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Effect of polymer compounds on base ions of salinized soil

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Secondary soil salinization will result in soil structure degradation. At present, soil salinization has become one of the main factors impeding the improvement of soil fertility. This study is targeted at salinized soil, and in the study, the effect of polymer compounds on the base ions of salinized soil is analyzed through an indoor pot experiment. The results indicate that polymer compounds, including polyacrylate (M1), cellulose (M3), polyacrylate + cellulose (M4), and polyacrylamide + cellulose (M5), are able to reduce the water-soluble base ion content and electrical conductivity of severely salinized soil. The main factors of polymer compounds that can significantly affect the properties of severely salinized soil are EC, Na^+, Cl^-, SO_4^{2-}, and Mg^{2+} ions, and the main factors that significantly affect the soil EC value are Na^+, Cl^-, SO_4^{2-}, and Mg^{2+}.

Keywords: Polymer compound; Base ion; Salt content; Main component analysis

INTRODUCTION

Soil salinization is a critical factor impeding the sustainable development of oasis agriculture in draught and semi-draught areas, and it poses a tremendous threat to the stability of the oasis ecological system [1]. The secondary soil salinization of agricultural fields in oasis-irrigated areas has caused a serious deterioration of soil structure, and salt content has become one of the main factors impeding the improvement of soil fertility [2]. The damage caused by soil salinization results in restricted irrigation in draught and semi-draught areas. When the irrigating water contains salt, the salt content in soil accumulates gradually, leading to an excessively high concentration in the soil solution and resulting in physiological drought, yield reduction, or crop death [3, 4]. Currently, the soil of 32.07% of the agricultural fields in Xinjiang has been damaged by salt and alkali, resulting in decreased soil quality. The total area of farmland that has been abandoned due to soil salinization in the entire Xinjiang region is up to 133 thousand hm^2 [5, 6].

The degree of soil salinization mainly depends on the base ion content in the soil solution [7]. In general, the total salt content in soil equals the sum of various base ions in the soil solution and is used to express the magnitude of the salt content of the soil and the level of soil salinization [8]. Polymer compounds are able to effectively improve the salt-containing condition of the soil [9]. Furthermore, researches demonstrate that polymer compounds can effectively reduce the salt content and pH value of salinized soil [10, 11].

Numerous studies have been conducted on the effect of polymer compounds on improving soil quality, maintaining water and soil, increasing crop yields, and improving the environment, and there have already been some achievements [12, 13, 14, 15, 16]. However, less research has been conducted on the effect of polymer compounds on the base ions of salinized soil. In this paper, the effect of polymer compounds on the base ions of salinized soil is studied through improving the soil with a number of polymer compounds, which provides reference for the study of the draught and salt resistance of salinized soil.

MATERIALS AND METHODS

Test materials

The soil used for testing was severely salinized soil, and its basic physical/chemical properties were summarized in Table 1. The wheat used for the tests was Xinchun No. 6. Table 2 details the classification criteria of salinized soil. For the relationship between electrical conductivity (EC) and total salt content for Xinjiang soil, refer to the Total salt content $=3.51\times EC_{1:5}+0.38$ (R^2=0.95, $P<0.01$)[17]. Table 3 gives the treatments of the pot experiment of the polymer compounds used for the tests.

Test design

Potted plant (top diameter 8 cm, bottom diameter 5cm, height 12 cm) was used for the tests. The wheat seedlings were planted in soil treated with different polymers and cultivated indoors.

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Table 1. Basic Physical and Chemical Properties of Soil Used for Testing

pH	EC ($dS.m^{-1}$)	K^+ ($g.kg^{-1}$)	Na^+ ($g.kg^{-1}$)	Ca^{2+} ($g.kg^{-1}$)	Mg^{2+} ($g.kg^{-1}$)	SO_4^{2-} ($g.kg^{-1}$)	Cl^- ($g.kg^{-1}$)	HCO_3^- ($g.kg^{-1}$)	CO_3^{2-} ($g.kg^{-1}$)
8.8	5.039	0.125	2.574	0.659	1.112	0.320	0.208	0.041	0.000

Table 2. Classification Criteria of Salinized Soil.

