EFFECT OF AMENDMENTS ON SOIL MOISTURE, SALINITY, Cl^- CONTENT, SAR, AND K^+/Na^+ RATIO

LIU, L.[1,2] – PAN, Y. H.[1*] – SHI, W. J.[2]

[1]*School of Resources and Environmental Engineering, Ludong University, Yantai, Shandong 264000, China*

[2] *State Key Laboratory of Eco-hydraulics in Northwest Arid Region, Xi'an University of Technology, Xi'an, China*

[*]*Corresponding author*
e-mail: 975954462@qq.com

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Abstract. Application amendments to saline-alkaline soils is considered to be a good practice for soil remediation. The effects of different amendments (e.g., biochar soil amendment, microorganism agents, polyacrylamide) on saline soils were investigated under a wheat-maize rotation system from 2017 to 2018 in Binzhou, Shandong Province, China. The field experiment was conducted with four soil treatments: control (CK), biochar soil amendment (BSA), polyacrylamide (PAM) and microorganism agents (MA). Surface soil (0-20 cm) moisture increased consistently under various amendment treatments compared with CK during crops growing season, especially under BSA treatment. The effect of amendments on subsoil (20-60 cm) moisture was not significant. Simultaneously, soil amendment remarkably reduced soil salinity at the 0-60 cm depth during wheat growing season especially under BSA treatment. During maize growing season, surface soil (0-20 cm) salinity decreased. Surface soil (0-20 cm) salt content was the lowest under PAM treatment, but the salt content in deeper soil (20-60 cm) changed little. Furthermore, amendments significantly reduced Cl^- content and sodium adsorption ratio (SAR), and increased K^+/Na^+ ratio. Soil moisture content was higher and salinity content was lower during maize growth season compared with those during wheat growth season. As a result, application of BSA, among the three amendments, produced the best effects. Therefore, it can be recommended for wide application in similar saline-alkali soil conditions.
Keywords: *soil moisture, salinity, amendment, soil deep profile*

Introduction

Saline-alkali land is an important reserve resource for the development of regional economies. Rational exploitation and improvement of land can relieve the pressure for arable land resources. In China, there are about 3 600×10^4 ha salt-affected soils (Yang, 2008), which is distributed in Northeast China Plain, Central-north area, Northwest inland, North China and coastal areas (Liu et al., 2007). However, the physical and chemical properties of saline-alkaline soil are poor due to the high content of salt, low natural desalination rate, heavy salinization. It has been one of the major environmental problems threatening agricultural productivity for a long time (Rengasamy, 2006). It is important to improve saline-alkaline soils especially mildly saline soils for ensuring the quantity of cultivated land, maintaining food security and promoting the sustainable development of ecological environment.

Shandong province is located in the northern coastal areas of China, which has distinctive physicochemical properties with about 592673 ha coastal saline-soil which accounts for more than 3.78% of the province area (Zheng et al., 2017). It is a typical distribution area of coastal saline-alkali soil in China. The coastal areas at the junction of sea and land, has high groundwater level, tidal erosion, frequent supply of seawater and

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evaporation-concentration, thereby a large expanse of saline-soil is formed (Rengasamy, 2006; Li et al., 2014). This coastal area has specific characteristics, primarily including harsh environmental conditions such as high salinity, shallow groundwater, a high evaporation-precipitation ratio, poor drainage and secondary salinization (Xia et al., 2019). Salt toxicity has negative effects on soil properties, including high pH, high level of sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP), poor soil structure and also low water permeability (Singh et al., 2012). Shandong province is one of the main bases of facility agriculture production in China, thereby it is essential to improve coastal saline-soil for Shandong's ecological environment and development of economy. Therefore, various methods have been investigated for the effectiveness in saline soil remediation.

In recent years, a growing number of literatures demonstrated that amendments application effectively improves soil quality in saline-alkali soils. Application amendments such as farm manure, poultry manure, compost and flue gas desulfurization (FGD) gypsum could be effective in improving plant growth through their beneficial impacts on physical, chemical, nutritional and biological properties of saline-alkali soil (Li et al., 2014; Cacini et al., 2020; Iqbal et al., 2020). These findings of amendments on soil improvement were mainly attributed to soil amendment type, soil type (soils varying in organic matter, texture and mineralogy), amendment application amount, application method and so on (Liang et al., 2019; Yu et al., 2019; Urra et al., 2020).

Biochar is considered as a potential amendment in accelerating salt-leaching process and improving saline-alkali soil quality (Chaganti et al., 2015a; Elshaikh et al., 2018; He et al., 2020; Quan et al., 2020; Zhang et al., 2020; Zhao et al., 2020) due to its unique physicochemical properties (i.e. high porosity and large specific surface area, etc.). Recently, numerous studies have been conducted to investigate the effects of biochar on improving soil quality (O'Laughlin et al., 2009). Biochar can improve soil structure by, such as reducing soil bulk density, promoting the formation and stabilization of soil aggregate, and improving hydrodynamic parameters (Wang et al., 2017; Fei et al., 2019; Zhang et al., 2020). Simultaneously, it can rapidly increase the content of soil organic matter, nitrogen, phosphorus and potassium, which is conducive to water conservation, salt leaching and salt suppression of saline soil (Yue et al., 2016). Biochar application to soil is widely recommended for a variety of reasons related to utilizability and sustainability. The application of biochar in salt-affected soil not only increases organic carbon content and nutrients, especially cationic ones (e.g. K^+, Ca^{2+}, Mg^{2+}, Zn^{2+}, Mn^{2+}), but also improves soil quality (Rajkovich et al., 2012; Usman et al., 2016; Yue et al., 2016; Zheng et al., 2018). Lashari et al. (2015) found that combined crop straw biochar with manure compost and pyroligneous solution could ameliorate salinity stress to maize and improve productivity in saline croplands in arid/semi-arid regions threatened increasingly by global climate change. Zhang et al. (2013) observed that with the increased amount of biochar, Na^+ content in saline-alkali soils has decreased by 20 times, and K^+, Ca^{2+}, Mg^{2+} and other ion contents have increased. Some scholars demonstrated that biochar has significantly contribute divalent cations (Ca^{2+} and Mg^{2+}) and facilitated the exchange of sodium from soil exchange sites. Use of biochar reduced soil salinity and alkalinity as much as or more than control treatment (Chaganti et al., 2015a). Among these applications, biochar has attracted a particularly increasing attention as an effective means in the remediation of salinity-affected soils (Ali et al., 2017; Saifullah et al., 2018).

Polyacrylamide (PAM) is a water-soluble polymer with strong cohesiveness and a strong water absorption capacity, it is used in numerous applications such as food

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industry, well drilling, and wastewater treatment as a flocculation agent (Albalasmeh et al., 2021). PAM has been widely used to modify soil structure (Lentz et al., 2015). Previous study found that addition of PAM can effectively improve soil aggregate structure, soil bulk density, soil permeability, and decrease surface and nutrient runoff (Green et al., 2004). In addition, PAM also affect saline-alkali soil structure and hydraulic properties (Fei et al., 2019). A study found that soil salinity could affect the effects of PAM on soil physical properties and water evaporation (Zhang et al., 2012). Large numbers of studies show that under brackish water infiltration, PAM application could reduce soil infiltration rate and increase soil water retention performance (Wang et al., 2014). Some studies have found that PAM also has positive effects on saline-alkali soil physical properties. PAM could increase the content of aggregates in saline alkali soil, improve soil porosity, and thus enhance the permeability coefficient of soil (Zhang et al., 2012; Zhang et al., 2017). Understanding the mechanism is also needed to keep knowledge of the contradictory effects of PAM on soil salinity. However, soil improvement by PAM is mostly used in laboratory experiments, studies carried out on field experiments are limited.

