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Effects of biochar and peat on salt-affected soil extract solution and wheat seedling germination in the Yellow River Delta

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ABSTRACT

Salt-affected soils are widely distributed in arable croplands, so it is important to reclaim these soils. In this study, the effects of different biochar/peat doses (1, 3, and 5%) on 1:5 salt-affected soil: water extract solutions with different soil salinity levels after seven days shaking; and on winter wheat seedling growth after 80 hours are discussed. Results showed that the SAR and $\text{Cl}^-/\text{SO}_4^{2-}$ ratio varied because of the changes of ion composition in the soil extract solution caused by the addition of biochar and peat. The maximum length of root and sprout of wheat grown in S1 (very slightly saline) soil extract treated by biochar/peat were 8.0/7.14 and 4.86/4.50 cm, respectively. The average length of wheat root and sprout grown in S2 (moderately saline) soil extract treated by peat was higher than that in soil treated by biochar. The results indicated that biochar and peat modified the ion composition of salt-affected soil extract solutions, as well as that of wheat. The abundant beneficial ions K^+ or Ca^{2+} in biochar/peat might be beneficial to reclaim the salt-affected soil, and the exogenous ions altered the composition of the soil solution to promote the seedling growth or enhance the resistance of plants to the salt stress. Moreover, cation exchange took place among soil, biochar/peat, and soil solution. The proportion of harmful Na^+ declined (SAR decreased) in the soil solution, which could be beneficial for the reclamation of the salt-affected soils.

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Amelioration; biochar and peat; salt-affected soil; wheat germination; Yellow River Delta

Introduction

Salt-affected soils are distributed in arable croplands worldwide (Mahmoodabadi et al. 2013; Rengasamy 2006). It is estimated that nearly 9.32×10^8 ha of land is undergoing

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salinization and sodicity globally (Wong et al. 2010). Climate change, seawater intrusion, and unreasonable irrigation can trigger salinization.

The salt-affected soils usually show a poor soil structure with reduced hydraulic conductivity, aggregate stability, and aeration because of the excessive Na^+ in the soil solution or the exchange phase to cause clay swelling and dispersion (Rengasamy and Olsson 1991; Suarez, Wood, and Lesch 2006). Moreover, plant growth is inhibited by excessive salts, especially during the germination and seedling stage. High salt levels cause higher osmotic pressure of the soil solution, difficulty in water absorption, ion toxicity, and ion imbalance, which further reduces nutrient uptake (Amini et al. 2016; Meena et al. 2016).

Methods for ameliorating salt-affected soils mainly include drainage facilities, chemical amendments, and phytoremediation (Mau and Porporato 2016). Alternative solutions for ameliorating salt-affected soils are limited in areas with scarce water sources. Application of organic amendments is an option to improve soil fertility as well as benefit plants' salt tolerance. Biochar and peat, materials containing a large quantity of carbon, have attracted considerable attention as soil amendments.

Biochar is generally produced from residuals under the complete/partial absence of oxygen at temperatures ranging from 300 °C to 1000 °C (Lehmann 2007). Many studies have proved that biochar is capable of improving the properties of salt-affected soils (Drake et al. 2016; Ali et al. 2017; Abbas et al. 2018), enhancing the growth of such crops as beans and potatoes, contributing to antioxidant activities, increasing absorption of K^+ , and reducing Na^+ uptake (Akhtar, Andersen, and Liu 2015; Farhangi-Abriz and Torabian 2017). Peat, more like a slow-burning product, is produced by decay/decomposition of plants or organic matter (Joosten and Clarke 2002). Peat with a high content of humic acid often has large adsorption capacity, chelating, cation exchange capacity, and salt balance control, thereby enhancing physiology and the drought/disease resistance of crops after application.

The Yellow River Delta has a large amount of salt-affected land that has farming potential. Peat resources are abundant in the Yellow River Delta, while many agricultural wastes, such as straw and residuals/branches of fruit trees, could be made into biochar. Therefore, the application of biochar and peat can have important economic and practical significance for the improvement of salt-affected soils in this area. Although biochar and peat have been applied in ameliorating salt-affected soils, the mechanisms of ameliorating are not yet clear. A hypothesis was made in this study that different properties, such as pH, specific surface, cation exchange capacity (CEC), and ion components of biochar and peat could have different effects on the amendment of salt-affected soil. It was assumed that the application of biochar and peat could modify the composition of the solute via dissolution and ion exchange to have a further impact on plant germination and growth. Therefore, in this study, a model experiment was conducted with extreme conditions on soils and wheat germination to clarify the expected changes.

Materials and methods

Salt-affected soils, biochar, and peat

The study area is located in the Yellow River Delta of China (N 37°41'17.25", E 118°36'03.76"), which is a typical ecologically fragile region with obvious seasonal

drought (Mao et al. 2016) with 78% of annual precipitation (564 mm) occurring from June to September (<http://www.dongying.gov.cn/html/xzqy/index.html>). Salt-affected topsoil (0–20 cm) samples were collected and coded as S1/S2/S3 in November 2016 after winter wheat sowing. Air-dried soils were crushed to pass through the 2 mm sieve. The pH of S1/S2/S3 was determined to be approximately 7.65/7.56/7.02, all less than 8.5. The electrical conductivity (EC) of S1/S2/S3 was 0.46/3.04/10.64 dS/m at a soil–liquid ratio of 1:5 and the converted EC_e (soil saturation extract for EC analysis) was 3.51/17.02/81.08 according to a previous study (Shahid, Zaman and Heng 2018). Based on the USDA classes, as nonsaline (EC_e <2 dS/m), very slightly saline (EC_e 2–4 dS/m), slightly saline (EC_e 4–8 dS/m), moderately saline (EC_e 8–16 dS/m), and strongly saline (EC_e >16 dS/m) (USSL Staff 1954), S2 was classified as moderately saline, because its EC was slightly higher than the threshold value of moderately saline class. S1 and S3 were classified as very slightly saline and strongly saline soil, respectively (Table 1). The texture of the soil was loam according to the taxonomy of the United States Department of Agriculture (USDA) (Shirazi and Boersma 1984). The organic matter content was 20.62/19.84/11.22 g/kg.

The biochar used in this study was derived from corn cobs with limited oxygen at 400 °C, while the peat was purchased from Jia He Co., Ltd. (Heilongjiang Province, China, <http://www.ljhhumicacid.com/ps-4.html>). Both biochar and peat were dried at 40 °C, crushed by a crusher and agate mortar, and then passed through a 0.15 mm dry sieve.

