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Ameliorants improve saline–alkaline soils on a large scale in northern Jiangsu Province, China

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ABSTRACT

In order to improve the coastal saline–alkali soil in north Jiangsu Province, the effects of a newly-developed ameliorant was compared with gypsum and cow manure in field trials in coastal saline soil in Dafeng County, China. Measurements included soil electrical conductivity, pH, soil nutrients, the plant (*Salicornia europea* L.) growth and ion concentration in stems and roots. The three ameliorants and their combinations improved soil physical and chemical properties and increased the plant height and stem diameter in the order of cow dung > gypsum > new ameliorant. During the experimental period, the soil electrical conductivity of the optimum combination decreased initially and then increased, but was lower than that in the other treatments. Compared with the control,the pH value in the optimum treatment increased by 10.4%, 9.2% and 5.2% in 0–5, 5–20 and 20–40 cm soil layers, respectively. The content of soil organic matter in the three soil layers increased by 22%, 28% and 10%, respectively. The total potassium content in different soil layers increased by 23%, 26% and 26%, respectively. In the optimal treatment, the height of *S. europea* increased by 32% and stem diameter by 20% compared with control. The K^{+} and Ca^{2+} concentration in roots and stems of *S. europaea* was significantly higher in the optimum treatment compared with control. The optimum combination (in t/ha) was: the new ameliorant 45, gypsum 18 and cow dung 300.

1. Introduction

Saline–alkali soils are influenced by dissolved salt accumulated on the surface in case of arid climate, intense evaporation environment or high salt content in groundwater table. Saline soils are an important land resource distributed widely in China (Farifteh et al., 2006). Rational exploitation and improvement of the salty land can relieve the pressure for arable land resources. The total area of available saline–alkali soil in China is 3.67×10^7 ha, of which 1.23×10^7 ha is with utilization value in agriculture (Yao, 2008). Salt-affected soils are mainly distributed in Northeast China Plain, Central-north area, Northwest inland, North China and coastal areas.

Coastal saline soils represent a subclass of saline soil formed from the sediment delivered by main rivers flowing into the sea. North Jiangsu plain is located along Yellow Sea with a long coastline of 744 km and 6.53×10^5 ha of saline–alkali soils, and expanding about 1300 ha per year (Luo et al., 2009). However, due to the high salt and exchangeable sodium content and low organic matter, these soils support only poor crop growth, thus not allowing sustainable agriculture. Therefore, the improved exploitation of coastal saline soil is important to underpin crop production and environment protection and relieve the stress of land shortage.

Various techniques have been tested to improve saline–alkali soils, including chemistry, physics, biology and engineering improvements to increase fertility and crop yield

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(Bird et al., 2004; Abdle-Fattah and Asrar-Acta, 2012; Zhu et al., 2012; Trejo et al., 2012; Long et al., 2014). For example, applying chemical ameliorant could improve physical and chemical properties of saline–alkali soils (Sharma and Yadav, 1989; Azhar et al., 2001; Nayak et al., 2013; Poraas et al., 2009; Robbins, 1986). In particular, gypsum appears to be remarkably effective in saline–alkali soil improvement (Gupta and Singh, 1988; Frenkel, 1989; Li et al., 1999). Gypsum adds Ca^{2+} to salty soils and decreases exchangeable sodium (Kelly and Brown, 1934). Other properties such as soil aggregate structure, soil bulk density, soil permeability and alkalization can be improved significantly with the addition of gypsum (Clark and Baligar, 2003; Wang et al., 2005). In addition, cow dung, being rich in organic matter and humic acids, may improve soil structure and increase the enzyme activity in soil (David, 1988; Wachendorf et al., 2005). Also, applying cow dung could effectively reduce salt content, improve soil fertility, enhance activity of soil microbes, and promote crop growth, making cow dung a feasible measure for saline–alkali soil improvement (Lovell and Jarvis, 1996; Njoku et al., 2008).

Our group has developed a new ameliorant of coastal saline–alkali soils that contains several effective components and bioactive matters. The aim of this work consisted in studying the effects of co-application of the new ameliorant, gypsum and cow dung on soil physical and chemical properties and plant growth in Dafeng County, North Jiangsu Province. In situ measurements of electrical conductivity allowed real-time data collection to test spatiotemporal variation in soil salinization under different experimental conditions in the field (Kemper, 1959; Rhoades, 1993). In order to provide a theoretical basis to the effect of different treatments on plant growth, *Salicornia europaea* L. was used as an indicator plant (Flower et al., 1977; Glenn et al., 1997), with plant height, stem diameter and total concentrations of each element (K, Ca, Na, Mg) in root and shoot measured in this experiment.