Microbial agents (MA) effectively improve soil quality, soil health, soil microbial activities and nutrient cycling (Talaat et al., 2019; Liu et al., 2020). MA was sufficient to significantly improve the number of potassium bacteria and bacillus subtilis, soil organic matter content, and available N, P, K content in salinized soil (Pang et al., 2011). Bossuyt et al. (2001) reported that microorganisms could promote the formation of soil aggregates, loosen soil after fungal repair, reduce bulk density, cut off capillary pores in the soil, increase non-capillary pores, accelerate salt leaching, and alleviate salt accumulation. Application MA in saline soil could reduce pH, EC and ESP of soil and increase soil fertility (Wang et al., 2015). In addition, MA can produce a variety of enzymes through their own life activities in saline soil (Song et al., 2007). However, the MA effects on soil salt ions, are still not clear and the improvement effect of MA on saline-alkali soils needs further research.

Amendments application to saline soils is one viable solution for improving soil quality. Therefore, in accordance with the characteristics of coastal saline soils in Shandong, three amendments were selected: Biochar soil amendment (BSA), Microbial agents (MA), Polyacrylamide (PAM). Therefore, the objectives of this study were to (1) investigate the effects of the three amendments on soil moisture and soil salt profile during 2017 to 2018 wheat-maize rotation growing season, (2) evaluate the influences of different amendments addition on soil salt content and salt ions. (3) determine the optimal amendment applied to obtain maximum soil moisture and minimum salt content in salinized Chao soil of Binzhou, Shandong Province, China.

Materials and methods

Details of experimental site

A winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.) rotation field experiment was carried out in 2017 and 2018 at an experimental research station (37° 29′ N, 118° 03′ E) for ecological and sustainability research in Binzhou, Shandong Province, China. This region has a semi-humid climate with an average annual rainfall of 560 mm, with a majority (70%) of the precipitation occurring from June through August. The mean annual air temperature was 12.7°C (Shi et al., 2019). The precipitation and average temperature from October 2017 to October 2018 are shown in *Fig. 1*. The

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precipitation during the test period was 787 mm, which was more than the multi-year average precipitation. The highest temperature is above 26℃ in July 2018, the lowest temperature was lower than 0℃ in January 2017. The groundwater table in experimental area was shallow, mostly between 0.8 and 2.4 m. The chemical properties of the topsoil (0–20 cm) in the experimental field are briefly described in *Table 1*.

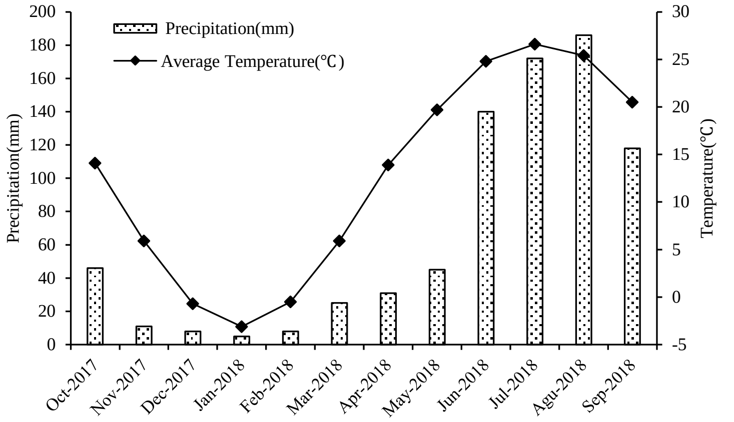

Figure 1. *Monthly climate data from October 2017 to October 2018 at the pilot site*

Table 1. *The initial salt content of topsoil (0-20 cm)*

Soil	EC (mS cm^{-1})	pH	Salt ions concentration (cmol kg^{-1})							
			CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+	Na^+
Salinized chao soil	0.83	7.93	*	0.53	2.08	0.18	0.52	1.94	0.04	20.07

Soil amendments

Three types of amendments were used in this experiment. Three amendments were biochar soil amendment (BSA), microbial agents (MA) and anionic polyacrylamide (PAM), respectively.

Biochar soil amendment (BSA), used in this study was a black particle with size of 2 mm, produced by Shanghai Shike biotechnology LTD (China), it was made from bamboo and the average pyrolysis temperature was 650°C. Microbial agents (MA) used in this study was black particle with size of 2-4 mm produced by Beijing Hengyuan Jiada technology LTD (China). It is mainly composed of nitrogen-fixing bacteria, phosphate-dissolving bacteria, potassium-resolving bacteria, bacillus, etc. MA’s carrier is organic matter. Anionic polyacrylamide (PAM) used in this study was a white powder with a molecular weight of 8 million Daltons and was produced by Chengdu YiSheng Environmental Engineering Technology Company (China).

Experimental design

The experiment was carried from Oct. 2017 to Oct. 2018, in a winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.) rotation systems. The winter wheat (*Triticum aestivum* L.) cultivar “Kaimai 18” was used in this study. Its seed were sowed

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at a density of 187.5 kg hm^{-2} on October 7th, 2017 and harvested on June 9th, 2018. The maize (*Zea mays* L.) variety "Denghai 605" was tested in the experiment. Its planting densities was 90,000 plants hm^{-2} on 15th June, 2018 and harvested on 18th October, 2018. Four treatments with three replications were established: (1) no amendment (CK), a local traditional field management regime; (2) Biochar soil amendment (BSA) treatment with 1500 kg ha^{-1}; (3) Microbial agents (MA) treatment with 1500 kg ha^{-1}; and (4) Polyacrylamide (PAM) treatment with 11.5 kg ha^{-1}. We chose these dosages according to the research results of the research group in the early stage. The field experiment was laid out in a randomized block design and each plot had an area of 7 m × 6 m = 42 m^2, and a protected zone with the width of 1 m was arranged between adjacent plots to eliminate the impact of the lateral movement of soil water and salinity. Before the wheat and maize sowing the same amount was used each time, all amendments (BSA, MA, PAM) were manually spread in each plot, and then evenly mixed into the soil with a spade to a depth of about 20 cm.

In each plot winter wheat was planted after maize harvest. No general irrigation practices were adopted, and the crop growth depended on natural precipitation. The other management practices, including weeding, and insect control were carried out based on local farmer's experience.

Soil sampling and analyses

This experiment followed a completely randomized block design with 4 treatments and 3 replicates. Soil samples were taken by soil drilling, and total soil sampling depth was 0-60 cm, with 10 cm increment. Samples were collected at different growth stages of wheat and maize including seedling (BBCH00), tiller (BBCH21), wintering (BBCH25), revival (BBCH30), heading (BBCH51), maturity (BBCH99) stage of winter wheat, jointing (BBCH30), tasseling (BBCH51) and maturity (BBCH99) of maize. (BBCH73 according to Meier (2019)).

