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Organic material combined with beneficial bacteria improves soil fertility and corn seedling growth in coastal saline soils

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ABSTRACT: Soil salinity is a major abiotic stress on plant growth in coastal saline soil. The objective of this study was to screen the optimal combination of organic materials with beneficial bacteria for application under real field conditions to improve coastal saline soil. A two-factor pot experiment was carried out with corn in coastal saline soil for 26 days. In the naturally aerobic environment, a split-plot experiment was conducted with different rates of organic materials (organic fertilizer and mushroom residue) and beneficial bacteria (phosphate - and potassium-solubilizing bacteria). The 10 treatments consisted of a control (inactivated bacteria cells and no organic material), and combinations of organic materials (2, 4, and 6 % of the total soil dry weight), respectively, with beneficial bacteria [at 1×10^8, 2×10^8, and 3×10^8 colony-forming units (cfu) plant^{-1}]. The application of 6 % organic material and beneficial bacteria at 3×10^8 cfu plant^{-1} (F6B3) promoted the highest seedling height, stem diameter, and dry biomass of corn seedlings, which increased by 0.30~26.78 %, 8.70~27.23 %, and 22.13~156.90 %, respectively, compared with the other FB (organic fertilizers and beneficial bacteria) treatments. Compared with all other FB treatments, soil total nitrogen, available phosphorus, and available potassium were increased by 4.78~18.04 %, 8.99~25.59 %, and 0.96~36.25 %, respectively, in F6B3. This treatment decreased soil total salt content by 0.79~12.72 %, compared with the other FB treatments. Based on the comprehensive improvement scores, F6B3 was identified as the best treatment for coastal saline soil. Organic materials combined with beneficial bacteria could improve nutrient availability and reduce salinity of coastal saline soil and promote corn seedling growth. The combined application of 6 % of organic materials with 3×10^8 cfu plant^{-1} of beneficial bacteria proved the most effective for coastal saline soil, and is recommended for field application.

Keywords: organic fertilizer, mushroom residue, phosphate-solubilizing bacteria, potassium-solubilizing bacteria, soil salinity.

INTRODUCTION

The global soil area affected by salinity exceeds 8×10^8 hectares (FAO, 2000). China has 1.3×10^7 hectares of coastal land with saline-alkali soil (Qin et al., 2002). The range of soil salinization has been increasing every year, due to the unreasonable use of saline soils, while the arable land area is decreasing (Gupta and Huang, 2014). Furthermore, business, industry, and housing are continuously occupying more agricultural land, resulting in a further reduction of available farmland.

Coastal saline soil is an important reserve of virgin farmland. However, its poor soil structure may cause soil deterioration and reduce crop growth and yield due to macronutrient deficiency, along with specific ion damage and nutrient disorder in the plant roots caused by NaCl (Farooq et al., 2015; Zhou et al., 2018).

The world population is expected to reach 8.9 billion by 2050, with increases particularly in developing countries (Cristol, 2003). The population increase will also lead to a rising demand for grain production (Godfray et al., 2010). Therefore, it is urgent to improve coastal saline soil, increase soil fertility and crop yields, and recover areas degraded by misuse.

The application of inorganic fertilizer may increase crop yields for short periods, but the long-term accumulation of mineral salts will aggravate salinization in coastal saline soil, reduce its quality and pollute the environment (Wu, 2011; Meena et al., 2019). In recent years, more attention has been paid to soil-plant-microorganism interactions. There are many kinds of microorganisms in the soil, which play an important role in soil nutrient cycling and promoting plant growth. The amount of inorganic fertilizer should be reduced and partly replaced by organic and microbial fertilizers to improve the coastal saline soil without affecting the environment (Adesemoye and Kloepper, 2009; Kumar et al., 2009). Moreover, this measure can stabilize the resistance and resilience of the soil microbial system and contribute to the maintenance of the diversity and stability of the soil ecosystem. Organic materials can improve soil nutrients and promote crop growth in saline soils. Recent studies pointed out that the use of different beneficial bacteria induced a beneficial effect on plant growth under salt stress (Zhang et al., 2016; Liu et al., 2019). Therefore, we hypothesized that organic material combined with beneficial bacteria could improve parameters related to corn seedling growth under saline conditions.