Experimental design

Biochar and peat were selected to amend salt-affected soils (S1, S2, and S3). After considering the cost and results of previous studies (Luo et al. 2016; Zhang et al. 2018) in the Yellow River Delta, four application doses (Control, T1, T2, and T3 treatments, with 1, 3 and 5% amendment, respectively) using three replicates were utilized. Soil or soil-amendment mixtures with weight of 8 g and 40 ml of deionized (DI) water were placed in a 50 ml centrifugal tube. Therefore, soil–liquid ratio was 1:5, and the liquid extract was filtered by a 0.45 µm membrane after being shaken at 300 rpm/min for seven days. In addition, pure biochar/peat was also treated according to the same procedure.

Given that wheat is one of the main food crops in this area, germination tests of winter wheat were performed to evaluate the effect of biochar and peat on ameliorating salt-affected soils. The soils (S1, S2, and S3) were mixed with the amendments at 0% (CK, control), 1% (T1), 3% (T2), and 5% (T3) dose and 20 g of amended soil was placed on the surface of Petri dishes. Deionized water was sprayed to reach the soil water content of 20% and the treated soils were incubated for three days before germination under air-permeable membrane cover to prevent water evaporation. The winter wheat (Ji mai #22) seeds were soaked in 5% NaClO₃ for 5 min for disinfection. Afterward, 30 plump seeds were selected for each dish. The dishes were placed in an artificial climate chest at 23 °C for 80 h. The lengths of root and sprout, as well as germination ratio, were determined at the end of the experiment. Seeds having roots at least 2 mm long were considered as germinated.

Table 1. Basic properties of the salt-affected soil and content of soluble cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) in soil solution.

Soil	Soil salinity	pH	EC (dS/m)	Organic matter (g/kg)	Sand (%)	Silt (%)	Clay (%)	Na^+ (mg/g)	K^+ (mg/g)	Ca^{2+} (mg/g)	Mg^{2+} (mg/g)	Cl^- (mg/g)	SO_4^{2-} (mg/g)
S1	Very slightly	7.65	0.46	20.62	23.87	33.30	42.82	0.12	0.04	0.17	0.03	0.06	0.07
S2	Moderately	7.56	3.04	19.84	20.24	39.88	39.88	2.09	0.04	0.39	0.17	3.48	0.77
S3	Strongly	7.02	10.64	11.22	15.14	29.95	54.91	6.25	0.05	2.88	1.56	18.60	1.71

Note: Na^+ , K^+ , Ca^{2+} , Mg^{2+} was determined at the liquid-soil ratio of 5:1 and same to EC (electrical conductivity) and pH. The organic matter was determined by the method of potassium dichromate heating (Bao 2005).

After germination, wheat seedlings were cleaned with DI water and dried using absorbent paper. A certain number of fresh wheat seedlings were cut into approximately 0.3 cm length, 10 ml of DI water was added, boiled for 10 min, and then filtered with a 0.45- μm filter membrane. Concentrations of cations (Na^+ , Ca^{2+} , Mg^{2+} , and K^+) and anions (Cl^- and PO_4^{3-}) of the seedling extracts were determined.

Analysis methods and data processing

The soluble salt content of the soil extract solution was determined by the residual drying method, CEC was determined using a sodium acetate flame photometry method, the organic matter in the soil was determined by a potassium dichromate heating method, and the total mass of Na^+ , Ca^{2+} , Mg^{2+} , and K^+ in biochar and peat digestion extract was determined according to the $\text{HNO}_3\text{-HClO}_4\text{-HF}$ method (Bao 2005). Soluble cations (Na^+ , Ca^{2+} , Mg^{2+} , and K^+) and anions (Cl^- , SO_4^{2-} , NO_3^- , and PO_4^{3-}) of soil extract solution, biochar, peat, or plant extracts were analyzed by ion chromatography (Dionex ICS3000, Dionex Corporation, USA). The contents of $-\text{COOH}$ and phenol $-\text{OH}$ in biochar and peat were determined through a titration method provided by the International Humic Substances Society (<http://humic-substances.org/>). Image J was employed to measure the lengths of roots and sprouts. Germination was confirmed when the bud length exceeded half of the root length.

Data were analyzed by Origin 8.1, Excel 2003, and SPSS 19.0. One-way analysis of variance, followed by Duncan's multiple comparison test ($p < 0.05$), was performed to determine the difference of the soil analysis results.

The SAR was calculated by the Eq. (1) and the concentrations of the involved soluble cations were expressed in mmol/l (Shaygan, Reading, and Baumgartl 2017).

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{1/2 \times [\text{Ca}^{2+}] + [\text{Mg}^{2+}]}} \quad (1)$$

The germination ratio was calculated by the Eq. (2).

$$\text{Germination ratio (\%)} = \frac{(\text{number of germinated seeds within 80 h})}{(\text{total number of seeds})} \times 100 \quad (2)$$

Results

Properties of biochar and peat

The chemical compositions and basic properties of biochar and peat are presented in Table 2. The amount of K^+ , which plays an important role in crop growth, reached 18 mg/kg in the biochar digestion solution. Both amendments had abundant carbon to increase soil organic materials significantly, even when the application dose is small. Phenol ($-\text{OH}$) and carboxyl ($-\text{COOH}$) are important oxidized functional groups. They are involved in ion exchange capacity, absorption, and complexation (Saifullah et al. 2018) with the salt in soil solution.

The contents and composition of soluble ions in the biochar and the peat extract solution were different (Table 2). Na^+ and K^+ accounted for approximately 95% of the soluble

Table 2. Chemical compositions and basic properties of biochar and peat.

(a) Basic chemical characteristics of biochar and peat											
Amendment	Total mass (mg/g)				-COOH (mol/kg)	Phenol-OH (mol/kg)	Ash (%)	C (%)	N (%)	H (%)	S (%)
	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺							
Biochar	7.81	18.84	19.00	5.38	1.85	1.63	64.02	46.92	0.58	3.07	0.14
Peat	2.01	2.99	3.69	2.57	0.72	1.71	18.00	49.73	2.56	0.07	0.76

(b) Water extract composition of biochar and peat										
Water extracts	Na ⁺ (mg/g)	K ⁺ (mg/g)	Ca ²⁺ (mg/g)	Mg ²⁺ (mg/g)	Cl ⁻ (mg/g)	SO ₄ ²⁻ (mg/g)	CEC cmol/kg	pH	EC (dS/m)	
										Biochar
Peat	0.27	0.07	0.97	0.47	0.01	4.93	75.97	4.57	1.70	

Note: EC (electrical conductivity) and pH was determined at the liquid-soil ratio of 5:1. Total mass of was Na⁺, K⁺, Ca²⁺, Mg²⁺ determined according to HNO₃-HClO₄-HF method (Bao 2005); CEC (cation exchange capacity) was determined by a sodium acetate – flame photometry method (Bao 2005). -COOH and phenol-OH were important oxidized functional groups determined through titration method provided by the International Humic Substances Society (<http://humic-substances.org/>).

cations in the biochar water extract, while soluble cations in the peat extract mainly consisted of Ca²⁺ and Mg²⁺. Soluble Cl⁻ and SO₄²⁻ were the main anions in the water extracts of biochar and peat. Moreover, the water extract of biochar was alkaline (pH = 7.99) because of the metal oxide, while that of peat was acidic (pH = 4.87) in the presence of humic substances. High concentrations of soluble Na⁺ and K⁺ of biochar resulted in a much higher EC than that of peat, which probably caused the increase in soil EC after application.

