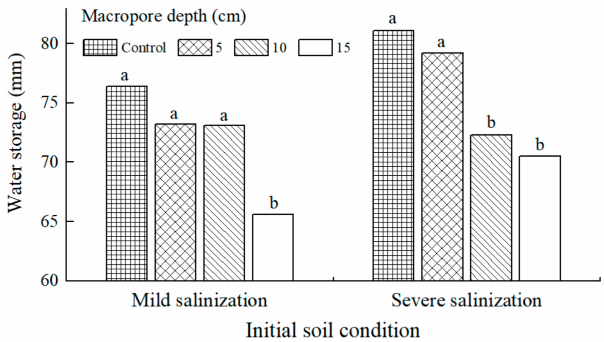

Figure 4. Mean water storage in top 30 cm soil layer 25 days after irrigation under different macropore depth treatments for artificial macropores with sandy fillings (AMSF) method. Control means soils without macropore. Mean values within same initial soil condition followed by different letters are significantly different ($p = 0.05$).

3.3. Soil Salt Content

As the water transport was accompanied by salt change, mean soil salt content under different macropore depth treatments was shown in Figure 5. For both of these two salinization levels, salt content appeared to decrease, firstly, and then increased with the increasing of soil depth. Specifically, in mild salinization condition, the salt content in top 20 cm for 10 cm macropore depth treatment was 1.2% to 15.5%, and for 15 cm macropore depth treatment 5.8% to 21.8% less than that of control group ($p = 0.05$). Meanwhile, means in 20 to 60 cm soil layer under each macropore depth treatments were not significantly different ($p = 0.05$). Under severe salinization condition, the salt content with 10 cm macropore depth treatment was 1.5% to 4.7% less than control group throughout the 0–30 cm soil layer. For 15 cm macropore depth treatment, the salt content was 2.3% to 9.8% less than that of control group throughout the 0–30 cm soil layer.

3.4. Soil Desalinization

Mean salt storage to the depth of 30 cm for different macropore depth treatments was calculated in Table 3, in order to compare the effect of AMSF method on soil desalinization. The mean total salt appeared to be a similar tendency of decrease for both initial salinization conditions with the increasing of macropore depth, i.e., the order of means was 15 cm < 10 cm < 5 cm < 0 cm macropore depth treatment.