Coastal soils have low contents of available phosphorus, which is mainly due to the high content of calcium ions, which fixate and precipitate most of the available phosphorus (Kaur and Reddy, 2015). Potassium is abundant in coastal saline soils, but about 90~98 % of it is found in silicate minerals, such as potassium feldspar and mica (Goldstein, 1994), i.e., most of the potassium is not readily available and cannot be absorbed and utilized by plants (Zorb et al., 2014). Phosphorus- and potassium-solubilizing bacteria (PSB and KSB, respectively) can improve the phosphorus activity and available K content in the soil rhizosphere by increasing the dissolution and release of these nutrients (Meena et al., 2014).

Organic materials combined with beneficial bacterial not only promote the production of vitamins, hormones, and enzymes and stimulate plant growth, but also improve the diversity of soil microorganisms and enhance the stability of the soil ecosystem (Singh et al., 2011). In addition, organic material itself contains a large amount of nutrients, and application to coastal saline soil with poor soil fertility can effectively increase the available nutrients in the soil (Wu et al., 2018). Thus, our second hypothesis is that organic materials combined with beneficial bacteria can improve the nutrient availability in coastal saline soil, especially of phosphorus and potassium.

We tested our hypotheses by growing corn plants in collected soil and adding organic matter and beneficial bacteria. We also measured the soil pH and total salt content to better understand the effects of organic materials and beneficial bacteria on corn growth and nutrient availability. At the same time, the optimal dosage of organic matter and beneficial bacteria under salt stress was determined by comprehensive evaluation of improvement, to provide a basis for the development of sustainable agricultural practices for coastal saline soil.

MATERIALS AND METHODS

Soil, organic material, and beneficial bacteria solution

The coastal saline soil used in the pot experiment was collected in the county of Wudi, Shandong province, China (117° 55′ 15″ E, 37° 55′ 56″ N), near the south coast of Bohai sea gulf. The soil was classified as Salic Cambisol (IUSS Working Group WRB, 2015), with a clay loam texture and the following properties: soil pH(H_2O) 8.2; alkali-hydrolyzed N 52.15 mg kg^{-1}; total N 0.74 g kg^{-1}; available P 25.14 mg kg^{-1}; available K 78.59 mg kg^{-1}; soluble Na^+ 2.02 g kg^{-1}; soluble Cl^- 2.34 g kg^{-1}; and total salt 6.1 g kg^{-1}.

The experimental organic material was a combination of organic fertilizer (produced by *Shandong huade chemical technology Co. Ltd.*) and mushroom residue (produced by *Taian Academy of Agricultural Sciences*). The respective components of the organic fertilizer and mushroom residue were as follows: organic carbon contents 325.24 and 471.82 g kg^{-1}; total N contents 40.52 and 9.98 g kg^{-1}; total P contents 58.03 and 10.35 g kg^{-1}; total K contents 2.33 and 22.95 g kg^{-1}; and moisture contents 19.03 and 60.00 %. According to the optimum C/N ratio for microbial growth, the organic materials consisted of organic fertilizer and mushroom residue and had a C/N ratio of 23:1. The experimental beneficial bacteria consisted of phosphorus- and potassium-solubilizing bacteria (PSB and KSB, respectively), produced by *Guangzhou microelements and biotechnology Co. Ltd.* The numbers of viable bacteria were $\geq 2 \times 10^{10}$ cfu g^{-1} and $\geq 2 \times 10^{10}$ cfu g^{-1}, respectively. The composite bacteria included *Bacillus sp.* and *Brevibacillus sp.*

Luria-Bertani (LB) medium (solid and liquid media) was used in the preparation process of beneficial bacteria fluid. About 1 g bacteria powder of PSB and KSB was suspended in 99 mL sterile distilled water. The suspensions were shaken, subjected to serial dilutions (10^{-1}~10^{-9}), and 0.1 mL of 10^{-7}~10^{-9} dilutions was spread on solid medium in triplicate and incubated at 28~30 °C for 72 h. Colonies of target bacteria were inoculated on liquid medium, shaken and cultivated at 37 °C for 18 h. At this time, the bacteria had reached the logarithmic growth phase. Then the bacterial solution was diluted and spread on plates with solid medium. The counted number of colonies per plate was valid if it was between 30 and 300 cfu $plate^{-1}$. Colonies were spread on liquid medium, shaken, and cultivated at 37 °C for 18 h. The KSB solution concentration was 74×10^6 cfu mL^{-1} and that of the PSB solution 97×10^6 cfu mL^{-1}. The two types of beneficial bacterial solutions were preserved for later use.