The surface morphologies of biochar and peat are provided in Figures 1(a, b), respectively. The porous and carbonized plant tissues were shown in the surface morphology of biochar. The surface morphology of the peat was denser and more uniform. The oxygen-containing functional groups were the most characteristic groups for biochar and peat (Figure 1(c)). A large number of functional groups were present on the surface of biochar and peat, such as the carboxyl group with C=O (1694 cm⁻¹), aromatic C=C (1600 cm⁻¹), and C-H (1000 cm⁻¹), which could contribute to ion exchange and form complexes with cations.

EC, pH, and ion composition of soil extract solution

EC is thought to relate positively to the concentration of soluble ions to reflect the salinity of saline soil roughly. The biochar and peat used in this experiment contained abundant water-soluble ions (Table 2), which resulted in an increase of soil EC ($p < 0.05$) in S1 (very slightly saline) and S2 (moderately saline) soils. The EC values of S1 and S2 soils with the amendments increased by 40–50% and 5–7%, respectively. The effect of amendments on the EC of S3 (strongly saline) could be neglected because of the high background salt content, although a slight decrease in S3 was observed at high doses, which demonstrated the potential capacity of fixing soluble salts.

The soil pH indicates the acidity and alkalinity of soil and affects the growth of crops. Contrary to an earlier study that reported an increase in soil pH after biochar application (Saifullah et al. 2018), the addition of biochar did not significantly change the pH

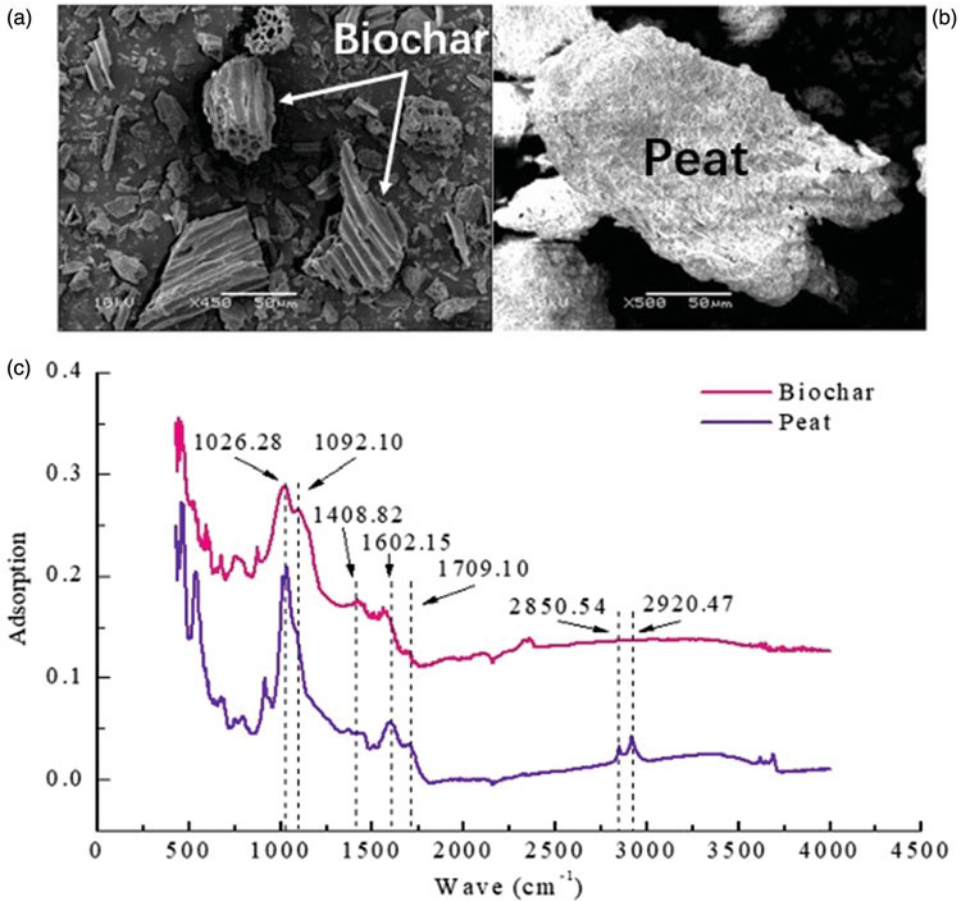


Figure 1. Scanning electron-microscope image of biochar (a) and peat (b) as well as FTIR of biochar and peat (c).

of salt-affected soils in this study (Figure 2). Peat with different addition doses changed the pH of soils by approximately 0.1 unit. The pH of soils in all treatments was below 8.0, indicating non-alkalinity of the soil.

The addition of the biochar or peat modified the ionic composition (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , SO_4^{2-} , and Cl^-) and concentration of soil extract solutions (Figure 3). The results showed that the concentration of soluble Na^+ and K^+ was linear with the dose of biochar ($R_{\text{Na}}^2=0.999$; $R_{\text{K}}^2=0.994$). Concentrations of Na^+ and K^+ in T3 (at 5% addition dose) increased by 80 and 310% compared with CK. The divalent cations in the soil extract solution increased owing to abundant soluble and exchangeable Ca^{2+} and Mg^{2+} in peat. Concentrations of Ca^{2+} and Mg^{2+} doubled at the 5% addition of peat compared with CK, reaching 2.4 and 0.76 mmol/l, respectively. Changes of the cation composition in higher salinity S2 and S3 soil extract solutions were less affected by biochar and peat treatments (Figure 3). Furthermore, soluble K^+ and Na^+ increased with the addition of the biochar in S2 ($R_{\text{K}}^2=0.994$; $R_{\text{Na}}^2=0.870$), while Ca^{2+} and Mg^{2+} increased with peat dose ($R_{\text{Ca}}^2=0.997$; $R_{\text{Mg}}^2=0.971$). In addition, Na^+ content declined