The collected soil samples were stored in sealed plastic bags and shipped to the laboratory. All soil samples were divided into two parts, one part was oven dried (DHG-9003, Shanzhi, Shanghai, China) at 105°C for 8-10 h to determinate moisture content. The other part was air-dried and passed through a 2 mm sieve and stored at room temperature for the determination of chemical properties. After that, 10 g of each soil sample was removed, sifted (through a 1 mm sieve) and then placed in a 150 mL Erlenmeyer flask with 50 mL of distilled water to analyze salt properties. The Erlenmeyer flask (water: soil mass ratio=5:1) was stirred by an oscillator (Shanghai, China) for 10 min. After standing for 15 min, electrical conductivity (EC) of the water extract was measured using a DDS-307 conductivity meter (INESA, Shanghai, China). Soil was analyzed for soluble ions (K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-) following the methods described by Bao (2000). Soluble sodium and potassium were measured with a flame photometer (Jenway PEP-7) having Na^+ and K^+ filters, whereas Ca^{2+}, $Mg^{2+}$and Cl^- were determined by titration. Ca^{2+} and Mg^{2+} by titration with EDTA, Cl^- with $AgNO_3$ using K_2CrO_4 indicator.

Data analysis

A higher soil sodium adsorption ratio (SAR) poses a greater risk to soil. SAR are traditionally used as indices for assessing soil structural stability upon interaction with water (Bennett et al., 2016). The SAR was calculated according to *Eq.1* (McGeorge, 1954):

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$$SAR = \frac{\left[Na^+\right]}{\sqrt{\frac{1}{2}(\left[Ca^{2+}\right]+\left[Mg^{2+}\right])}} \quad \text{(Eq.1)}$$

where $[Na^+]$, $[Ca^{2+}]$ and $[Mg^{2+}]$ are expressed in cmol L^{-1}.

However, the chemical components of clay structural integrity are primarily a function of ionic valence and hydrated radius, meaning that not only Na^+ but also K^+ expected to affect clay structure on this basis (Bennett et al., 2016). The ratio of exchangeable K^+ to exchangeable Na^+ is given by the following *Eq.2*:

$$K^+ / Na^+ \text{ Ratio} = \frac{\left[K^+\right]}{\left[Na^+\right]} \quad \text{(Eq.2)}$$

where $[Na^+]$, $[K^+]$ are expressed in cmol L^{-1}.

All data were showed as the average value of three replicates. SPSS Statistics 19.0 software was used to conduct the Analysis of Variance (ANOVA). Least significant difference (LSD) tests at α = 0.05 level was used to determine significant differences between all treatments.

Results

Dynamics of soil moisture

Fig. 2 showed soil water dynamic change in soil layers of different treatments. During both crops growing season, the soil moisture varied with the applied type of amendments and soil depth.

The soil moisture during crops growing season in 0–30 cm soil layer showed strong temporal variability because the depth of infiltration under precipitation was within the range of the 0–30 cm soil layer. However, in the topsoil layer (0–10 cm), the soil moisture was greater in BSA treatment than that of the CK treatment (P<0.05). The difference of soil moisture in all treatments was significant (P<0.05). Application of amendments mainly caused a difference of soil moisture in the 0–30 cm soil layer. However, in the deep soil layers (30–60 cm depth), the difference disappeared (*Fig. 2d, e, f*).

Dynamics of soil salinity

During crops growing season, the dynamics of soil salinity within 0-60 cm depth were shown in *Figure 3*. Under CK and BSA treatments, soil salinity in surface layer (0-10 cm) increased from winter seeding to wintering and then gradually decreased. Under MA and PAM treatments, soil salinity in surface layer had a peak during winter wheat revival stage. Amendments affect infiltration of rainfall and loss of soil water from the 0-20 cm due to evaporation, which primarily affects the salt distribution in the soil profile (0-60 cm). There was almost no difference in salt concentration in all soil layer between the MA and PAM treatment during late growth stage of winter wheat and maize growing season. However, the salt content under BSA treatment were significantly lower than under CK treatment, the average salt content for the CK, BSA, MA and PAM in the 0-60 cm soil layer were 2.68 mS cm^{-1}, 1.83 mS cm^{-1}, 2.58 mS cm^{-1} and 2.09 mS cm^{-1},

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respectively. There was intensive rainfall during maize growing season, which decreased salt content in the upper soil layer and increased them in the deeper soil layer under all treatments. Compared with the growing season of wheat, average soil salt content during maize growing season decreased 47.9%, 35.6%, 56.4% and 39.7%, respectively. Soil salinity of all amendment treatments were also lower than that of CK treatment in 0-60 cm and 20-40 cm during the winter wheat seeding season. Furthermore, from maize tasseling to harvest, no significant differences in salinity were observed comparing BSA, MA and PAM treatments in these layers.

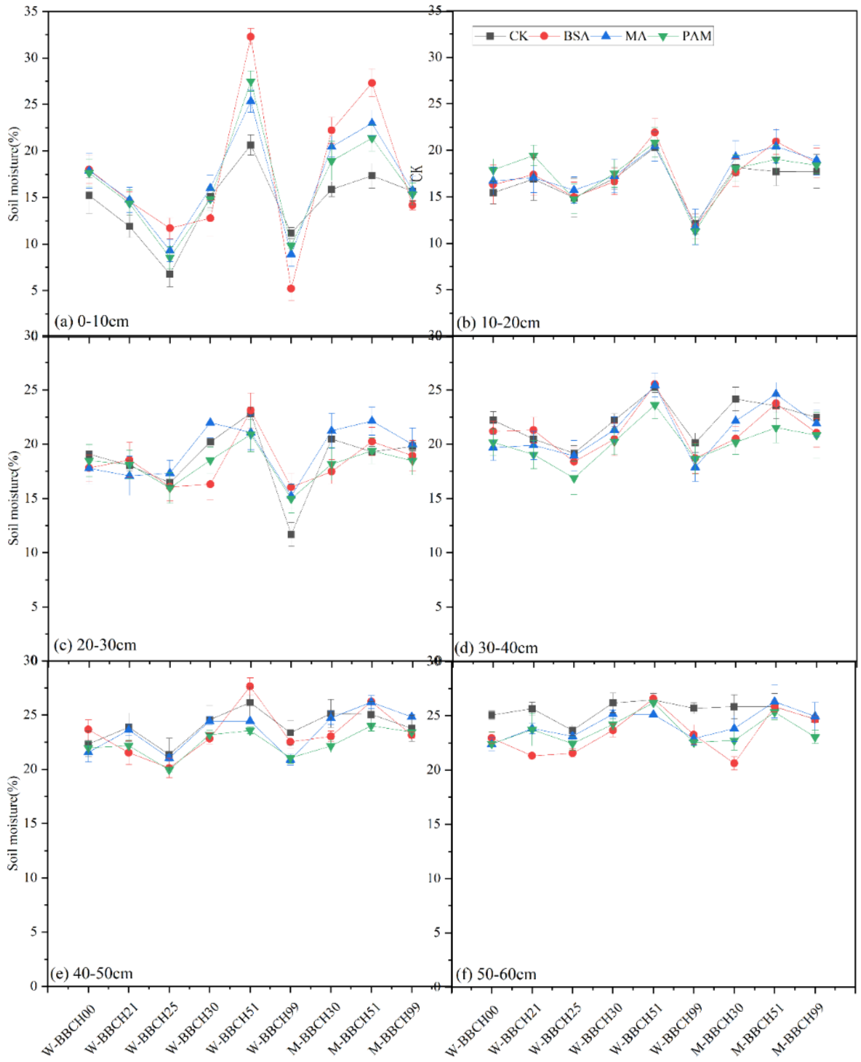

Figure 2. *Dynamics of soil moisture in the soil layers of 0-10 cm, 10-20 cm, 20-30 cm, 30-40cm, 40-50 cm and 50-60 cm under CK, BSA, MA, and PAM treatments during crops growing season. Error bar refers to the $LSD_{5\%}$ error value. W, winter wheat; M, summer maize. Seedling(BBCH00), tiller(BBCH21), wintering(BBCH25), revival(BBCH30), heading(BBCH51), maturity(BBCH99) stage of winter wheat. Jointing(BBCH30), tasseling(BBCH51) and maturity(BBCH99) of maize*

Spatial characteristics of soil Cl^- content

Fig. 4 showed the soil Cl^- content under different treatments. During winter wheat growing season, BSA decreased the soil Cl^- content. However, PAM caused a higher soil

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Cl^- content during winter wheat tillering stage. At wheat maturity, the soil Cl^- content of MA treatment was significantly greater higher than CK in 30-60 cm soil layer.