Experimental design

The split-plot design consisted of 10 treatments (including the control) with three replications. The pot experiment lasting for 26 days was carried out at the experimental station of Shandong Agricultural University. The experimental site has a warm temperate continental monsoon climate, the average precipitation of this region is 43.6 mm, the average high and low temperature in May is 26 and 15 °C, respectively. Our pot experiment was conducted under field-like conditions. Coastal saline soil of the Wudi experimental station was air-dried and sieved (<2 mm) for the pot experiment. One kilogram of natural un-sterilized soil was thoroughly mixed with organic materials (C/N ratio of 23:1) at rates of 2 % (F2), 4 % (F4), and 6 % (F6) of dry soil weight. The soil was packed into clay pots (φ 16 cm, height 18 cm), which were buried two-thirds in the ground.

On May 1, 2016, six corn (variety: *Zhongzhong 8*) seeds were sown at a depth of about 3 cm and thinned to three plants per pot after emergence. The mixed beneficial bacteria solution was applied close to the roots of each plant. The application rates of the different treatments were 1×10^8 (B1), 2×10^8 (B2), and 3×10^8 (B3) cfu $plant^{-1}$, respectively. Treatments B1 and B2 were supplemented with distilled water. For the control experiments, bacteria cells were killed by autoclaving, or sterile phosphate buffer was used. During the experiment, the pots were watered weekly with distilled water to field capacity (70 %). Other agronomic practices were applied when necessary during the growth process. The experimental treatments are shown in table 1.

Plant and soil measurements and analysis

The corn seedling height and stem diameter were determined with a measuring tape and Vernier caliper. On May 26, 2016, SPAD values per plant were read six times in the field, and the average value was determined with a Minolta SPAD-502 chlorophyll meter. Each treatment was repeated three times. At 26 days after planting, the whole plant of each pot was harvested. Both shoots and roots were washed with distilled water and stored in brown paper bags. The corn seedlings were oven-dried at 105 °C for 30 min and then at 65 °C to constant weight of the dry biomass. At the same time, soil samples of about 100 g were collected, air-dried, and analyzed.

The soil pH(H_2O) was determined at a 1:2.5 soil/liquid ratio, according to Jackson (1973); soil total salt content by the dry residue weight method (1:5 w/v water) according to Bao (2000); soil total nitrogen content by the Kjeldahl method; soil alkali-hydrolyzed nitrogen by alkali-hydrolysis diffusion as described by Bao (2000); soil available phosphorus by molybdenum-antimony colorimetry (Murphy and Riley, 1962); and soil available potassium by flame photometry (Bao, 2000).

Statistical analyses

One-way analysis of variance (ANOVA) was used to analyze each data set, and means were separated by Tukey’s post hoc test ($p<0.05$). Correlation analysis was used to analyze the dependence of soil chemical properties and cluster analysis to classify the different treatments. All statistical analyses were performed using software SPSS 19.0.

To avoid multicollinearity among indexes, principal component analysis (PCA) was used to construct a comprehensive evaluation function. Ultimately, the higher the score of the comprehensive evaluation, the better the soil fertility and seedling growth. The steps of comprehensive evaluation are as follows: according to the original 10 indexes, PCA is used to obtain the two principal components with a contribution rate greater than

Table 1. Different organic materials and beneficial bacteria treatments

Treatment	Organic material (F)	Organic material code	Beneficial bacteria (B)	Beneficial bacteria code
	%		$\times 10^8$ cfu $plant^{-1}$	
Control	0	--	0	--
F2B1	2	F2	1	B1
F2B2	2	F2	2	B2
F2B3	2	F2	3	B3
F4B1	4	F4	1	B1
F4B2	4	F4	2	B2
F4B3	4	F4	3	B3
F6B1	6	F6	1	B1
F6B2	6	F6	2	B2
F6B3	6	F6	3	B3

75 % and the eigenvectors (e_i) of each index (X_i); then the principal component score (Z_j) is given by equation 1:

$$Z_j = \sum_{i=1}^{10} e_i X_i \quad \text{Eq. 1}$$

Taking the rate of variance contribution of the principal component as weight (λ_i), the comprehensive score (F_i) is given by equation 2:

$$F_i = \lambda_1 Z_1 + \lambda_2 Z_2 \quad \text{Eq. 2}$$

RESULTS

Soil chemical properties

Total N, alkali-hydrolyzed N, available P, and available K increased significantly in the treatments with organic materials and beneficial bacteria when compared with the same soil properties of the control (p<0.001; Table 2). There were significant positive correlations between total N, alkali-hydrolyzed N, available P, and available K (p<0.001; Table 2).