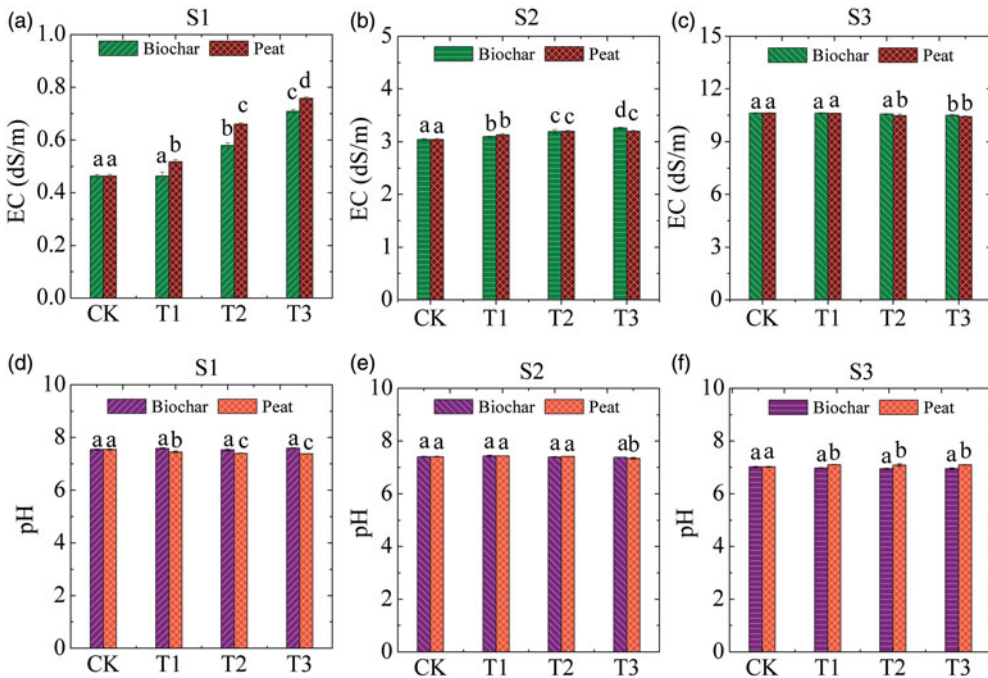


Figure 2. Variation of electrical conductivity (EC) and pH of the soil extract solutions. (a) EC variation of S1 soil by different treatments; (b) EC variation of S2 soil by different treatments; (c) EC variation of S3 soil by different treatments; (d) pH variation of S1 soil by different treatments; (e) pH variation of S2 soil by different treatments; (f) pH variation of S3 soil by different treatments. *Note:* S1 was the soil with very slight salinity; S2 was the soil with moderate salinity; S3 was the soil with strong salinity. T1 was the treatment of 1% dose; T2 was the treatment of 3% dose; T3 was the treatment of 5% dose. Different lower case letters indicate significant differences between treatments at $p < 0.05$. The extract was obtained after 7 days shaking at soil: water ratio of 1:5.

with peat dose ($R_{Na}^2=0.888$) in S2. In S3, soluble K^+ was still affected by the addition of biochar, because the R_K^2 was 0.990.

Biochar/peat increased/decreased the SAR values of the salt extract solutions (Figure 4). The SAR of S1 soil increased from 0.86 (CK) to 1.49 (T3) because of the introduction of Na^+ by the biochar. Compared with S1, biochar treatment had less impact on the SAR values of S2 and S3 soil extract solutions. K^+ in biochar provided necessary nutrients for plants. On the other hand, the released Na^+ increased the salt content and hazard to plants. Unlike the biochar, peat treatment increased the concentrations of Ca^{2+} and Mg^{2+} in S1/S2/S3 soil extract solutions to result thereby in the decline of the SAR. The results also indicated that the SAR values of S1/S2/S3 soil extract solutions decreased with the dose of peat and the maximum decline was obtained in the T3 treatment (addition dose of 5%) by 15.1, 17.5, and 5.9% compared to CK values, respectively.

Similar to cations, anions in soil extract solutions caused different changes in response to the application of biochar and peat (Figure 3). Concentrations of Cl^- increased in S1/S2/S3 soil extract solutions treated by biochar. In S1 soil extract solutions, the Cl^- concentration significantly increased from 0.38 to 2.76 mmol/l at a biochar dose of 5%, while concentrations of Cl^- in soil extract solution treated by peat