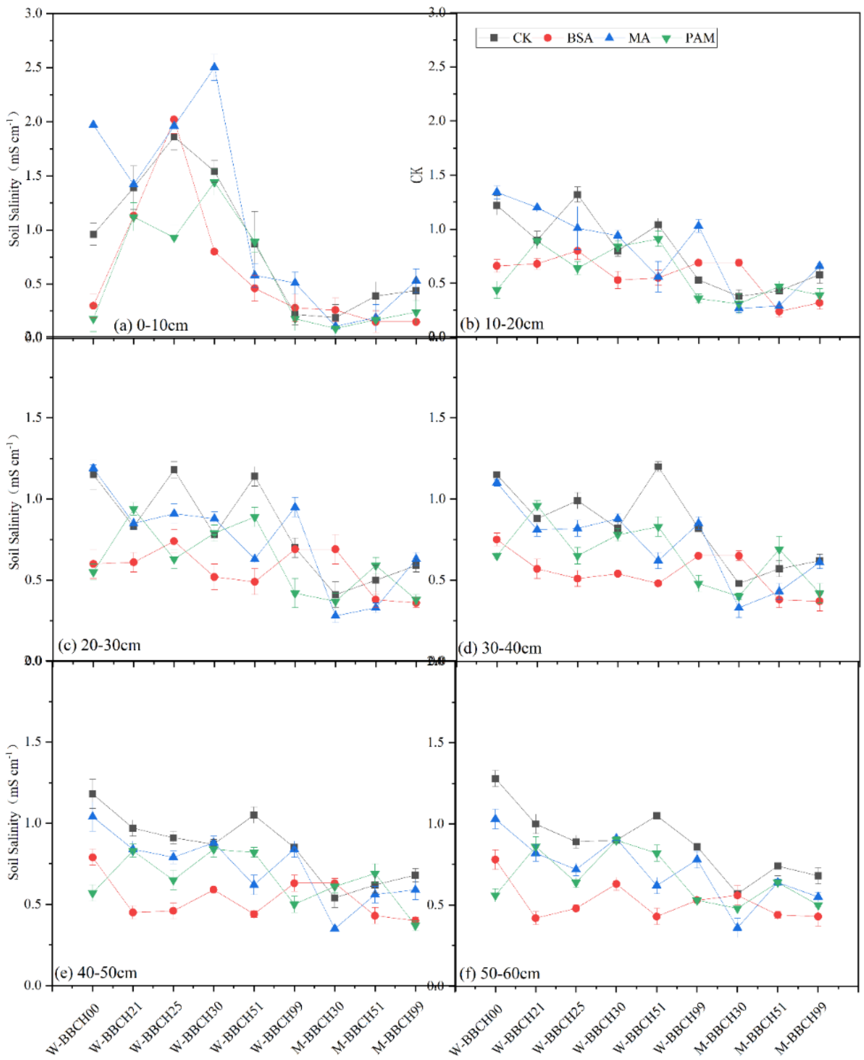

Figure 3. *Dynamics of soil salinity in the soil layers of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and 50-60 cm under CK, BSA, MA and PAM treatments during crops growing season. Error bar refers to the $LSD_{5\%}$ error value; W, winter wheat; M, summer maize. Seedling(BBCH00), tiller(BBCH21), wintering(BBCH25), revival(BBCH30), heading(BBCH51), maturity(BBCH99) stage of winter wheat. Jointing(BBCH30), tasseling(BBCH51) and maturity(BBCH99) of maize*

From winter wheat tillering to revival period, all treated surface soil (0-10 cm) Cl^- content increased and tended to migrate upward, and soil Cl^- content showed a surface accumulation pattern. From winter wheat revival to harvest, soil Cl^- content increased with increasing soil depth and tended to migrate downward, soil Cl^- content showed a bottom accumulation pattern. Throughout winter wheat growing season, at a depth of 0-20 cm, Cl^- content in all treatments greatly changed. The Cl^- content in the 30-60 cm soil layer decreased slightly($P<0.05$). At winter wheat seedling, Cl^- distribution under BSA and CK treatment profiles showed similar trends. The Cl^- content of BSA treatment was

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0.46-1.33 cmol kg^{-1}, and Cl- content in CK treatment was 2.35-2.91 cmol kg^{-1}. During this period, Cl^- content was the lowest under BSA treatment, followed by PAM treatment. During winter wheat tillering, soils under BSA, MA and PAM treatment had more Cl^- content compared with CK treatment. From winter wheat revival to maturity, the mean soil Cl^- content was lower than 1.8 cmol kg^{-1} under BSA treatment. During the winter wheat revival stage, in vertical direction, soil Cl^- content under MA and PAM treatment compared with CK treatment showed no significant difference.