The addition of organic materials and beneficial bacteria increased soil total N content, which was significantly different from the control (Table 2). The soil total N content increased significantly in treatment F6B3 (4.78~47.43 %), compared with the other treatments. Except for F6B3, there were no significant differences in soil total N among all other FB treatments. Soil alkali-hydrolyzed N contents of treatments F6 were significantly higher than of the control and increased significantly in F6B3 (25.42 %), compared with the control. No significant differences in soil alkali-hydrolyzed N were observed among all FB treatments except F6B2.

The combined PSB and KSB application could effectively enhance the soil available P and K contents (Table 2). Soil available P contents of the different beneficial bacteria treatments with the same amount of organic materials (F4 and F6) increased significantly with the higher bacteria dosages. Treatment F6B3 increased the soil available P contents

Table 2. Soil chemical properties and correlation analysis

Treatment	Total N	Alkali-hydrolyzed N	Available P	Available K	pH(H_2O)	Total salt
	g kg^{-1}	mg kg^{-1}				g kg^{-1}
Control	0.84 c[1]	56.18 d	25.47 d	77.25 f	8.36 a	2.40 c
F2B1	1.08 b	60.50 bcd	37.60 c	118.27 e	8.36 a	2.41 c
F2B2	1.11 ab	68.97 abc	37.74 c	123.50 de	8.37 a	2.36 bc
F2B3	1.11 ab	63.43 abcd	39.14 c	130.77 cde	8.38 a	2.24 ab
F4B1	1.05 b	59.70 cd	37.40 c	138.80 cd	8.39 a	2.34 bc
F4B2	1.08 b	66.52 abcd	39.08 c	142.37 c	8.25 a	2.22 ab
F4B3	1.10 b	70.07 abc	42.70 b	144.38 abc	8.22 a	2.12 a
F6B1	1.09 b	68.50 abc	38.72 c	143.07 bc	8.38 a	2.22 ab
F6B2	1.19 ab	71.30 a	43.10 b	159.60 ab	8.24 a	2.16 a
F6B3	1.24 a	70.47 ab	46.98 a	161.13 a	8.20 a	2.10 a
Total N	--	0.66**	0.88**	0.81**	-0.29	-0.24
Alkali-hydrolyzed N	0.66**	--	0.71**	0.68**	-0.24	-0.31
Available P	0.88**	0.71**	--	0.93**	-0.42*	-0.18
Available K	0.81**	0.68**	0.93**	--	-0.40*	-0.31

[1] Means followed by the same letter (s) within each column are not significantly different at p<0.05 by Tukey's test available. ** indicate significance at p<0.01; and * indicate significance at p<0.05. Total N: Kjeldahl method; alkali hydrolyzed N: alkali-hydrolysis diffusion method; Available P: molybdenum-antimony colorimetric method; available K: flame photometry method; pH in water at a ratio of 1:2.5 soil:solution; total salt: dry residue weight method.

by 8.99~25.59 %, compared with all other FB treatments. Furthermore, the soil available P contents in F6B2 and F6B3 were significantly increased, (11.32 and 21.33 %) over treatment F6B1, respectively. The FB treatments led to a significant increase in soil available K contents compared with the control ($p<0.001$). The F6B3 increased the soil available K contents by 0.96~36.25 % over all other FB treatments.

The increase in organic materials and beneficial bacteria decreased the soil pH(H_2O) (Table 2). Although the difference between F6B3 and control was 0.16 units, the differences in soil pH were not significant among the treatments ($p = 0.175$). Soil total salt content of all treatments decreased significantly with the increase in organic materials and beneficial bacteria dosage. Soil total salt content of F4B3, F6B2, and F6B3 were significantly (11.67, 10.00, and 12.50 %) lower than in the control treatment. Compared to F2B1, F6B3 significantly reduced the total salt content by 12.72 %. Correlation analysis showed that soil pH(H_2O) was significantly negatively correlated with soil available P and K ($p<0.05$), and total salt content was highly significantly negatively correlated with total N, alkaline N, available P and K ($p<0.01$).