Salt content (dry soil weight %)	Degree of salinization
<0.3	Non-salinized soil
0.3-0.5	Slight salinization
0.5-1.0	Moderate salinization
1.0-2.2	Severe salinization
> 2.2	Saline soil

Table 3. Pot Experiment Treatments.

Treatments	Polymer compound
CK	Polymer compound not used.
M1	0.2% polyacrylate
M2	0.2% polyacrylamide
M3	0.2% cellulose
M4	0.1% polyacrylic acid+0.1% cellulose
M5	0.1% polyarcylamide +0.1% cellulose
M6	0.1% polyacrylic acid +0.1% cellulose

Table 4. Main Index Measuring Method

Items	Measuring method
Moisture content	Oven drying
pH value	2.5:1 Water-soil ratio electrode
Electrical conductivity	5:1 Conductivity meter
K^+ and Na^+	Flame photometry
Ca^{2+} and Mg^{2+}	EDTA titration
SO_4^{2-} measurement	EDTA titration
Cl^- measurement	Silver nitrate titration
CO_3^{2-} and HCO_3^-	Double indicator-neutral titration

Three types of polymer compounds were selected and used for the test, and seven treatments were designed, including CK (blank), M1 (polyacrylate), M2 (polyacrylamide), M3 (cellulose), M4 (polyacrylate and cellulose), M5 (polyacrylamide and cellulose), and M6 (polyacrylate and polyacrylamide).

Each treatment was repeated three times, and 10 wheat grains are planted for each treatment. Prior to the experiment, the collected soil was dried naturally. Next, the soil was ground and evenly mixed, and then, the soil was sieved with a 2.5 mm sieve. A pot was filled with 10cm soil in layers at 1.2 $g\cdot cm^{-3}$ bulk density so that the soil in each pot weighs 0.5 kg.

Then, the polymer compound was mixed evenly with the soil at the specified mix ratio (polymer compound/salinized soil mass ratio was 0.2%, and the mass ratio of each two polymer materials mixed together was 0.1%).

Finally, nitrogen, phosphate, and potassium fertilizers were applied one time during soil filling at a 1:0.9:0.5 ratio to serve as the basal dressing. The test method was shown in Table 4.

RESULTS AND DISCUSSION

Effect of polymer compound on salt content and pH value of salinized soil

As shown in Fig. 1, organic polymer compounds significantly affect the electrical conductivity of saline-alkaline soil. As compared with soil treated with SK, the electrical conductivity of the soil treated with M2 increases significantly, and the changes of the electrical conductivity of the soil treated with M6 are not significant. As compared with CK, the soil electrical conductivities of M1, M3, M4, and M5 are significantly (*P*<0.05) reduced by 8.3%, 12.1%, 11.8%, and 8.5%, respectively. These results indicate that the polymers increase the water retention capacity of the soil as well as reduce the loss of water evaporation, which weakens the accumulation of soil salt.

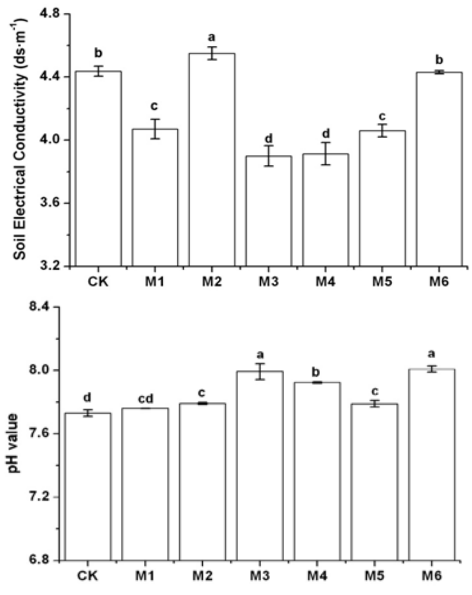

Fig. 1. Effect of polymer compound on soil electrical conductivity and ph

Note: A lower-case letter denotes significant difference (*P < 0.05*), and the same below.