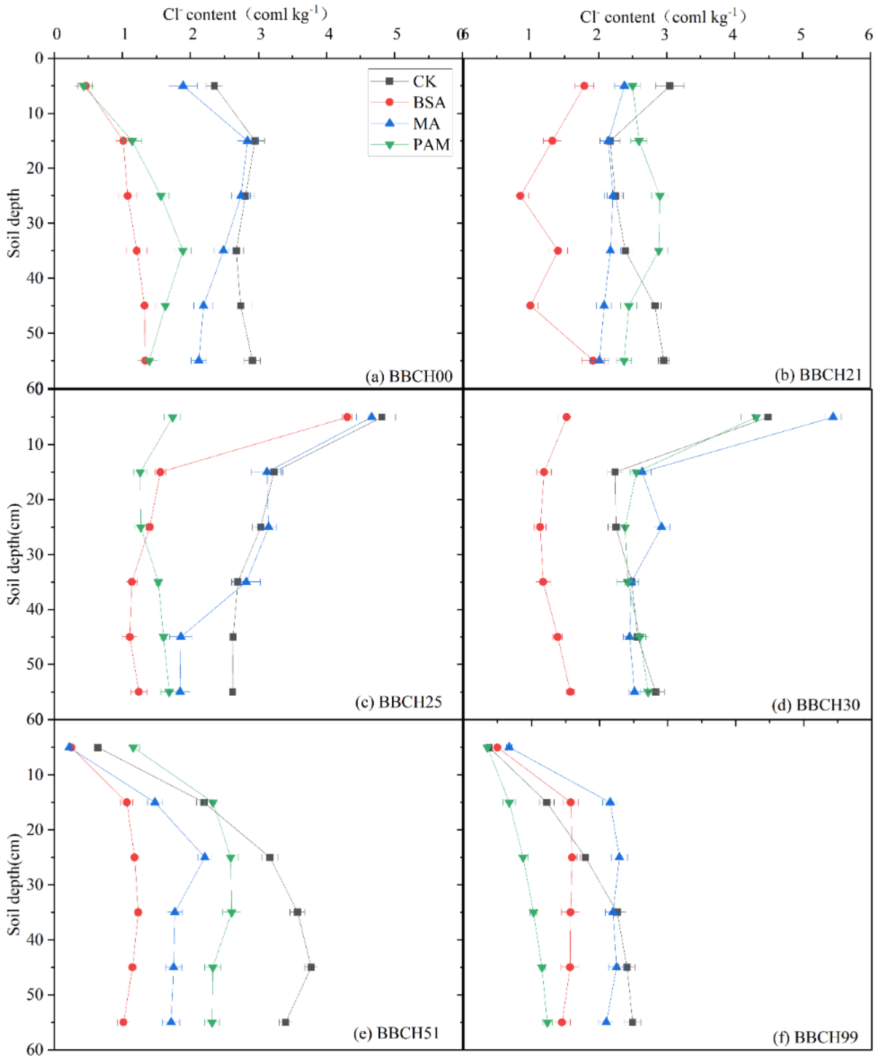

Figure 4. *Spatial characteristics of soil Cl^- content in winter wheat growth season. Error bar refers to the LSD$_{5\%}$ error value; Seedling(BBCH00), tiller(BBCH21), wintering(BBCH25), revival(BBCH30), heading(BBCH51), maturity(BBCH99) stage of winter wheat*

Soil Cl^- content under different treatments during maize growing season were shown in *Figure 5*. With increasing soil depth, soil mean Cl^- content showed the following vertical distribution characteristic: 40-60 cm > 20-40 cm > 10-20 cm> 0-10 cm, thus revealing a bottom accumulation tendency. During maize growing season, soil Cl^- content under PAM treatment was higher than CK treatment in most soil layer at jointing (BBCH30) and maturity stage (BBCH99). During tasseling stage (BBCH51), all

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treatments soil Cl^- content was lower, and there was no significant difference in all soil layers. The results indicated that BSA treatment had lower soil Cl^- content, compared to other treatments. What's more, during the whole growing season of maize, the soil Cl^- also showed the bottom accumulation tendency. In addition, soil Cl^- content at the growing season of maize was lower than that during wheat season.

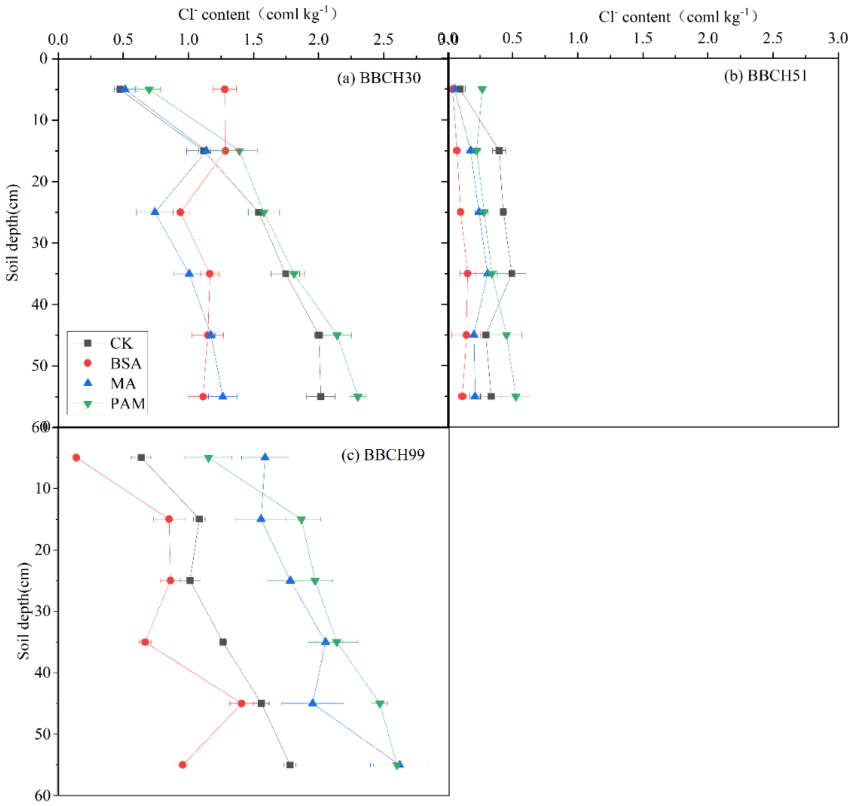

Figure 5. *Spatial characteristics of soil Cl^- content during summer maize growth season. Error bar refers to the $LSD_{5\%}$ error value; Jointing(BBCH30), tasseling(BBCH51) and maturity(BBCH99) of maize*

Dynamics of soil SAR

SAR in soil profile varied greatly among experimental year (*Tables 2,3*). During winter wheat growing season, the soil SAR increased first but then decreased. At wheat revival stage soil SAR was the highest, and maize tasseling stage soil SAR was the lowest. Soil SAR in maize growing season was lower than that in winter wheat growing season. Among these treatments, surface soil (0-10 cm) SAR under BSA, PAM and MA treatments were consistently lower than that under CK treatment throughout an-experimental-year. Compared with CK, soil SAR average decreased of BSA, MA and PAM by 48.1%, 13.5%, 18.9%, respectively ($P < 0.05$). In addition, soil SAR under BSA treatment were also significantly lower than that under CK treatment in all soil layer during crops growing season. There was a significant difference between 0-20 cm soil SAR under MA treatment and CK treatment (except during wheat wintering period). However, at depth of 20-60 cm soil layer, SAR under MA treatment showed significantly lower than that under CK treatment, whereas the difference comparing MA and CK treatment was not significant. In general, (*Table 3*) soil SAR under PAM treatment

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decreased gradually during maize growing season. From wheat tillering to maturity, the average of each soil layer SAR from PAM treatment decreased by 20-30.5% compared with CK, whereas no significant difference in ANOVA. Furthermore, no significant differences in SAR were observed between PAM and MA treatment in 20-60 cm layers during crops growing season.

***Table 2.** Dynamics of soil SAR in soil layers of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and 50-60 cm under CK, BSA, MA, and PAM treatments during winter wheat growing season. Different letters in the same column indicates significant differences between different treatments at P < 0.05*