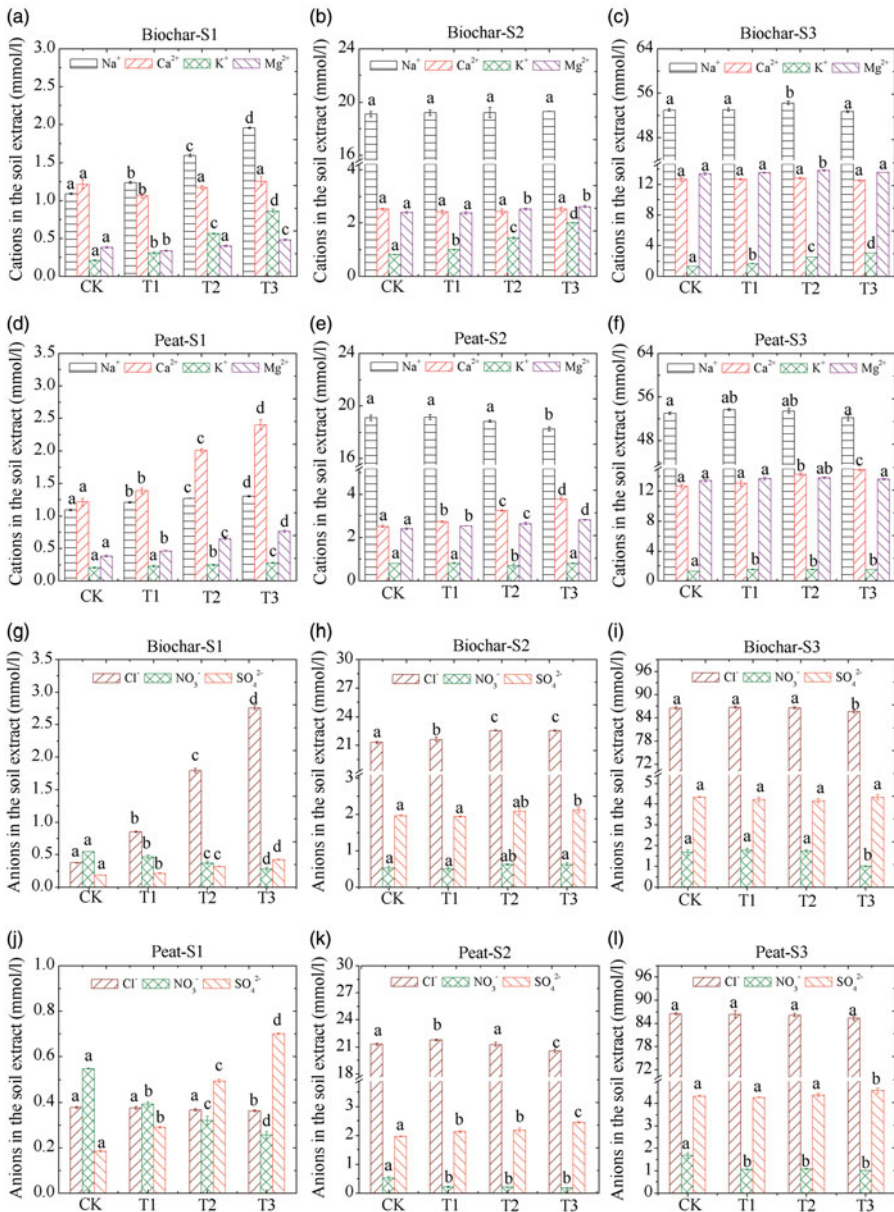


Figure 3. Variation of ions in the of S1–S2–S3 soil extract solutions. (a) cation variation of S1 amended by biochar; (b) cation variation of S2 amended by biochar; (c) cation variation of S3 amended by biochar; (d) cation variation of S1 amended by peat; (e) cation variation of S2 amended by peat; (f) cation variation of S3 amended by peat; (g) anion variation of S1 amended by biochar; (h) anion variation of S2 amended by biochar; (i) anion variation of S3 amended by biochar; (j) anion variation of S1 amended by peat; (k) anion variation of S2 amended by peat; (l) anion variation of S3 amended by peat. *Note:* S1 was the soil with very slight salinity; S2 was the soil with moderate salinity; S3 was the soil with strong salinity. T1 was the treatment of 1% dose; T2 was the treatment of 3% dose; T3 was the treatment of 5% dose. Different lower case letters indicate significant differences between treatments at $p < 0.05$. The extract was obtained after 7 days shaking at soil: water ratio of 1:5.

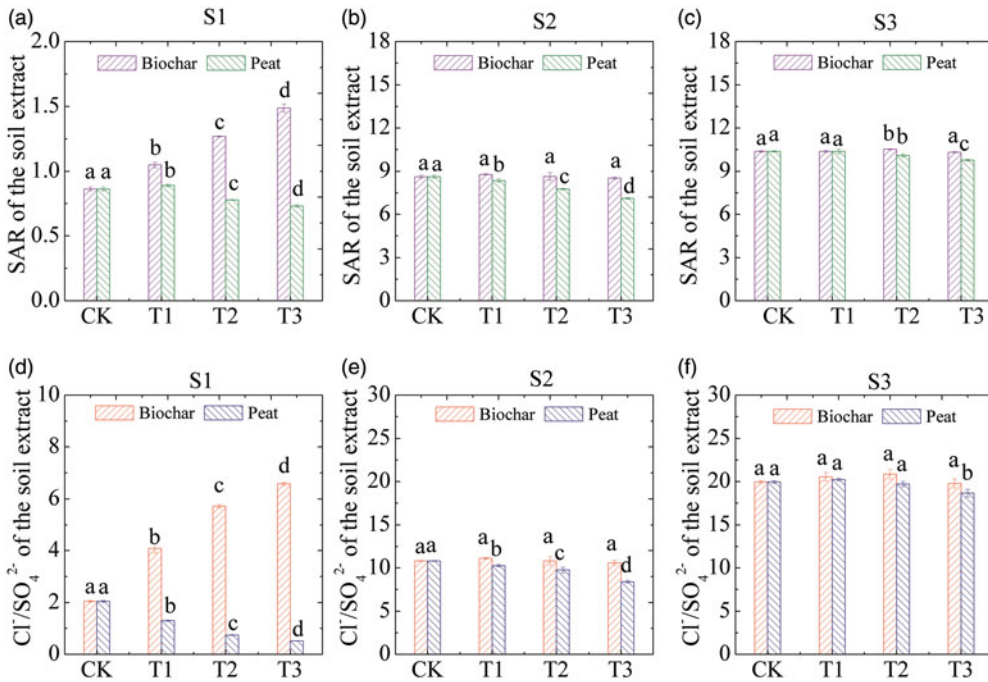


Figure 4. Sodium adsorption ratio (SAR) and $\text{Cl}^-/\text{SO}_4^{2-}$ of S1–S2–S3 soil extract solutions. (a) SAR variation in S1 by different treatments; (b) SAR variation in S2 by different treatments; (c) SAR variation in S3 by different treatments; (d) $\text{Cl}^-/\text{SO}_4^{2-}$ variation in S1 by different treatments; (e) $\text{Cl}^-/\text{SO}_4^{2-}$ variation in S2 by different treatments; (f) $\text{Cl}^-/\text{SO}_4^{2-}$ variation in S3 by different treatments. *Note:* S1 was the soil with very slight salinity; S2 was the soil with moderate salinity; S3 was the soil with strong salinity. T1 was the treatment of 1% dose; T2 was the treatment of 3% dose; T3 was the treatment of 5% dose. Different lower case letters indicate significant differences between treatments at $p < 0.05$. The extract was obtained after 7 days shaking at soil: water ratio of 1:5.

were not affected. The application of biochar and peat increased the concentration of SO_4^{2-} in S1 and S2 soil extract solutions. The concentration of SO_4^{2-} in S1 and S2 soil extract solutions reached 0.42/0.70 and 2.08/2.12 mmol/l in T3 (5% dose) by biochar/peat treatments, respectively. Only peat treatment had a significant impact on SO_4^{2-} in the strongly saline soil-S3 soil extract solutions ($p < 0.05$), whose concentration of SO_4^{2-} increased from 4.33 (CK) to 4.58 (T3) mmol/l. The carbon-rich amendments decreased soluble NO_3^- in the soil extract solutions. The concentrations of NO_3^- in all applied salt-affected soil extract solutions declined with the dose of the peat, while the addition of the biochar only decreased nitrate concentration in S1 soil extract solutions.

The values of $\text{Cl}^-/\text{SO}_4^{2-}$ ratio in S1 and S2 soil extract solutions increased with the addition of the biochar. The value of $\text{Cl}^-/\text{SO}_4^{2-}$ ratio in S1 soil extract solutions showed a linear relationship with the biochar application dose ($R^2 = 0.91$). The values of $\text{Cl}^-/\text{SO}_4^{2-}$ in all soils were affected by the addition of the peat and the influence of the peat faded with the increase of soil salinity. The value of $\text{Cl}^-/\text{SO}_4^{2-}$ in S1 soil extract solutions declined from 2.04 to 0.52, while that in S2 soil extract solutions decreased from 10.82 to 8.39 with the addition of peat. A high background concentration of Cl^- in S3 (strongly saline) soil extract solutions weakened the effect of peat treatment, so

that the peat amendment affected $\text{Cl}^-/\text{SO}_4^{2-}$ ratio only at 5% dose. Moreover, Cl^- in soils might be adsorbed or exchanged by the functional groups of the peat, which alleviated the harm of Cl^- to wheat and resulted in a decline of $\text{Cl}^-/\text{SO}_4^{2-}$ ratio.