Polymer compounds can increase the soil pH value significantly to a range of 7.7~8.0 with a small amplitude of change (Fig. 1). As compared with soil treated with CK, the soils treated with M1, M2, M3, M4, M5, and M6 have pH value rate increases of 0.4%, 0.8%, 3.4%, 2.5%, 0.8%, and 3.6%, respectively. For M1, the difference is not significant, This indicates that the carboxyl group at the end of the hydrophobic association monomer increases the solution viscosity under the alkaline condition, thus increasing the soil pH value.

Effect of polymer compounds on base ion of salinized soil

The effect of different polymer compounds on the cations of severely salinized soil is significant (*P<0.05*) (Fig. 2). The water soluble cation content in severely salinized soil can be reduced by treating the soil with polymer compounds. As shown in Fig. 2, as compared with the CK treatment, the M1, M2, M3, M4, M5, and M6 treatments reduce the content of water soluble K^+ in the soil by 34.0%, 21.5%, 21.5%, 21.5%, 8.7%, and 23.3%, respectively.

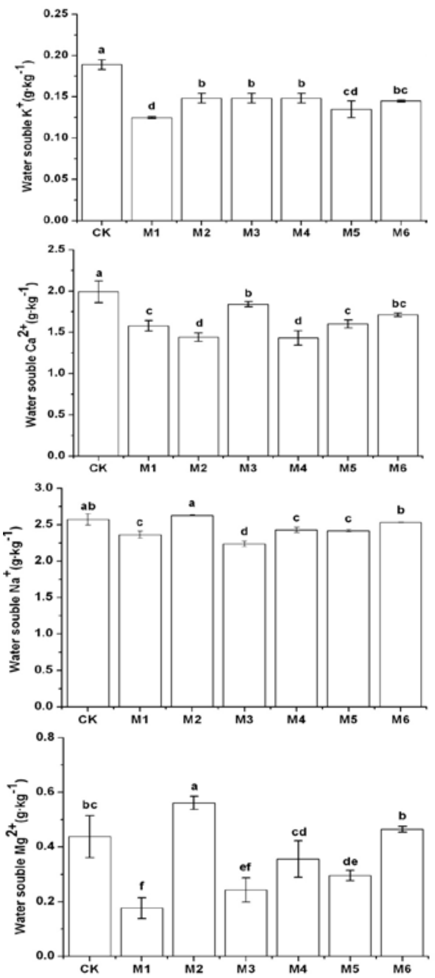

Fig. 2. Effect of different treatments on cationsthe

effect of different polymer compounds on the anions of severely salinized soil is significant (*P<0.05*).

Furthermore, the M1, M3, M4, and M5 treatments significantly reduce the content of water soluble Na^+ in the soil by 8.2%, 13.1%, 5.7%, and 6.1%, respectively. The M2 and M6 treatments do not significantly affect the water soluble Na^+ content in the soil. Additionally, the M1, M2, M3, M4, M5, and M6 treatments significantly reduce the content of water soluble Ca^{2+} in the soil by 20.7%, 27.6%, 7.6%, 28.16%, 19.7%, and 14.0%, respectively. Finally, the M1, M3, M4, and M5 treatments reduce the content of water soluble Mg^{2+} in the soil by 59.81%, 44.50%, 18.66%, and 32.54%, respectively. The effects of the M1, M3, and M5 treatments are significant. The M6 treatment does not significantly affect the water soluble Mg^{2+} content; however, the M2 treatment does significantly increase the water soluble Mg^{2+} content in soil.

These results indicate that the M1, M3, M4, and M5 treatments better reduce the base ion content in soil. The Ca^{2+} and Mg^{2+} exchange adsorption is activated by soil colloids Na^+, which indicates that the polymer compounds disperse $CaCO_3$ and $MgCO_3$. It can easily be washed out of the soil in the pot experiment because the Na^+ in the soil has a strong mobility, which results in a decrease in the soil water-soluble Ca^{2+}, Mg^{2+}, and Na^+ contents. The original sodium hydrophilic colloid becomes a loose calcium colloid, which enhances the salinization of soil structure and permeability and can significantly promote soil desalination and inhibit soil desalinization [18].