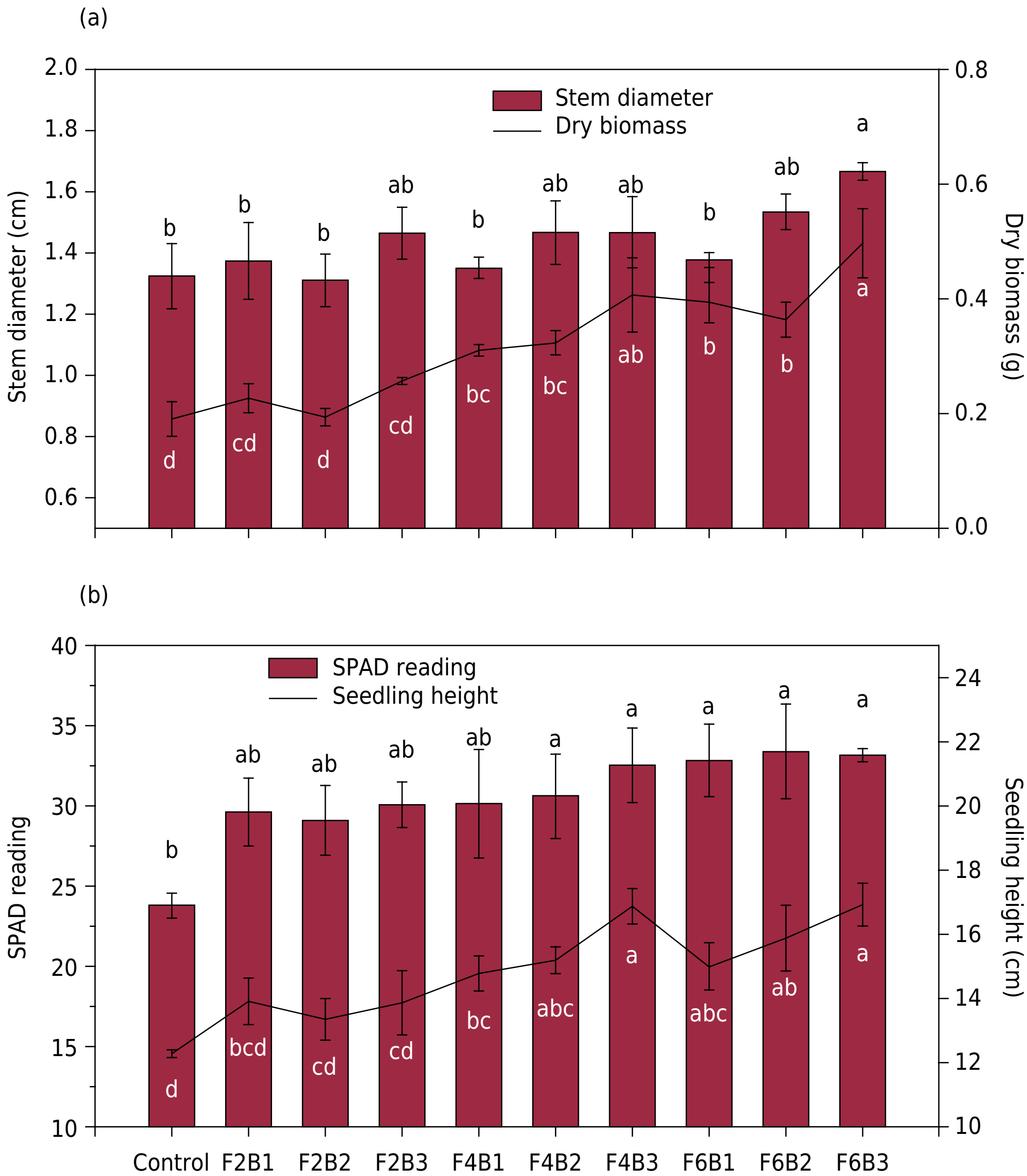

Figure 1. Stem diameter and dry biomass of corn seedlings in different treatments (a), SPAD reading and height of corn seedlings in different treatments (b).

Corn seedling growth

Dry biomass, stem diameter, seedling heights, and SPAD readings of corn seedlings of all treatments increased significantly with the increase in the amount of organic materials and beneficial bacteria (Figure 1), and any two parameters were significantly positively correlated in all treatments ($p<0.05$).