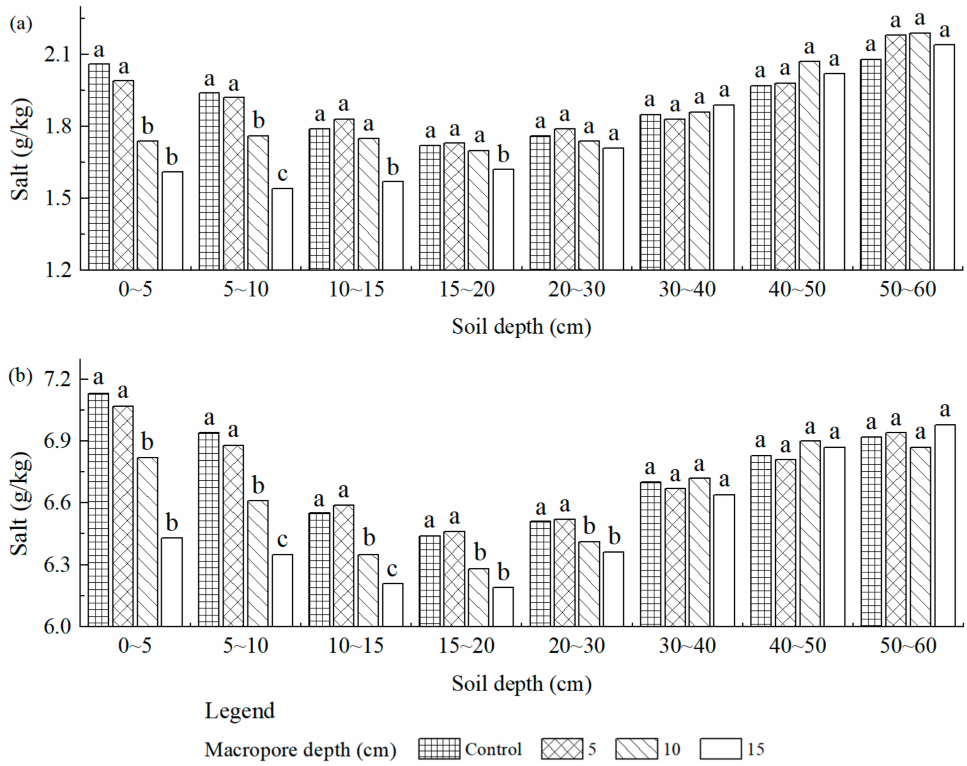

Figure 5. Mean soil salt content to the depth of 60 cm 25 days after irrigation under different macropore depth treatments for artificial macropores with sandy fillings (AMSF) method. (**a**) Initial soil condition of mild salinization; (**b**) initial soil condition of severe salinization. Control means soils without macropore. Mean values within same soil profile followed by different letters are significantly different ($p = 0.05$).

Table 3. Mean total salt and total desalinization in top 30 cm soil layer after 25 days of irrigation for different macropore depth treatments for artificial macropores with sandy fillings (AMSF) method. Control means soils without macropore. Mean Values within a column followed by different letters are significantly different ($p = 0.05$).

Initial Soil Condition	Macropore Depth (cm)	Total Salt (g m^2)	Total Desalinization (g m^{-2})
Mild salinization	control	766.6a	50.0c
	5	760.1a	56.5c
	10	724.9b	91.7b
	15	678.3c	138.3a
Severe salinization	control	2785.6a	159.9c
	5	2769.8a	175.6c
	10	2702.2b	243.3b
	15	2634.1c	311.4a

Total desalinization in top 30 cm soil profile was determined by the difference in total salt before irrigation and after 25 days of irrigation. More specifically, in a 1200 m^3 ha^{-1} irrigation event, under mild salinization condition, 10 cm and 15 cm macropore depth treatments reduced total salt by 41.7 and 88.3 g m^{-2}, and accordingly increased total desalinization by 83.5% and 176.6% significantly ($p = 0.05$), respectively, as compared to control group without macropore. Meanwhile, the total desalinization under severe salinization condition with $\geq$10 cm macropore depth treatments were 52.1% to 94.7% ($p = 0.05$) higher than control group.

3.5. Plant Biomass

Figure 6 compares the aboveground plant biomass of alfalfa under different macropore depth treatments for AMSF method. After 2 months of growth, AMSF method harvested more plant biomass. The biomass was 20.8% higher under 15 cm macropore depth treatment than that in control group ($p = 0.05$). Moreover, more alfalfa biomass was observed under mild salinized level as compared with severe salinized level.

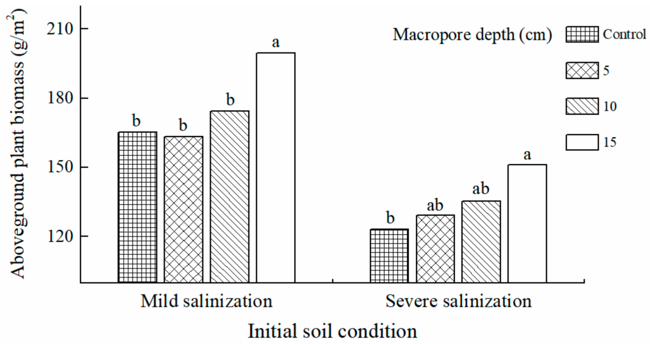

Figure 6. Aboveground plant biomass of alfalfa under different macropore depth treatments for artificial macropores with sandy fillings (AMSF) method. Control means soils without macropore. Mean values within same initial soil condition followed by different letters are significantly different ($p = 0.05$).