Soil depth (cm)	Treatment	Winter wheat growing season					
		Jointing (BBCH30)	Tasseling (BBCH51)	Maturing (BBCH99)	Revival (BBCH30)	Heading (BBCH51)	Maturity (BBCH99)
0-10	CK	8.92±1.4b	29.15±1.3a	25.93±3.2a	33.91±4.2a	8.4±2.1b	5.26±1.9ab
	BSA	4.71±1.5c	9.36±1.7c	9.84±2.4c	10.38±1.3b	4.55±1.9c	8.25±2.1ab
	MA	13.66±1.9a	16.12±1.4b	15.36±3.6b	27.33±3.6a	1.02±0.9c	13.9±2ab
	PAM	5.03±2.1c	26.27±1.5a	15.84±2.1b	23.75±2.5a	36.38±3.4a	2.21±0.5b
10-20	CK	29.88±2.9a	19.88±2.2a	19.9±2.3a	27.93±2.9a	29.46±4.5a	17.3±2.1ab
	BSA	11.95±2.1b	11.16±2.3b	10.66±1.3b	18.93±1.7b	15.57±2.6b	22.46±1.9b
	MA	24.94±1.2a	17.37±2.4ab	14.45±1.1b	25.2±1.8a	14.51±2.7b	25.05±3.1b
	PAM	13.93±1.1b	26.92±2.4a	11.43±1.1b	28.11±1.5a	27.29±2.4a	11.66±2.1a
20-30	CK	29.02±1.3a	22.64±2.5a	23.13±2.4a	28.25±2.6a	26.63±3.4a	19.57±1.9a
	BSA	12.44±1.2b	10.66±4.5a	11.42±2.9b	17.89±1.5b	13.19±3.1b	21.27±2.4a
	MA	26.29±1.4a	21.92±2.4b	16.33±1.3ab	29.74±2.9a	21.91±2.6a	26.53±2.5a
	PAM	18.2±2.4a	22.51±3.1a	14.23±2.4b	29.96±3.1a	26.63±3.8b	16.14±2.1a
30-40	CK	28.25±2.3a	22.43±2.9a	23.98±2.1ab	33.14±2.5a	29.35±2.9a	21.16±1.9a
	BSA	13.09±1.4b	11.9±1.3a	11.92±1.4b	18.09±1.6b	13.87±2.6b	18.27±1.6a
	MA	29.56±2.3a	31.62±3.4b	29.02±1.5a	39.18±4.7a	25.74±2.4a	29.24±1.6a
	PAM	20.75±1.4ab	23.47±2.4a	19.78±1.7ab	26.17±2.4a	24.36±2.5a	18.65±1.5a
40-50	CK	30.51±1.1a	26.59±2.4a	26.18±1.4a	29.2±2.7a	29.47±3.4a	22.11±2.5a
	BSA	14.25±1b	10.99±2.7b	12.82±1.5b	19±2.3b	14.34±2.3b	18.16±2.9a
	MA	24.97±1.5ab	21.87±2.6a	20.67±2.4ab	23.99±2.4ab	16.22±2.5b	21.1±2.7a
	PAM	16.45±1.3b	22.04±3.1a	19.65±2.1ab	27.46±2.5a	24.05±1.4a	17.85±2.5a
50-60	CK	30.02±2.9a	25±1.3a	26.29±1.9a	31.52±3.5a	32.35±2.5a	22.97±2.3a
	BSA	12.96±1.3b	10.33±1.7b	13.27±1.7b	18.83±1.4b	12.6±1.9b	17.46±2.7a
	MA	24.21±1.3a	28.32±1.5a	20.79±1.2a	30.13±3.6a	17.17±2.6ab	14.25±1.8a
	PAM	15.66±1.2b	22.07±1.8a	20.15±1.4a	27.98±2.8a	27.32±2.3a	19.49±1.9a

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Table 3. *Dynamics of soil SAR in soil layers of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and 50-60 cm under CK, BSA, MA, and PAM treatments during summer maize growing season. Different letters in the same column indicates significant differences between different treatments at P < 0.05*

Soil depth (cm)	**Treatment**	**Maize growing season**		
		Jointing (BBCH30)	**Tasseling (BBCH51)**	**Maturing (BBCH99)**
0-10	CK	10.89±2.3a	11.54±2.3a	20.73±3.1a
	BSA	1.93±0.9b	0.46±0.2c	2.26±0.3c
	MA	4.49±0.7b	0.83±0.3c	14.27±1.4b
	PAM	2.99±0.9b	6.25±0.9b	4.89±1.3c
10-20	CK	21.32±2.3a	5.97±0.9a	19.6±2.1a
	BSA	10.34±1.9b	1.26±0.6b	8.45±0.9b
	MA	13.58±2.5b	4.3±1.1ab	20.57±2.3a
	PAM	16.48±2.9ab	8.26±2.1a	12.96±1.3ab
20-30	CK	23±3.4a	5.42±1.3b	18.68±1.5a
	BSA	11.51±3.1b	1.91±0.3b	9.23±1.4b
	MA	8.81±2.1b	10.33±1.8a	22.25±2.5a
	PAM	19.15±2.7a	8.49±1.6a	13.95±2.1b
30-40	CK	27.07±3.7a	4.47±1.3b	19.52±1.3b
	BSA	14.64±2.9c	2.59±0.8b	11.06±1.1c
	MA	18.41±1.4b	8.87±2.1a	28.8±2.3a
	PAM	19.8±2.6b	7.46±1.6a	14.96±1.2c
40-50	CK	29.28±3.2a	2.56±0.4a	21.67±3.1a
	BSA	15.06±2.5b	2.17±0.5a	11.99±1.2b
	MA	15.6±2.5b	2.7±0.6a	17.26±2.3a
	PAM	30.12±3.6a	4.7±2.1a	12.38±2.1b
50-60cm	CK	30.67±4.2a	2.95±0.4a	21.27±2.2a
	BSA	13.83±2.1b	1.31±0.3a	12.26±1.2b
	MA	18.63±1.6a	2.42±1.1a	18.63±1.3ab
	PAM	16.34±1.3b	4.46±0.8a	13.78±1.4b

Dynamics of soil K^{+}/Na^+ Ratio

As shown in *Table 4* and *Table 5*, different amendments affected soil K^+/Na^+ ratio in all soil layers during crops growing season. The K^+/Na^+ ratio of the topsoil layer (0-10 cm) could be increased significantly after application amendments. Relative to CK, an increase of BSA, MA and PAM were average 2.5, 2.9 and 4.8 times. However, in the subsoil layers (20–30 cm depth), the difference decreased. What's more, at the depth of 30-60 cm soil layer, there was no significant difference in soil K^+/Na^+ ratio comparing all

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treatments. In addition, the average of soil K^+/Na^+ ratio comparing all treatments was in the order BSA>MA>PAM>CK during experimental year.

Table 4. *Dynamics of soil K^+/Na^+ ratio in the soil layers of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and 50-60 cm under CK, BSA, MA, and PAM treatments during winter wheat growing season. Different letters in the same column indicates significant differences between different treatments at P < 0.05*