2. Materials and methods

2.1. Experimental materials

The new ameliorant (A), gypsum (B) and cow dung (C) were used as soil amendments. The moisture content of cow dung (provided by a branch of Shanghai Bright Dairy Company located near the experiment site) was 20–30%. Gypsum and *Salicornia europea* L. seed were provided by Dafeng Seed Company Limited.

The new ameliorant includes clay minerals, which contains Pumice Powder (10%), Medical Stone Powder (15%), Vermiculite Powder (10%), FGD Gypsum (15%), Steel Slag (Si)(10%), Coal Ash (dry)(40%). Basic nutrients for soil microorganism: niacin (2%), p-aminobenzoic acid (3%), inositol (4%), serine (2%), B1 vitamin (1%), B2 vitamin (1%), glucose (87%).

2.2. Soil properties of the experimental field

The experiment was performed in Dafeng, Jiangsu experimental station of Nanjing Agriculture University (32°59′30 to 33°0′31.N and 120°49′40 to 120°51′4.E). The area enjoys northern subtropica monsoon climate and distinct seasons, with an annual rainfall of 1058 mm (mostly from June to August). The soil properties of experimental field were shown in Table 1.

2.3. Experimental design

The experimental design was orthogonal test method with three factors of three level design (three ameliorants at three doses each) as follows: the new ameliorant (15, 45 and 90 t/ha for A1, A2 and A3, respectively), gypsum (0, 18 and 36 t/ha for B1, B2 and B3, respectively) and cow dung (0, 75 and 300 t/ha for C1, C2 and C3, respectively) (Table 2). There was also the control treatment (no ameliorant). The experiment was set up with four replicates.

Table 1
Soil properties at the trial site.

Depth (cm)	pH	EC ($mS\,cm^{-1}$)	Salt content ($g\,kg^{-1}$)	Organic matter ($g\,kg^{-1}$)	Total cations ($g\,kg^{-1}$)			
					K^+	Ca^{2+}	Na^+	Mg^{2+}
0–5	8.15	18.5	29.4	6.20	1.76	0.46	6.8	0.81
5–20	8.11	12.0	13.5	6.20	1.14	0.31	3.5	0.52
20–40	8.12	9.0	9.4	6.50	0.78	0.18	3.7	0.36

Each plot was 3.0 m long and 2.0 m wide and ridged with bricks (a height of 0.15 m) against cross contamination. In late May three ameliorants were mixed at required doses according to the experimental design and then spread evenly across a given plot. The treatments were incorporated into soil by digging to 20-cm depth. On June 3, 2012, *S. europea* seeds were sown in 3 cm depth of soil (0.15 g/plot).

2.4. Soil sample collection

The soil samples were collected by a corer on July, 26, 2012. There were six random sampling spots in each plot. Three soil depths were sampled: 0–5, 5–20 and 20–40 cm. Soils were air-dried and sieved (1-mm mesh) for physico-chemical analyses.

2.5. Plant sample collection

Ten *S. europaea* L. plants were taken randomly (on July, 20, and at its fresh and juicy period) in each plot for measuring average height by an iron ruler, and the stem diameter by a vernier caliper. After washing roots under running tap water and rinsing in deionized water, the roots and shoots were separated, dried at 80 °C for 2 days to a constant weight, ground (0.5-mm sieve) and digested (0.2 g plant sample and 6 ml mixed acid [V(HNO3 + V (HClO4 = 4 + 1))] by the electricity plate digestion).

2.6. Analytical methods

In the field, the soil electric conductivity was measured by a hand-held meter at depths of 0–1 (topsoil), 10 and 20 cm. The periods of soil sample collecting were in July 23, August 18, September 21 and November 10, 2012. The collected samples were analyzed for pH value with a pH meter (soil/water ratio: 1:1), and

Table 2
Orthogonal experimental design.

Treatment no.	The new ameliorant (A)(t/ha)	Gypsum (B) (t/ha)	Cow manure (C)(t/ha)	Treatment code
1	15	0	0	$A_1B_1C_1$
2	15	18	75	$A_1B_2C_2$
3	15	36	300	$A_1B_3C_3$
4	45	0	75	$A_2B_1C_2$
5	45	18	300	$A_2B_2C_3$
6	45	36	0	$A_2B_3C_1$
7	90	0	300	$A_3B_1C_3$
8	90	18	0	$A_3B_2C_1$
9	90	36	75	$A_3B_3C_2$