Growth of winter wheat

The effects of biochar and peat on the germination of winter wheat were only investigated for S1 (very slightly saline) and S2 (moderately saline) soils (Figure 5). Winter wheat failed to germinate in S3 (strongly saline) soil, both in the presence and absence of amendments. The germination rate of winter wheat in S1 soil was relatively high and no significant difference was found among the different treatments ($p < 0.05$). The addition of biochar effectively increased the germination rate in S2 soil ($p < 0.05$). The wheat germination rate was 71.67%/57.60% in T1/T2 (treatment of 1 and 3% dose), while it was only 49.73% in CK. The addition of peat did not increase the germination rate of winter wheat in S1 and S2 soils ($p < 0.05$).

Both biochar and peat could increase wheat root and sprout growth in S1 soil. The longest root and sprout reached 8.04/7.14 and 4.86/4.50 cm in S1 soil treated by the biochar/peat in T2 (treatment of 3% dose), respectively. Because the salt from biochar and peat increased the salinity of the soil, T3 (treatment of 5% dose) soil inhibited the growth of wheat compared with that in T2 soil. Statistically, peat had no impact on the root, but it increased the length of the sprout in T2 soil. Biochar had negative effects on the average length of the root/sprout of seedlings in S2 soil.

Ion contents in early seedlings of winter wheat

The ion (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , and PO_4^{3-}) concentration of the wheat seedling extracts is shown in Figure 6. Na^+ and K^+ were the main cations in wheat seedling extract. In S1 (very slightly saline) soil, the concentration of Na^+ in wheat seedlings treated by biochar was lower than in those treated with peat. A large amount of Na^+ entered the cytoplasm of plants, causing the lower germination ratio and hindering the development of root and sprout in S2 (moderately saline) soil (Figure 6). The content of K^+ in wheat seedling extract increased with the application of biochar/peat. K^+ content in wheat seedlings grown in S1 (very slightly saline) treated by biochar at a dose of 3% (T2) reached 3.45 mg/g and increased by 91.7% in comparison with CK treatment, while the highest K^+ content in seedlings grown in S1 treated by the peat at the 1% addition dose (T1) reached 4.10 mg/g. The K^+ concentration in seedlings germinated in S2 (moderately saline) treated by the peat or biochar was higher than CK. The dose of biochar had no influence on K^+ in seedlings; no statistically significant difference was observed among T1, T2, and T3 treatments. The K^+/Na^+ ratio of soils treated with the amendments was generally higher than that of CK treatment. Biochar contained abundant potassium (Table 2), which provided sufficient K^+ for wheat seedlings to uptake. Therefore, the ratio of K^+/Na^+ in seedlings treated by biochar was higher than in those treated by peat. The highest ratio of K^+/Na^+ in S1 treated by biochar was 3.25 (Figure 6), nearly twice the maximum ratio obtained by peat (1.68).

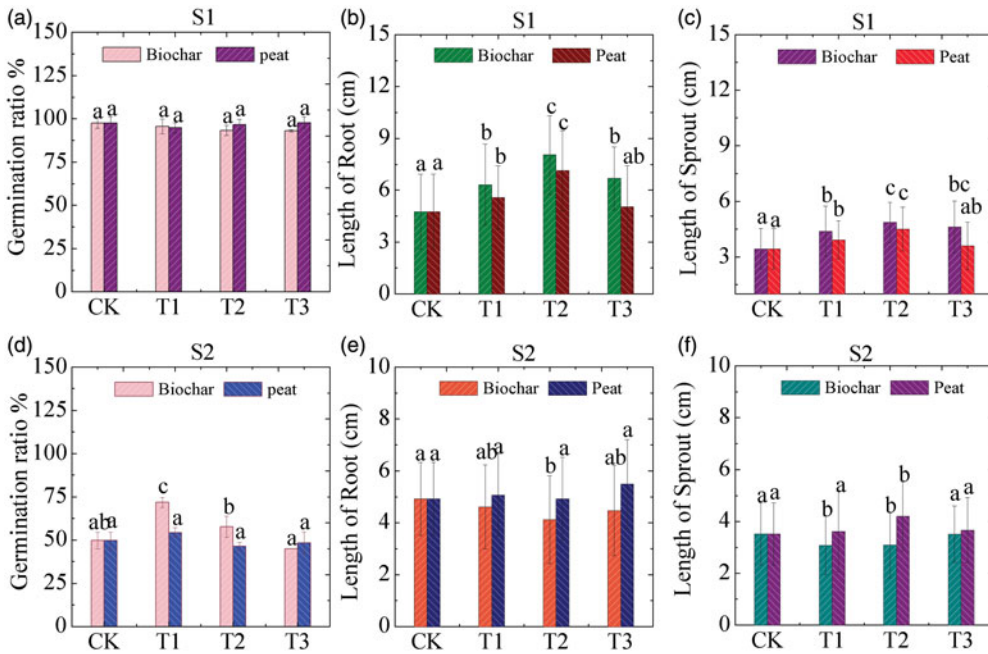


Figure 5. Germination ratio of wheat grown in S1(a) and S2 soils (d) under different treatments, root length of wheat grown in S1(b) and S2 (e) under different treatments and sprout length of wheat grown in S1(c) and S2 (f) under different treatments. Note: S1 was the soil with very slight salinity; S2 was the soil with moderate salinity. T1 was the treatment of 1% dose; T2 was the treatment of 3% dose; T3 was the treatment of 5% dose. Different lower case letters indicate significant differences between treatments at $p < 0.05$. The extract was obtained after 7 days shaking at soil: water ratio of 1:5. The germination ratio, length of root and sprout was calculated or determined after 80 hours of growth.

Concentrations of Ca^{2+} and Mg^{2+} were lower than those of Na^+ and K^+ in seedling extracts (Figure 6). Biochar had no effect on concentrations of Ca^{2+} and Mg^{2+} in wheat seedlings in S1 soil, whereas concentrations of Ca^{2+} in seedlings grown in S2 soil treated by the biochar declined with the application dose ($p < 0.05$). The application of peat did not trigger any changes in Ca^{2+} concentration in seedlings statistically, except for the T3 (treatment of 5%) in S2 (moderately saline). However, the concentration of Mg^{2+} in seedling extract treated by peat was higher than that in CK.

Compared with CK, the absorption of Cl^- in the wheat seedlings, especially cultured in S1 was promoted by the application of biochar and peat to some extent. Cl^- in the wheat seedlings cultured in S1 treated by biochar (Figure 6) increased with the added dose and the maximum concentration of Cl^- reached 1.83 mg/g. In peat treatment, the highest concentration occurred at a dose of 1% (T1) with 1.19 mg/g. Biochar addition resulted in larger uptake of Cl^- in wheat seedlings grown in S1 soil than in treatments with peat at the same addition dose (except 1% dose). The influence of biochar or peat addition on Cl^- concentrations in S2 soil was less than that in S1 soil.