4. Discussion

4.1. Salt Affects Water Movement

It was reported that the macropores worked as prior water flow channels, which stimulated infiltration to deeper profile, but the empty macroporous structure is difficult to maintain. Based on the above, authors incorporated sandy material into artificial macropores to stabilize the structure [21]. However, the role of sand grains sieved from experimental soil in water transport has not been well analyzed. In addition, the salinity in coastal lands fluctuated periodically due to the incursion of seasonal tidal activity and monsoons [22]. In fact, the domestic coastal saline soils, within west Bohai Gulf, are highly argillaceous with poor permeability. Particularly from May to September, the salt accumulation near surface is severe because of high temperature and strong evapotranspiration, making the soils complicated to restore [23]. Therefore, experimental design in current research differed extremely from the previous ones. Firstly, soil column experiments were conducted to elucidate the roles of sandy particles in enhancing drainage capacity, in which silt and clay were removed from the column center. Secondly, contrasting soils under two salinized levels were selected considering the fluctuation characteristics of salinity. In contrast, in the previous experiments, soils were exposed to slight salinized environments throughout the monitoring stages (i.e., 2.4 g kg^{-1} of salt, Zhang et al. [21]). Moreover, irrigation for the total plots were carried out simultaneously to ensure the same climate parameters such as temperature, evaporation, and wind, and to thereby simplify measuring process. Finally, a seasonal observation for alfalfa, 2 months approximately, was introduced to investigate its potential significance.

In present irrigation events, 25-day observation was conducted. This short-term monitoring came for the following reasons. Primarily, 25 days after irrigation, water movement entered a relatively stable status, and the moisture in each soil layer appeared to be close to the unirrigated farmland area around the study region. Moreover, it was reported that salt accumulating up occurred about 20 days after irrigation under similar soil texture [17]. Although Ju et al. [24] demonstrated that salt accumulation occurred in the 60th day after irrigation by field crop experiments. This different result could be explained by the 3-time continuous irrigation which made the salt maintain at low values in the initial 40 days of experiments, and the influence of root on salt may also delayed the accumulation process.

Higher soil water holding capacity was measured with the increasing of salt content under similar soil texture. This relevant tendency was consistent with the results of Feng and Yang [25]. However, this correlation between salt and improved water environment could not be concluded because the enhanced water holding capacity was relevant to soil hygroscopic coefficient, which could hardly verify the increase in available water. Li [26] found that soil hygroscopic coefficient increased to more than 17.9% when salt content was over 7.6 g kg^{-1}. Meanwhile, with the increasing of soil salt content, wilting coefficient increased [27], and accordingly, the soil available water absorbed by crops was decreased. Therefore, although salt increased the soil water content, the field water environment was not improved because crop water stress was also exacerbated. Subsequent observations for alfalfa verified the above inference, because alfalfa biomass under severe salinized level was less than that of mild salt condition.

The salts precipitated at surface would be dissolved and then washed below the rooting zone. Results here demonstrated a positive effect on leaching soil particles with freshwater, as $\geq$50 g m^{-2} total salt in top 30 cm soil layer was flushed into deeper profile. In general terms, extra input with freshwater can dilute the liquid water which contains soluble salt and drive them downward during infiltrating.

4.2. Artificial Macropores Enhances Desalinization and Plant Yield

Soil column experiments showed a significant improvement for Ks by more than 260% when cohesive particles were removed. This result confirmed the key role of macropore in water movement, especially under saturated condition. Meanwhile, this result also provided a basis for the promotion of water infiltration and solute migration in flood irrigation events.

