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Effects of different amendments for the reclamation of coastal saline soil on soil nutrient dynamics and electrical conductivity responses

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ABSTRACT

High salinity and macronutrient deficiencies are two important limitations of coastal saline soils. The present study focused on the changes in electrical conductivity (EC), and the redistribution of water soluble carbon (C), total nitrogen (N), and absorbable phosphorus (P) during the reclamation of coastal saline soil using different amendments. Eight soil treatments were tested: cotton straw powder (J), domestic sewage sludge (W), sewage sludge + cotton residue (J + W), beach sand (S), cotton straw powder + beach sand (J + S), domestic sewage sludge + beach sand (W + S), domestic sewage sludge + cotton residue + beach sand (J + W + S), and a control treatment (CK). Triplicate soil samples for each treatment were initially treated once with underground saltwater (with or without bacterial manure). After the first month of incubation, irrigation was conducted weekly. EC measurements in different soil layers showed that sewage sludge was the best amendment for reducing soil EC, while cotton straw powder had no significant effect. Concentrations of N and C increased with soil depth, while the highest P concentration was observed in the uppermost soil. Soil amended with organic matter showed the highest P concentrations, and P availability increased with the application of all amendments except sand, which had no significant effect. The compound treatments had more positive impacts on N availability than did single amendments; however, their effects on P concentration were minimal. The results indicated that sewage sludge was the most effective amendment for reclaiming coastal saline soil and improving the availability of macronutrients.

1. Introduction

Soil salinity and macronutrient deficiencies are major concerns in the potential utilization of land resources in coastal areas worldwide. Most of the lands within these areas are covered by moist saline soils accompanied by highly mineralized groundwater near the surface (Yao et al., 2009, 2013; Meng et al., 2013). High-salinity groundwater and saline soils hinder the germination and growth of plants (Tedeschi et al., 2011; Guo and Liu, 2014), leading to environmental degradation. To improve these conditions, domestic sewage sludge has been applied as an amendment (Stamatiadis et al., 1999; Kızılkay and Bayrak, 2005; Parat et al., 2005 Hefa et al., 2007). Different plant residues, such as maize and straw, have also been used to improve soil organic matter (Ros et al., 2010; Tao et al., 2012 Tao et al., 2012). Yazdanpanah et al. (2013) found that pistachio residue is an effective amendment for reclaiming saline sodic soils and improving the availability of macronutrients. Kızılkay and Bayrak (2005) reported that the addition of sludge caused rapid and significant increases in the enzymatic activities of soils. Stamatiadis et al. (1999) observed that sludge injection increased the readily decomposable organic matter, ammonium, and available nitrogen (N) in soils.

Carbon (C), nitrogen(N) and phosphorus (P) play important roles in soil fertility. Deficiencies and uneven distributions of these nutrients limit plant growth and distribution in the environment. Different researchers have reported varied rates of nutrient complementation and redistribution through the addition of organic matter (Singh et al., 1998; Raiesi, 2007; Vian et al., 2009; Jacobs et al., 2010; Singh et al., 2012a,b). Organic soil amendments have also been evaluated for their soil restoration potential in recent years (Tejada et al., 2006). In highly saline soils, the addition of organic matter improves soil texture by intensifying ion assimila-

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tion (Muhammad et al., 2008; Chowdhury et al., 2011a). Microbial metabolites can dissolve organic components as well as assimilate ions, which alters soil conductivity. Furthermore, the addition of organic amendments results in higher soil permeability (Tejada and Gonzalez, 2003, 2004, 2005; Tejada and Gonzalez, 2006; Wang et al., 2011; Yazdanpanah et al., 2011; Sun et al., 2013), which in turn reduces evaporation and salt content at the soil surface and is conducive to plant germination (Haisheng et al., 2008).

While many researchers have studied the effects of amendments on the chemical (David and Dimitrios, 2002; Singh, 2004 Gill et al., 2009; Zhang et al., 2013) and physical (Tejada and Gonzalez, 2004; Tejada and Gonzalez, 2004Tejada and Gonzalez, 2004; Clark, 2007; Jacobs, 2010) properties of saline and sodic soils, little attention has been paid to the changes of electrical conductivity (EC) in different soil layers after the application of amendments. EC can be used as a direct indicator of soil salt content, and an increase of EC has adverse effects on soil structural stability, bulk density, and permeability (Tejada and Gonzalez, 2006). Mathur et al. (1993) observed that high ionic concentrations in the soil are associated with large EC values. In saline soils, Tejada and Gonzalez, 2006 found that soil EC significantly decreased with the addition of low-EC material. El-Shakweer et al. (1998) demonstrated that the application of organic matter to saline soils accelerated NaCl leaching, decreased the exchangeable sodium percentage and EC, and increased water infiltration, water-holding capacity, and aggregate stability.