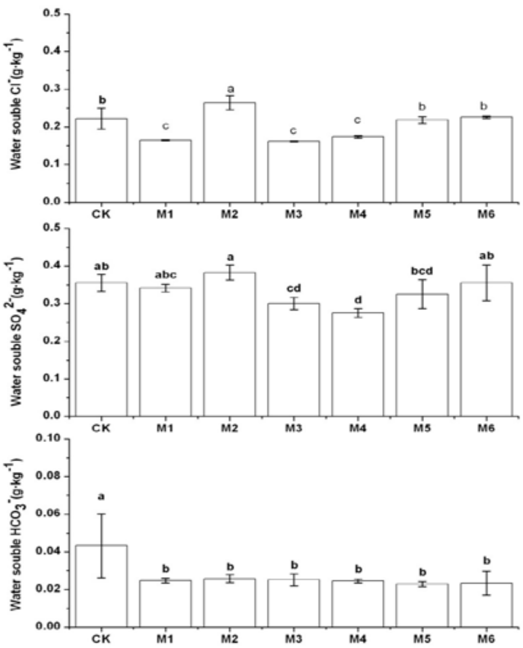

Fig. 3. Effect of different treatments on anions

However, polyacrylamides dissolve to form carboxylate ions, and due to the higher Na content, the carboxylate ions are shielded. Molecular clusters occur, and there is a corresponding reduction in apparent size, which results in lower viscosity, and polyacrylamides on soil Na^{+} and Mg^{2+} adsorption capacity decrease.

The content of water soluble anions in severely salinized soil can be reduced by treating the soil with polymer compounds. As shown in Fig. 3, as compared with the CK treatment, the M1, M3, M4 and M5 treatments reduce the content of water soluble SO_4^{2-} in the soil by 4.1%, 15.6%, 22.8%, and 8.7%, respectively, and the M3 and M4 treatments had significant effects. Furthermore, the M1, M3, M4, M5, and M6 treatments reduce the Cl^{-} content in the soil by 26.0%, 27.2%, 21.7%, 1.6%, and 1.7% respectively, and the M1, M3 and M4 treatments had significant effects. Finally, the M1, M2, M3, M4, M5, and M6 treatments reduce the content of water soluble HCO_3^{-} in the soil by 42.63%, 40.40%, 41.81%, 43.31%, 46.96%, and 45.95%, respectively. These results indicate that the M1, M3, M4, and M5 treatments better reduce the base ion content in soil. Additionally, these results demonstrate that the carboxyl group, the hydroxyl group, and the other active groups of these polymers can chelate with the salt ions in the soil and reduce the harm of the salt to the plant [19]. At the same time, the salt concentration of the soil solution can be diluted by maintaining the moisture.

Principal component analysis of salt content in salinized soil treated with different polymer compounds

Principal component analysis was performed for the base ion content, EC values, and pH values of severely salinized soil. The analysis related to main component factor loading is summarized in Table 5. For severely salinized soil, the variance contribution rate of principle component 1 (PC1) is 54.38%, and that of principle component 2 is 24.23%, i.e., the total variance contribution rate of PC1 and PC2 is 78.61%, which can basically reflect most information of the saline/alkaline factors of the soil. The positive correlations between PC1 and soil Na^{+}, Cl^{-}, and EC are very significant ($P<0.01$), and the correlation factors are 0.94, 0.88, and 0.95, respectively. Additionally, the positive correlations between PC1 and soil Mg^{2+} and SO_4^{2-} are significant ($P<0.05$). These five indicators are closely related to soil salinization, and they further indicate that the soil salinization is mainly caused by chloride and sulfate, which is probably due to the formation of parent material and water source salt ion composition.

The negative correlations between PC2 and soil Ca^{2+} and HCO_3^{-} are significant, and the correlation factors are 0.85 and 0.78, respectively. This indicates that HCO_3^{-} and Ca^{2+} also affect the soil salinization in the region to a certain extent, and they mainly affect the soil alkalinity.