The concentration of SO_4^{2-} in wheat seedlings grown in S1 and S2 treated with biochar or the peat was linearly (in S1: $R_{\text{biochar}}^2=0.93$, $R_{\text{Peat}}^2=0.73$; in S2: $R_{\text{biochar}}^2=0.83$; $R_{\text{Peat}}^2=0.87$) correlated with the dose (Figure 3). The phosphate content in wheat

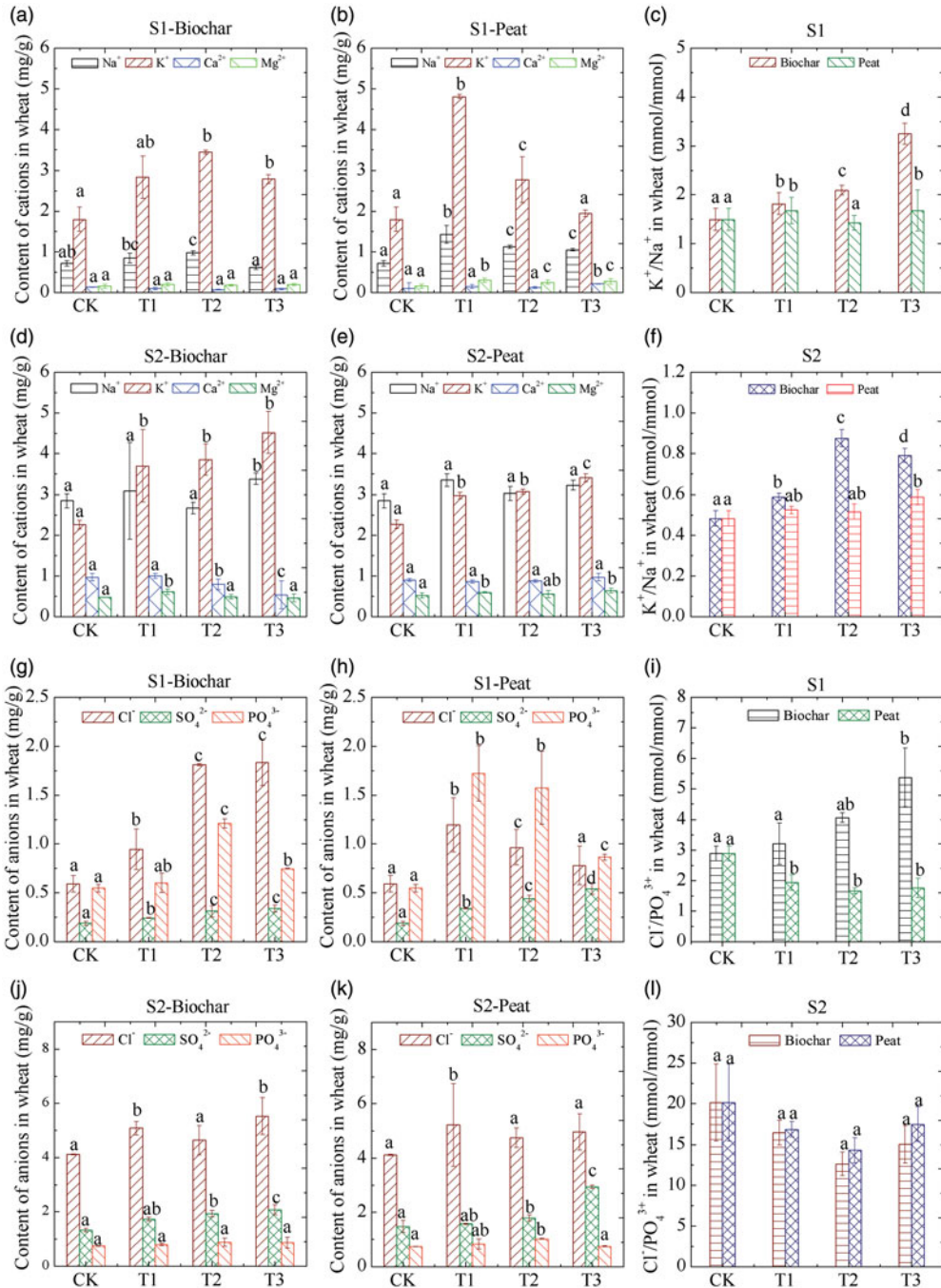


Figure 6. Cation contents of S1 amended by biochar (a) and peat (b), cation contents of S2 amended by biochar (d) and peat (e), anion contents of S1 amended by biochar (g) and peat (h), anion contents of S2 amended by biochar (j) and peat (k), K^+/Na^+ ratio of S1 (c) and S2 (f), and Cl^-/PO_4^{3-} ratio of S1 (i) and S2 (l). Note: S1 was the soil with very slight salinity; S2 was the soil with moderate salinity. T1 was the treatment of 1% dose; T2 was the treatment of 3% dose; T3 was the treatment of 5% dose. Different lower case letters indicate significant differences between treatments at $p < 0.05$. The extract was obtained after 7 days shaking at soil: water ratio of 1:5. The content of cations and anions in wheat were obtained through determining water extraction of wheat after 80 hours of growth.

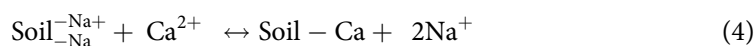
seedlings cultured in S1 soil reflected the biomass change (Figure 6). The addition of biochar in S2 increased the phosphate uptake of wheat seedlings and inhibited the accumulation of biomass. The application of peat did not have a significant influence on the phosphate of wheat seedling extracts among different doses. The relative concentration of PO_4^{3-} and Cl^- (mole ratio value of $\text{Cl}^-/\text{PO}_4^{3-}$) in S1 treated by biochar increased by 86.1%, while that in S1 treated by peat decreased by 39.1% in comparison with CK (Figure 6).

Discussion

Effects of biochar and peat on salt-affected soils

Biochar and peat differed in many properties, such as pH, specific surface, CEC, and ionic composition. These differences might lead to different effects or mechanisms.

Many soluble ions existed in biochar and peat (Table 2). It was assumed that the ions in biochar (such as K^+) and peat (such as Ca^{2+} and Mg^{2+}) could alter the solute composition by the relevant processes of dissolution and ion exchange. The results in Figure 3 indicate that the concentration of K^+ increased in the soil extract solution after the application of biochar, whereas the concentration of Ca^{2+} and Mg^{2+} increased by the addition of peat. As organic amendments, both biochar and peat had a high CEC (Table 2), which made it possible to adsorb ions in the soil solution. Redistribution of ions in the soil-water system is affected by the addition of biochar and peat. It was deduced that the main cation exchange reactions might be the replacement of Na^+ in the soil solution by exchangeable Ca^{2+} in the amendments (Eq. 3) (Akhtar, Andersen, and Liu 2015) and the displacement of the exchangeable Na^+ of the soil particles by Ca^{2+} of the solution (Eq. 4).