Soil depth (cm)	Treatment	Winter wheat growing season					
		Jointing (BBCH30)	**Tasseling (BBCH51)**	**Maturing (BBCH99)**	**Revival (BBCH30)**	**Heading (BBCH51)**	**Maturity (BBCH99)**
0-10	CK	0.238±0.01c	0.083±0.01b	0.091±0.03b	0.064±0.03b	0.221±0.02b	0.201±0.02b
	BSA	0.380±0.01b	0.257±0.02a	0.310±0.02a	0.316±0.02a	0.259±0.03b	0.160±0.01b
	MA	0.177±0.02c	0.273±0.01a	0.278±0.06a	0.165±0.03ab	1.577±0.04a	0.151±0.03b
	PAM	0.757±0.04a	0.245±0.03a	0.392±0.06a	0.243±0.01a	0.12±0.01b	2.249±0.01a
10-20	CK	0.039±0.01b	0.050±0.04b	0.061±0.03b	0.050±0.04b	0.041±0.01a	0.035±0.02b
	BSA	0.105±0.03a	0.136±0.01a	0.152±0.04a	0.144±0.02a	0.092±0.02a	0.071±0.02b
	MA	0.058±0.02b	0.112±0.08a	0.131±0.02a	0.058±0.03a	0.096±0.01a	0.052±0.01b
	PAM	0.106±0.04a	0.072±0.01b	0.122±0.04a	0.048±0.02a	0.078±0.01a	0.114±0.03a
20-30	CK	0.034±0.01a	0.037±0.01a	0.042±0.04b	0.034±0.01a	0.030±0.03a	0.030±0.02a
	BSA	0.085±0.03a	0.090±0.02a	0.129±0.01a	0.059±0.01a	0.063±0.02a	0.065±0.01a
	MA	0.044±0.02a	0.059±0.03a	0.064±0.02a	0.028±0.04a	0.036±0.02a	0.041±0.02a
	PAM	0.071±0.03a	0.070±0.02a	0.095±0.05ab	0.034±0.01a	0.089±0.01a	0.082±0.03a
30-40	CK	0.031±0.01a	0.026±0.03a	0.029±0.05a	0.022±0.04a	0.023±0.04a	0.025±0.01a
	BSA	0.066±0.03a	0.061±0.01a	0.079±0.03a	0.051±0.05a	0.051±0.04a	0.045±0.01a
	MA	0.041±0.02a	0.031±0.03a	0.042±0.01a	0.021±0.02a	0.046±0.02a	0.033±0.02a
	PAM	0.047±0.01a	0.054±0.04a	0.038±0.02a	0.024±0.04a	0.070±0.04a	0.054±0.02a
40-50	CK	0.029±0.02a	0.018±0.03a	0.019±0.03a	0.041±0.01a	0.019±0.03a	0.021±0.01a
	BSA	0.058±0.03a	0.049±0.03b	0.062±0.01a	0.030±0.04a	0.041±0.04a	0.032±0.02a
	MA	0.037±0.01a	0.022±0.01a	0.030±0.02a	0.020±0.02a	0.054±0.03a	0.027±0.01a
	PAM	0.050±0.03a	0.055±0.04a	0.025±0.03a	0.019±0.03a	0.045±0.04a	0.041±0.03a
50-60	CK	0.028±0.02a	0.017±0.03a	0.019±0.01a	0.018±0.04a	0.021±0.02a	0.020±0.01a
	BSA	0.053±0.03a	0.041±0.02a	0.059±0.04a	0.029±0.05a	0.046±0.02a	0.031±0.01a
	MA	0.036±0.01a	0.020±0.04a	0.025±0.02a	0.025±0.02a	0.054±0.03a	0.033±0.02a
	PAM	0.049±0.03a	0.034±0.01a	0.026±0.04a	0.020±0.04a	0.054±0.02a	0.037±0.04a

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Table 5. *Dynamics of soil K^+/Na^+ ratio in soil layers of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and 50-60 cm under CK, BSA, MA, and PAM treatments during maize growing season. Different letters in the same column indicates significant differences between different treatments at P < 0.05*

Soil depth (cm)	**Treatment**	**Maize growing season**		
		Jointing (BBCH30)	**Tasseling (BBCH51)**	**Maturing (BBCH99)**
0-10	CK	0.123±0.03b	0.079±0.02b	0.062±0.02b
	BSA	0.667±0.02a	0.991±0.01a	0.814±0.02a
	MA	1.016±0.01a	0.567±0.01a	0.379±0.03a
	PAM	1.507±0.01a	0.257±0.01a	0.996±0.01a
10-20	CK	0.043±0.03b	0.083±0.01b	0.043±0.03b
	BSA	0.108±0.03a	0.159±0.01a	0.137±0.02a
	MA	0.111±0.02a	0.138±0.01a	0.073±0.03b
	PAM	0.104±0.02a	0.070±0.01b	0.120±0.01a
20-30	CK	0.027±0.01b	0.078±0.01a	0.029±0.01b
	BSA	0.069±0.02b	0.097±0.02a	0.008±0.01a
	MA	0.108±0.01a	0.077±0.01a	0.041±0.02a
	PAM	0.083±0.03b	0.049±0.03a	0.105±0.04a
30-40	CK	0.023±0.03a	0.059±0.02a	0.028±0.01a
	BSA	0.049±0.02a	0.103±0.03a	0.059±0.03a
	MA	0.045±0.03a	0.063±0.02a	0.025±0.03a
	PAM	0.057±0.02a	0.041±0.02a	0.071±0.02a
40-50	CK	0.020±0.03a	0.042±0.02a	0.025±0.02a
	BSA	0.031±0.04a	0.065±0.02a	0.035±0.03a
	MA	0.032±0.02a	0.048±0.03a	0.028±0.02a
	PAM	0.036±0.02a	0.041±0.02a	0.085±0.03a
50-60	CK	0.019±0.03a	0.030±0.02a	0.025±0.01a
	BSA	0.039±0.03a	0.057±0.03a	0.039±0.01a
	MA	0.027±0.02a	0.043±0.03a	0.025±0.02a
	PAM	0.040±0.01a	0.041±0.02a	0.053±0.01a

Discussion

Effect of amendment on soil moisture

Coastal saline-alkali soil is characterized by low porosity, easy compaction, and poor water and air permeability. The key to improve coastal saline soil is to improve soil moisture (Jia et al., 2017). Soil moisture is critical to plant growth and soil salinity leaching and forms one of the important physical properties used to evaluate the quality of saline-alkali soil. In present study, the applied field management efficiently increased retention of soil moisture, and reduced soil salinity levels. It is widely reported that

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application of MA have beneficial effects on soil properties by reducing soil bulk density (Gill et al., 2009; Clark et al., 2007). In this study, at the depth of 0-20 cm soil layer, moisture was higher under MA treatment compared with CK treatment. PAM is commonly adsorbed by soil through cationic bridges between soil and polymer anionic groups, and multivalent cations in the soil solution would bridge the negatively charged soil particles and polymers together (Laird, 1997; Chen et al., 2016). The effect of PAM on improving soil water holding capacity has been confirmed in many literatures (Tadayonnejad et al., 2017; Albalasmeh et al., 2021). In our experiment, PAM treatment consistently increased 0-20 cm layer soil moisture compared with CK during crops growing season. However, at the depth of 20-60 cm soil layer, there was no significant difference in soil moisture content between PAM and CK treatments. We used dry granular PAM, surface application dry granular PAM without a source of electrolytes was not effective in maintaining a good infiltration rate, 20-60 cm soil moisture content did not increase significantly (Abrol et al., 2013).

Effect of amendment on soil salinity

Biochar can hasten salt leaching and thus decrease the time required for reducing salt concentration to a level suitable for growing plants (Zhao et al., 2020; Zhang et al., 2020; He et al., 2020). In our study, in surface layer (0-20 cm), soil salinity content under BSA treatment was lower than that under CK treatment during crops growing season. But in deep soil layer (20-60 cm), the difference gradually decreases. This might be due to the that the application of BSA can improve salt-leaching efficiency of surface salts as explained by Yue et al. (2016).

Applying MA have beneficial effects on decreasing salt concentration, improving soil fertility and enhancing soil microbial activity (Clark et al., 2007; Gill et al., 2009). At winter wheat maturation stage, only 0-10 cm soil layer was desalination area, the scope of the desalination area was small. At maize matured, soil desalination rate increased from 17% to 30%. MA were rich in organic matter, addition of MA to soil could increase soil colloid concentration and EC. Moreover, the influence mechanism of MA on soil salinity needs further studies.

Application of PAM can effectively improve soil physical structure. After contacting with water, hydration occurs through these groups and osmotic pressure can absorb more water, improve the soil water retention capacity, and then reduce the salt content of the soil colloid (Zhang et al., 2012). In this study, at the depth of 0-60 cm soil layer, soil salinity under PAM treatment was lower than that in CK. Previous studies have found that PAM could improve the capillary porosity of saline-alkali soils, thereby increasing salt-leaching efficiency.