Salt toxicity is a major restrictive element in soil structural degradation characterized by high exchangeable sodium percentage (ESP), which will worsen soil fertility and water permeability extremely [28,29]. AMSF method in irrigation experiments showed some benefits for improving soil leaching in the upper 30 cm soil profile, as well as environmental improvement for rooting zone. These positive results benefited from more water infiltrating into the deeper layer. Artificial macropores provided continuous pores, which introduced flow channels in the soil. Another possible reason for this would come from the eliminated surface flooding [30], which reduced the tendency of generating secondary salinization resulting from soil evapotranspiration. Secondary salinization or anthropogenic salinization is the result of improper water input from human activities such as excessive irrigation and longstanding flooding [31,32]. More alfalfa biomass was observed, which may result from the enhanced soil leaching to deeper layer, as a lower salinized environment can alleviate the salt stress on crops.

Furthermore, salt crust, i.e., crystals or efflorescence was reported to formed at soil surface when salt content exceeded its solubility. This hydrological phenomenon could maintain the underlying soil wetter and allow more salt accumulation below the crust. However, it was also a complicated process and required long-term continuous monitoring. In present study, no salt crust was detected throughout the whole testing duration, probably because the shorter monitoring time.

4.3. Future Applications for Agriculture Practice in Salt-Affected Soils

The accumulation of sodium chloride is a vital reason for salinization in coastal agricultural region [33]. Due to the filling of fine sand, the artificial macropore structure maintained effectively, and the salt redistribution for topsoil could be detected under 25-day observation. Irrigation experiments showed that total desalinization in top 30 cm soil profile with $\geq$10 cm macropore depth treatments for AMSF method were improved by more than 50% as compared to control group without artificial macropore.

In this study, we also focused on validating the feasibility of sandy materials in agricultural farming. In salt-affected soils, fertilizers and amendments are the most common agronomic resources, which would be applied into plough layer in the form of physical particles. Based on the proven hypothesis, we have reasons to infer that water and salt environment can be further improved by optimizing particle composition ratio and application strategy for amendment, and thereby stimulate crop performance.

In general terms, it is essential to establish an optimized management method for salt-affected farmland, considering the interaction between water input, plant tolerance and agronomic measures. There are two unanswered questions that need to be completed in subsequent research. Firstly, soil evaporation makes a vital role in water movement, and long-term monitoring is required to explain the role of evaporation in soil salt accumulation. Secondly, the study of AMSF method affecting soil properties and crop growth was not involved. It is necessary to apply the hypothesis to agriculture practice to deepen the research on soil amendment utilization. For example, whether farmers can obtain better rhizosphere environment by artificial macropores with amendment incorporation can be further discussed. Deeper insights into the effect of amendment's spatial distribution on response to the ionic migration and the potential values for particles size redesign in field crop experiments will probably contribute to the successful farming practice of our findings.

Importantly, the short-term observations described here about how AMSF method can affect salt condition provide an exploration demonstration to pursue these studies with the ultimate goal of incorporating new application approaches for amendment into coastal salt-affected lands of northern China.

5. Conclusions

In this study, artificial macropores with sandy fillings (AMSF) method was proposed to improve topsoil leach. Soil column experiments showed a significant improvement of saturated hydraulic conductivity (Ks) by more than 260% under AMSF method. In farmlands, freshwater irrigation was conducted, and 25-day sampling showed that 10 cm or more macropore depth treatments of AMSF method enhanced total desalinization by 52.1% to 176.6% in 0–30 cm soil layer, in comparison to the control group without artificial macropore. Subsequent observations for alfalfa showed higher plant biomass by 20.8% under 15 cm macropore depth.

Despite the evidence mentioned above demonstrating that AMSF method enhanced downward movement of water and salts, salt accumulation has also resulted from some other aspects of ecosystem such as climatic change and man-made agricultural activities. Therefore, further studies will be needed to define how to combine AMSF method or grain-size optimizing for amendment with crop cultivation best and more microscopic information of soil physicochemical properties.

Author Contributions: All authors contributed to this study; Y.Z., conceptualization, methodology, software, data curation, writing—original draft preparation; R.Z., resources, visualization, funding acquisition, validation; X.X., formal analysis, project administration; B.Z., investigation, supervision, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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