The SAR, a common index that reflects the exchangeable sodium percentage, was used in this model experiment to clarify the changes in cations (Na^+ , K^+ , Ca^{2+} , and Mg^{2+}) in soil solution. The results in Figure 4 demonstrate that the SAR value decreased with peat addition. Ca^{2+} and Mg^{2+} proved to facilitate the removal of Na^+ from soil colloid by cation exchange reaction (Ghafoor et al. 2001; Bourrie 2014; Chaganti, Crohn, and Šimůnek 2015). However, abundant biochar led to a relative increase in the K^+ concentration in the extracts, which is beneficial, since soluble K^+ is regarded as a source of nutrient for crop growth (Abbasi, Anwar, and Raffaella 2015).

In addition to Na^+ , excessive Cl^- is toxic to the growth of the plants in salt-affected soils of the Yellow River Delta (Teakle and Tyerman 2010; Luo et al. 2017; Xiong et al. 2018), while SO_4^{2-} has a less harmful impact. Therefore, $\text{Cl}^-/\text{SO}_4^{2-}$ ratio was used to evaluate the main anions in salt-affected soils. In this study, peat increased the concentration of SO_4^{2-} , and $\text{Cl}^-/\text{SO}_4^{2-}$ failed to present a positive effect.

Effects of the amendments on the growth of winter wheat seedlings

The application of biochar and peat modified the ion composition in soil extract solution and the ions subsequently were assumed to cause different effects on wheat seedling growth. The results in [Figure 6](#) illustrate that Na^+ and K^+ were the main cations, with higher contents in the wheat seedlings than Ca^{2+} and Mg^{2+} . The content of K^+ in wheat treated by biochar and peat was higher than that of CK treatment of S1 (very slightly saline) soil. A higher K^+/Na^+ ratio in wheat seedlings treated by biochar and peat was also observed in the germination experiment. Also, the K^+/Na^+ ratio treated by biochar was higher than by peat. Many studies have reported that K^+ was not only a key nutrient but also involved in many vital physiological processes. It has the capacity of reducing the uptake of Na^+ (Akhtar, Andersen, and Liu 2015; Lin et al. 2015). A high cytoplasmic K^+/Na^+ ratio is critical to improve salt tolerance and reduce salt toxicity for many plant species (Chen et al. 2007; Arzani 2008). The length of root and sprout treated by biochar was longer than that treated by peat in S1 (very slightly saline) soil, which was similar to previous studies (Hao and Chang 2003; Pavlikova et al. 2017; El-Naggar et al. 2019). Therefore, it can be inferred that biochar and peat promote the ability of K^+ uptake for wheat. More K^+ was absorbed to enhance the development of wheat seedlings because of the sufficient K^+ amount provided by biochar.

The concentration of Na^+ in wheat seedlings cultured in S2 (moderately saline) soil was obviously higher than that in S1 (very slightly saline) soil, illustrating that Na^+ easily accumulated in wheat seedlings under salt stress. The influx of a large amount of Na^+ into the cytoplasm of plants probably increased osmotic pressure, which led to low germination and growth retardation ([Figure 5](#)). Moreover, the initial uptake of K^+ by crops aggravated the osmotic pressure. Previous studies (Miller et al. 2017; Saifullah et al. 2018) reported the potential harm of biochar to crops by increasing the salinity of soil. The germination rate of wheat seed in S2 soil treated by biochar increased, but the length of the sprout and root decreased compared with CK treatment. There was no significant difference between peat application and CK treatment on the germination rate of wheat and the length of the sprout/root. Therefore, it was inferred that the application of biochar in soils with moderate salinity might aggravate the salt stress to plants. The peat effect on plants in S2 soil was not observed in this study.

Concentrations of divalent cations (Ca^{2+} and Mg^{2+}) in wheat plants were much lower than those of monovalent cations (Na^+ and K^+). Calcium and magnesium were reported to participate in physiological and biochemical reactions in plants, such as forming cell membranes or composing protein complex (Demidchik et al. 2018). Ca/Mg-dominated peat did not cause a significant difference of Ca^{2+} content in wheat ($p < 0.05$) among peat treatments and CK ([Figure 6](#)), although the concentration of Ca^{2+} in soil solution was largely affected by peat. However, Ca^{2+} content decreased with biochar dose in S2 (moderately saline) soil. The addition of biochar inhibited the uptake of Ca^{2+} , which might partially explain why biochar retarded the root and sprout of the wheat.

Cl^- , SO_4^{2-} , and PO_4^{3-} were the major mineral anions in wheat ([Figure 6](#)). Biochar and peat altered the anion composition of wheat extracts. In S1 soil, the absorption of

Cl^- in the wheat was higher because of the Cl^- concentration increased by biochar. Similarly, the application of peat contributed to the increase of SO_4^{2-} concentration in the seedlings. The result demonstrated that anions in plants were related to the ion composition of the soil solution and the application of amendments (Figure 3). High soil salinity weakened the ability of amendment to alter the ion composition of the soil solution that could affect crops in the end.

Conclusions

This study was based on a model experiment to provide valuable information for the later field experiments in the Yellow River Delta. The process of interactions among biochar/peat, soil, and plants was expected to be clarified. Biochar and peat showed different effects on salt-affected soils because of their different predominating ion composition. An ion exchange reaction took place as the dissolution process altered the ionic composition of the soil solution. The index SAR and $\text{Cl}^-/\text{SO}_4^{2-}$ ratio was significantly reduced in the soil solution treated by peat, while in that treated by biochar increased. Furthermore, the ions in wheat seedlings were affected, as well as the germination ratio and the lengths of roots and sprouts. Soluble K^+ was one of the dominating cations of biochar water extract and higher content of K^+ or K^+/Na^+ in treatments of biochar demonstrated the uptake of K^+ . Compared with K^+ , the content of Ca^{2+} and Mg^{2+} was less, even in the treatments of peat whose soil solution was dominated by Ca^{2+} and Mg^{2+} . Therefore, biochar was considered to impose more obvious effects on the wheat, while peat was modifying the soil solution.

Useful information was obtained for future field trials by analyzing the mechanism of biochar and peat in terms of their effects on the soil solution or crops. However, there were some limitations to this study. (1) The model experiment simplified the process of the dynamic change of water-salt in the field and the results might deviate from actual agricultural production. (2) To cover the salinity of the target field experiment area (the Yellow River Delta), the range of salinity is rather wide. More specific salinity range should be set up in future studies to match the salinity tolerance range of wheat. (3) Indicators (such as catalase) for evaluating germination and growth of wheat need to be used.

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