Dry biomass of corn seedlings increased significantly with the increase in organic material rates (Figure 1a). Dry seedling biomass of F6B3 was not significantly different from that of F4B3 and increased by 28.21~156.90 % compared with the other FB treatments. Also, F6B3 increased the seedling stem diameter by 25.94 and 8.70~27.23 %, compared with the control and all other FB treatments, respectively. In addition, post-hoc multiple comparisons showed that there were no significant differences in corn stem diameter between the control and all FB treatments (except for treatment F6B3).

Comprehensive evaluation function

The Euclidean distance was used as inter-treatment distance and the inter-group connection as clustering method. Soil total nitrogen, alkali-hydrolyzed nitrogen, available P and K, total salt, pH(H_2O), plant height, stem diameter, dry biomass, and SPAD readings were used as identification indexes. Cluster analysis was applied to 10 different treatments to establish the cluster tree graph (Figure 2). Results showed that the control was separated into a single class, while F6B3 and F4B3 were grouped in the same class. However, due to the lack of organic matter in coastal saline soil, applying additional amounts of organic material (F6B3) can contribute to a continuous improvement of coastal saline soil over time.

Principal Component Analysis (PCA) was used to comprehensively evaluate the 10 determined indexes of soil properties and corn growth. Two principal components were obtained by PCA, the first principal component eigenvalues were 6.729, the variance contribution rate 49.865 %; the second principal eigenvalue 1.000, and the variance contribution rate 27.428 %. Therefore, the cumulative contribution rate of the first and the second principal component was 77.293 %, which accounted for most of the variation. The respective loads of two principal components related to the original

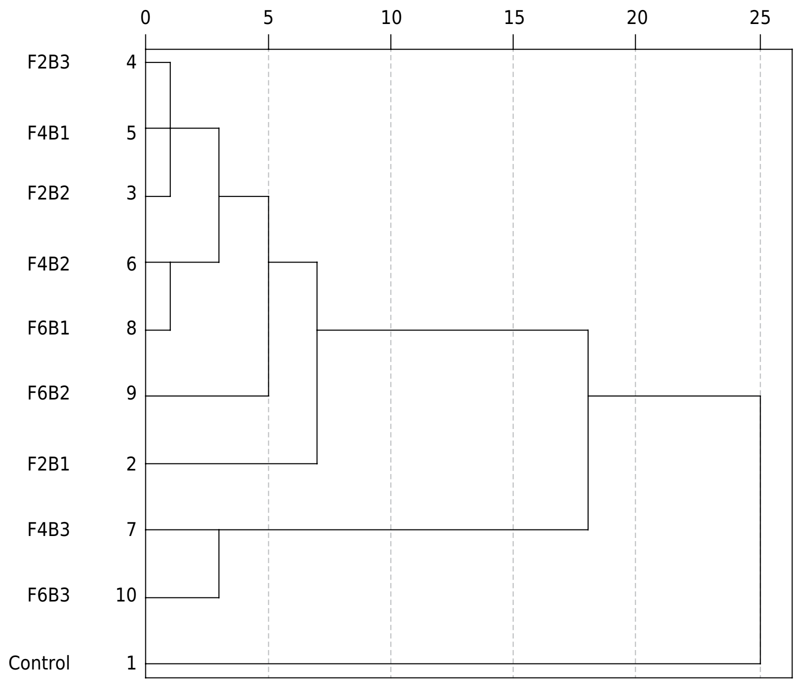

Figure 2. Cluster analysis of soil properties and corn growth under different treatments.

Table 3. Loads of two principal components and the comprehensive score of each treatment

Index	PC1	PC2	Treatments	Comprehensive score
Available P	0.942	0.157	Control	60.803
Available K	0.925	0.148	F2B1	82.015
Seedling height	0.894	0.011	F2B2	85.931
Dry biomass	0.867	-0.220	F2B3	87.704
Total nitrogen	0.844	0.247	F4B1	88.912
Soil total salt content	-0.827	0.281	F4B2	92.995
SPAD reading	0.799	0.298	F4B3	97.066
Stem diameter	0.756	-0.250	F6B1	96.554
Alkali-hydrolyzed nitrogen	0.750	0.319	F6B2	102.558
Soil pH	-0.516	0.715	F6B3	104.464

PC1: first principal component; PC2: second principal component.

variables are listed in table 3. The first principal component was the component with the largest amount of information, including available P, available K, seedling height, dry biomass, total N, total salt, SPAD reading, stem diameter (with an absolute loading value of >0.75). The second principal component was soil pH (H_2O). Therefore, the best indexes to evaluate the improvement effect in this study were the contents of available P and available K.