Effect of amendment on soil salt ions

Chloride ion (Cl^-) is often used to indicate the salinization degree of saline soil as the main reference index for the classification and improvement of saline soil (Bao, 2000). Cl^- is the anion with the highest content of salinized Chao soil. In this study, we found that Cl^- content in 0-10 cm layer soil is contradictory to soil moisture content, which also confirms the characteristics of effective Cl^- leaching. Compared with CK, Cl^- content in surface soil layer (0-20 cm) decreased after applying amendments. Soil profile Cl^- content under BSA treatment was lower than that under CK treatment during crops growing season. It is demonstrated that biochar has improved the infiltration characteristics of soil

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moisture, which in turn promoted the efficiency of water leaching of Cl^- (Zhang et al., 2019).

Soil SAR depend on the relative proportion of Na^+ and Ca^{2+} in soil solution. Soil porosity is expressed in terms of SAR, with high SAR values having the potential for deterioration of soil structure, low infiltration rate, specific-ion effect, and deficiencies of several micro and macro nutrients (Murtaza et al., 2006). In this study, we found that the change of soil SAR was consistent with soil salt content. In short, the soil SAR appears in order of BSA> MA> PAM> CK. Compared with CK, BSA can significantly reduce soil SAR during crops growing season. Many studies have confirmed the beneficial impact of BSA on decreasing SAR of saline soils (Lashari et al., 2013; Chaganti et al., 2015b). BSA could decrease SAR directly by providing exchangeable Ca^{2+} to replace Na^+ on the soil colloids, similar results were observed by Lashari et al. (2013) and Chaganti et al. (2015b). At the same time, BSA may increase partial pressure of CO_2 in the rhizosphere to mobilize Ca^{2+} from calcareous soils for replacing Na^+ from the soil colloids (Jalali and Ranjbar, 2009). PAM has no significant effect on soil SAR during the growth season of winter wheat, but it can significantly reduce soil SAR during maize growing season. In this study, we used anionic-PAM. According to Gungor's (2001) research, when the application amount of PAM is too large, the presence of exchangeable Na^+ will reduce the viscosity of the PAM aqueous solution, thereby increasing the rate of soil moisture infiltration. Since there was more precipitation in the maize growing season in field experiment area, application of PAM could improve the salt leaching efficiency and improve the effect of salt leaching. Therefore, during the growth season of maize, the SAR of soil was low. No matter what crops were grown, MA had no obvious effect on soil SAR. From the aspect of soil SAR, MA had no significance effect on improving salinized soil. In short, the interaction between microbial agents and soil salt ions needs further research.

Exchangeable K^+ can create similar effects as Na^+ on soil structure, but it has received less attention than Na^+ because K^+ amounts are typically low in salt-affected soils (Rengasamy, 2011). In other words, it is believed that K^+/Na^+ affect clay structure.

In present study, we investigated K^+/Na^+ in the soil during crops growing season to analyze the effect of amendments on soil salt ions. The K^+/Na^+ ratio of the topsoil (0-10 cm) could be increased significantly after application amendments. A conclusion can be drawn that the three amendments had beneficial effects on soil quality.

MA could improve the soil porosity and aggregate structure, increase soil permeability, and promote plant root growth; on the other hand, it relies on the beneficial microbial flora, organic and other substances it contains to increase the amount of soil microorganisms, and participate in humus formation (Pang, 2011). In this study, MA was rich in organic materials and a variety of microorganisms. Previous studies have demonstrated that application of organic materials to saline soils has been shown to accelerate Na^+ leaching and reduce exchangeable sodium percentage (ESP) and electrical conductivity (EC) (Tejada, 2006; Lopez-Valdez el al., 2010). In this study, SAR of the surface soil (0-10 cm) significantly decreased, especially during maize growing season.

Earlier studies demonstrated that the presence of Na^+ in soil could decrease the viscosity of PAM aqueous solution, and improve water infiltration and promote salt leaching (Silvestri, 2005; Tho, 2008; Liu et al., 2015a,b). PAM was an anionic polyamide, which may possess ability to absorb soil cations. In present experiment, at the depth of 0-20 cm, K^+/Na^+ value of the soil after applying PAM was significantly increased. In this study, surface soil moisture gradually decreased while soil salinity gradually increased

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under all treatments, and both showed a strong temporal variability, which was related to the seasonal precipitation and evaporation patterns (*Fig. 3*). Previous studies have demonstrated that soil salinity in coastal saline area has obvious seasonal variability, which is generally characterized by strong accumulation in winter and spring, and desalination in summer and autumn (He et al., 2015; Feng et al., 2018). This is mainly because the summer and autumn in the study area were rainy seasons, and the abundant precipitation makes the soil salt gradually leaching to the deeper layer. While the winter and spring were dry seasons, with less rainfall and strong evaporation, makes the soil moisture evaporates violently, and the salinity accumulates to the surface rapidly (Wu et al., 2009; Feng et al., 2018). In our experiment, winter wheat was sown in October 2017 and harvested in June 2018, with low rainfall and high evaporation. Summer maize was sown in June 2018 and matured in October. The whole growing season was in the rainy season with more rainfall. Therefore, during maize growing season, soil had higher water content and lower salt content than that during wheat growing season. At the same time, we observed soil salinity gradually increased and accumulated to the surface soil during early growing stages of wheat (from seedling to revival), which might attribute to the rapid rise of temperature and increase of evaporation in spring, making soil salinity accumulate to the surface (*Figs. 1 and 3*). Soil moisture and salinity also varied with different treatments in surface soil. In this experiment, we used three different properties of amendments. A consistently lower salt content was observed in the 0-40 cm soil layer treated with BSA than that of CK treatment (*Table 2*). However, soil moisture of BSA treatment decreased in the later growth stage, whereas the soil salinity increased rapidly (*Figs. 2 and 3*). This might be owing to the combined influence of transpiration and evaporation as explained by Huo et al. (2017). It should be noted that the water supply from deep soil layer (40-60 cm) was sufficient as no amendments were applied under CK treatment, and consequently a relative stable soil moisture and significantly higher soil salinity were observed for CK treatment during crops growing season.

Conclusions

The soil moisture and salt spatial distribution characteristics during wheat-maize rotation growing season were investigated in saline soil region. A conclusion can be demonstrated that all applied amendment treatments had significant effects on dynamics of soil moisture, soil salinity, Cl^-, SAR and K^+/Na^+ ratio. During the growing season, all amendment treatments increased the surface (0-20 cm) soil moisture compared with CK. Simultaneously, amendments decreased soil salinity at 0-20 cm depth. Moreover, soil amendment treatment apparently promoted salt-leaching, reduced Cl- and SAR, increased K^+/Na^+ ratio. During crops growth season, the maximum water retention of soil and salt leaching were obtained in 1500 kg $ha^{-1}$for BSA treatment. Therefore, when chemical measures were used to improve saline alkali land in Binzhou, Shandong, it is recommended to prioritize the application of biochar soil amendment (BSA), under the dosage of 1500 kg ha^{-1}, to improve soil quality and prevent secondary salinization. Our results provide insights into the effects of four different amendments added to saline-alkaline soils under a wheat-maize rotation system. Further investigations are suggested to find the best mixture of amendments to improve saline-alkali soil and crops production.

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