Table 5. Factor Loading Matrix of Soil

Index	PC1	PC2	EC
K^{+}	0.61	0.70	0.43
Na^{+}	0.94**	-0.23	0.90**
Ca^{2+}	0.19	0.85*	0.13
Mg^{2+}	0.85*	-0.27	0.83*
SO_4^{2-}	0.82*	-0.22	0.91**
Cl^{-}	0.88**	-0.36	0.88**
HCO_3^{-}	0.58	0.78*	0.39
EC	0.95**	-0.17	1
pH	-0.42	-0.16	-0.29

Note：* means the correlation between the factor and the main component is significant on 0.05 level; ** means the correlation between the factor and the main component is very significant on 0.01 level, and the same below.

The positive correlations between EC and soil Na^{+} and SO_4^{2-} and Cl^{-} are very significant ($P<0.01$), and the correlation factors are 0.90, 0.91, and 0.88, respectively. Additionally, the positive correlation between EC and soil Mg^{2+} is significant ($P<0.05$). The positive correlations between EC and soil Na^{+}, SO_4^{2-}, and Cl^{-} are very significant ($P<0.01$), and the correlation factors are 0.90, 0.91, and 0.88, respectively. The positive correlation between EC and soil Mg^{2+} is significant ($P<0.05$). This further illustrates that the conductivity value can more accurately reflect the situation in the soil salinization area.

The effect of treatments with different polymer compounds on the salt/alkali content in severely salinized soil varies significantly. In Fig.4, the apparent difference between the polymer compound treatment and the CK treatment is indicated by the PC axis. The scores of the CK treatment and the M2 treatment on the PC1 axis are higher than those of the M1, M3, M4, M5, and M6 treatments. This indicates that the M1, M3, M4, M5, and M6 treatments significantly reduce the Na^{+}, Cl^{-}, EC, Mg^{2+}, and SO_4^{2-} contents in the soil and that the M1, M3, and M4 treatments contribute more to the reduction of ions. The score of the CK treatment on the PC2 axis is higher than those of the M1, M2, M3, M4, M5 and M6 treatments, which indicates that, on the basis of PC1, the M1, M3, M4, M5, and M6 treatments can further reduce the Ca^{2+} and HCO_3^{-} contents in the soil.

These results indicate that the carboxyl groups and other anionic functional groups are present in some polymer structures. These functional groups have strong ion exchange ability, activated soil calcium carbonate, complex metal ions, and so on [20], which changed the composition of the soil salts and salt-based ions. At the same time, for the same electrolyte, different polymers have very different holding capacities, so different polymers have quite different effects on base cations [18]. In this paper, the three polymers in the study were obtained using two mutual copolymerization methods, and the copolymer has a higher salt tolerance than the original monomer polymer because some of the groups in the copolymer are less sensitive to salt [21]. Meanwhile, the carboxyl and amide groups contained in the copolymer easily form hydrogen bonds with water, and the carboxylate ionizes with water, and the skeleton of the anionic repulsion between the negative pressures improves water absorption [11]; therefore, it has a better resistance to salt.

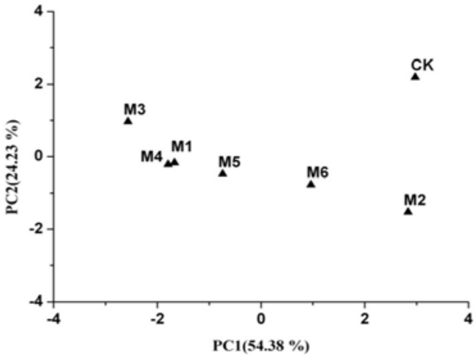

Fig. 4. Analysis of Main Saline/alkaline Components in the Soil Treated with Different Polymer Compounds

CONCLUSION

Polymer compounds can reduce the content of base ions in salinized soil. As compared with CK, polymer compounds, including polyacrylate (M1), cellulose (M3), polyacrylate + cellulose (M4), and polyacrylamide + cellulose (M5), are able to reduce the water-soluble base ion content and electrical conductivity of severely salinized soil.

The main factors of polymer compounds that can significantly affect the properties of severely salinized soil are EC, Na^+, Cl^-, SO_4^{2-}, and Mg^{2+} ions, and the main factors that significantly affect the EC value of the soil are Na^+, Cl^-, SO_4^{2-}, and Mg^{2+}.

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