According to the principal component score (Z_j) formula (Equations 3 and 4), the linear combination of the eigenvectors (e_i) and the 10 index vectors (X_i) is expressed as follows:

$$Z_1=0.363X_1+0.356X_2+0.345X_3+0.334X_4+0.325X_5-0.319X_6+0.308X_7+0.291X_8+0.289X_9-0.199X_{10} \quad \text{Eq. 3}$$

$$Z_2=0.157X_1+0.148X_2+0.011X_3-0.22X_4+0.247X_5+0.281X_6+0.298X_7-0.25X_8+0.319X_9+0.715X_{10} \quad \text{Eq. 4}$$

By introducing the weight (λ_i) of each principal component obtained from the eigenvalues into the comprehensive score model, the linear models of the comprehensive score (F_i) and the principal components score (Z_j) were obtained as follows by equation 5:

$$F=0.8706\ Z_1+0.1294\ Z_2 \quad \text{Eq. 5}$$

According to equations 3, 4, and 5, the equation 6 of the comprehensive evaluation function was established.

$$F=0.336X_1+0.329X_2+0.302X_3+0.262X_4+0.315X_5-0.241X_6+0.307X_7+0.221X_8+0.293X_9-0.081X_{10} \quad \text{Eq. 6}$$

According to soil fertility and growth parameters of corn seedlings under different treatments, 10 comprehensive scores were obtained by using the comprehensive evaluation function. The score of F6B3 was the highest (Table 3), which indicated that the coastal saline soil was best treated with organic materials of 6 % per kilogram of dry soil weight and with 3×10^8 cfu plant^{-1} of beneficial bacteria to increase soil nutrients and promote maize growth.

DISCUSSION

Nutrient availability and soil salinity are the main factors affecting the microbiota (Jiang et al., 2019). Salt stress not only reduced the solubility and availability of soil nutrients (Imran et al., 2018) but also impaired nutrient uptake by the corn roots and affected plant growth (Gong et al., 2011). Our results showed that the soil nutrient contents and corn seedling growth were significantly higher in treatments with organic matter and beneficial bacteria than those of the control, consistent with previous studies (Shrivastava and Kumar, 2015; Liu et al., 2019). According to Wichern et al. (2006), organic materials reduced the negative effects of salt on the microbiota. A recent study showed that bio-organic fertilizers can potentially stimulate beneficial microbiota, changing the composition and abundance of microorganisms (Qiao et al., 2019). In addition, the C:N ratio tested in our experiment was more appropriate for beneficial bacteria activity (Yazdanpanah et al., 2013).

Consistent with our first hypothesis, the dry biomass, height, and stem diameter of corn seedlings were significantly higher in F6B3 than in the other experimental treatments. In addition, the application of organic materials and beneficial bacteria can improve the SPAD reading, indicating that fertilization is beneficial to increase the relative chlorophyll content of corn. The higher relative chlorophyll content not only ensured a longer photosynthetic period of corn leaves, but also contributed to a higher net photosynthetic rate.

Many researchers stated that growth and yield traits of corn could be significantly improved by the addition of PSB and KSB, compared with the control (Yadav et al., 2018; Feng et al., 2019). Beneficial bacteria can avoid ion toxicity by regulating various physiological processes of plants in saline soil (Ilangumaran and Smith, 2017), with improved water-salt balance, and ion balance under saline conditions by regulating the transpiration rate, carbohydrate transport, and K^+ transporter activity of corn (Marulanda et al., 2010; Rojas-Tapias et al., 2012). Beneficial bacteria can also cause the accumulation of cell secretions such as hormones and organic osmotic fluid to protect the plants against the effects of salt stress (Kang et al., 2014; Bhattacharyya et al., 2015). Adding appropriate beneficial bacteria to the soil can dissolve and release nutrients, which can meet the nutrient demand of corn seedlings, effectively alleviate soil salt stress and promote crop growth.

The results of our experiment showed that organic materials and beneficial bacteria could decrease the salinity of coastal saline soil, especially treatment F6B3, and significantly reduced the soil total salt content by 12.50 % compared with the control. Previous studies have reported that the addition of organic materials can reduce the soluble Na^+ content, sodium solubility, and effectively decrease salinity (Wang et al., 2014). In addition, the increase of organic composition improved the stability of aggregates and physical properties of saline soils, as well as soil porosity and soil water conductivity (Rashid et al., 2016; Cong et al., 2017). In this experiment, the pH value did not decrease significantly with the increase in organic material and beneficial bacteria dosage. ANOVA showed that there was no significant difference in pH between different treatments. However, another study reported that beneficial bacteria produced a large amount of organic acid in the soil, which significantly reduced the soil pH (Ul Hassan et al., 2017). The results of our experiment may be attributable to the organic matter that weakened the effect of organic acid produced by beneficial bacteria so that the pH decrease is not significant in the coastal saline soil.

Our second hypothesis that organic material combined with beneficial bacteria application would increase nutrient availability of coastal saline soil was confirmed in all fertilization treatments, especially F6B3. The content of total nitrogen and alkali-hydrolyzed nitrogen in the soil of F6B3 was increased by 47.43 and 25.42 %, respectively, compared with that of the control. In the study, the increase of soil nitrogen may be due to the effect of nitrogen fixation by *Bacillus* in PSB and KSB. According to Sahin et al. (2004), *Bacillus* has some nitrogen fixation effect, thus increasing soil nitrogen content. Similar results were also reported by Meena et al. (2015a) and Kumar et al. (2015).

The available P content of F6B3 increased significantly by 8.99~25.59 %, to higher contents than in all other FB treatments. The PSB solubilized soil phosphorus by the exudation of organic acids and the production of indole acetic acid and siderophores (Tao et al., 2008; Richardson and Simpson, 2011), and enriched soil available phosphorus (Chang and Yang, 2009; Banerjee et al., 2010). Previous studies had shown that PSB application could increase the availability of phosphorus, reduce the amount of phosphorus fertilizer by 50 %, with no significant reduction in corn yield (Koliaei et al., 2011). At the same time, soil available P was strongly negatively correlated with soil pH (Chen et al., 2006).

The soil available K content was significantly increased with the addition of organic materials and beneficial bacteria, F6B3 promoted an increase of 0.96~36.25 % compared with all other FB treatments and there was a significant negative correlation between soil available K content and soil pH. Studies have shown that KSB could significantly increase potassium solubilization in soil minerals and that soil available K accompanied the decrease in soil pH (Basak and Biswas, 2009; Meena et al., 2015b). This might be due to the organic acids secreted by KSB, which dissolved mineral K directly or chelated silicon ions resulting in the release of the K ions from soil minerals (Parmar and Sindhu, 2013). However, Maurya et al. (2014) found that the bacteria caused the lowest soil pH with the smallest amount of available K released from soil mica, which was contrary to our studies. Further studies are necessary to determine the mechanism of KSB dissolving soil mineral potassium.

At the same time, a series of studies have shown that adding organic materials or PSB and KSB inoculation can not only significantly improve nutrient availability of corn, but also promote nutrient uptake of plant roots, especially of phosphorus and potassium (Nakayan et al., 2013; Kaur and Reddy, 2015).

This study confirmed that the application of beneficial bacteria and organic materials is promising to improve the coastal saline soil, raise the soil nutrient availability and promote corn seedling growth, by the exploitation of soil-plant-microorganism interactions. The best combination of the two tested materials of this study to alleviate salt stress, improve soil nutrients, and promote corn growth in coastal saline soil consisted of organic materials applied at 6 % of the soil dry weight, together with 3×10^8 cfu plant^{-1} beneficial bacteria that decreased the salinity and enriched the soil with more available P and K than the other treatments.

CONCLUSION

The contents of soil nutrients, especially the key elements of the coastal saline soil fertility nitrogen, phosphorus and potassium, were increased significantly by applications of organic materials and beneficial bacteria under local salt stress. The soil total salt content decreased with the increase in organic material and beneficial bacteria, which alleviated sodium ion toxicity. Therefore, of the tested treatments, the application of 6 % organic materials with beneficial bacteria of 3×10^8 cfu plant^{-1} had the best effects on soil fertility and salt reduction of coastal saline soil. In addition, the improvement caused by organic materials and beneficial bacterial on coastal saline soil fertility and salt stress significantly promoted corn seedling growth. To sum up, the application of organic materials of 6 % of soil dry weight with beneficial bacteria of 3×10^8 cfu plant^{-1} could be further exploited as a very promising technical measure for grain production in coastal saline soil areas. Nonetheless, further field experiments are necessary to corroborate the findings of this pot study and to define the most effective practice for saline soil improvement and crop production in the future.

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AUTHOR CONTRIBUTIONS

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