Many experiments have been performed on the restoration of saline soil, but few have focused on coastal saline soil (Tripathi et al., 2007; Sahin, 2011; Siddikee et al., 2011; Singh et al., 2012a,b; Yazdanpanah et al., 2013). Generally, coastal saline soils have poor macronutrient availability and high soil salinity. The native coastal soils of west Bohai Gulf, for example, are highly argillaceous saline soils with poor porosity. Few studies have assessed the impacts of different amendments on macronutrient availability in this region. Appropriate measures must be developed to improve the agricultural and ecological value of such soils. Therefore, the objective of this research was to study the redistribution of macronutrients (C, N and P) through evaluating the distribution of macronutrients and changes of EC at three soil depths (0–10, 10–20 and 20–30 cm) after the application of different amendments for the restoration of coastal saline soils from Bohai Gulf.

2. Materials and methods

2.1. Soil and amendment sampling and analysis

The study was conducted on the Farm of Dagang oilfield (38°50′40″N and 117°10′36″E) located within Tuanbo Town in Tianjin City in west coast of Bohai Gulf. The climate is temperate continental monsoon with obvious seasonal fluctuations. The annual mean air–temperature is 12.6 °C, and the annual mean precipitation and evaporation are 604.3 mm and 1750–1840 mm, respectively (Li, 2013). Soil type in this region is mainly Fluvo-aquic soil, derived from the river alluvium, sediment and the parent materials of salinized silt soil.

Soil samples were collected with six duplicates in five different sites from the upper 30 cm in the study region. One soil core (5 cm diameter) in each site was randomly collected for determining soil bulk densities. Bulk density was measured by core method from undisturbed soil cores dried for 48 h at 105 °C (Meng, 2013). Other soil samples were air-dried and crushed to pass through a 2-mm sieve. Prior to the addition of amendments, soil physical and chemical properties were measured as described by Mahmoodabadi et al. (2013), as shown in Table 1. Soil texture, EC, pH, total salt content, organic matter, sodium adsorption ratio (SAR), and absorbable potassium (K) were measured as described by Bao (2000). EC was determined in a 1:1 soil:water solution using an electronic conductivity meter (DDSJ-308F, Shanghai Leici). Water-soluble carbon (WSC) was determined by oxidation with potassium dichromate in an acid medium and measurement of the excess dichromate using the method described by Yeomans and Bremner (1988). Total N and absorbable P were measured using the method described by Pansu and Gautheyrou (2006) and spectroscopy, respectively. The initial soil had low amounts of organic matter, absorbable P and total N, but had high concentrations of salt content and absorbable K, as is common in coastal regions.

Table 1
Some chemical and physical properties of the initial soil used in the study prior to the application of amendments.

Soil character	Unit	Value
Clay	%	46
Silt	%	40
Sand	%	14
Total sand content	g kg^{-1}	11.33
pH	–	7.66
$EC_{(1:1)}$	d S m^{-1}	3.25
Organic carbon	g kg^{-1}	0.905
SAR	[meqL^{-1}]0.5	20.25
Water soluble carbon (WSC)	%	0.35
Total N	%	0.045
Absorbable P	mg kg^{-1}	9.28
Absorbable K	mg kg^{-1}	396.5

Sewage sludge was produced in an urban wastewater treatment plant, with primary and secondary treatments. Sewage sludge was stabilized through anaerobic digestion and evaporated naturally. Compost cotton straw was produced from a mixture of cotton stalk with leaves, and ripened for 8 months under atmospheric conditions. Beach sand was taken from the coast in dry season.To assess the quality of individual amendments, their chemical compositions were measured (Bao, 2000; Yazdanpanah et al., 2013), as shown in Table 2.

2.2. Application of amendments to soil

The soil column experiments were performed under laboratory conditions. Each treated soil was poured into the column; for each 2-cm layer, the soil was slightly compacted to achieve the field bulk density of 1.48 g cm^{-3} (Mahmoodabadi et al., 2013). To evaluate the effects of different amendments on the reclamation of coastal saline soil, eight treatments were applied in a randomized complete block design with three replications: the control (CK), cotton straw powder (J, 40 g kg^{-1}), domestic sewage sludge (W, 40 g kg^{-1}), beach sand (S, 40 g kg^{-1}), sewage sludge + cotton residue (J + W, 40 g kg^{-1} each), cotton straw powder + beach sand (J + S, 40 g kg^{-1} each), domestic sewage sludge + beach sand (W + S, 40 g kg^{-1} each), and sewage sludge + cotton residue + beach sand (J + W + S, 40 g kg^{-1} each).

The soil column experiments were conducted as described by Mahmoodabadi et al. (2013). In brief, each amendment treatment was mixed with collected coastal saline soil and placed into a PVC cylinder (30 cm high × 15 cm diameter). All soil cylinders were incubated for 30 days under laboratory conditions. After incubation, each treatment was irrigated with underground saltwater from a drainage sump near the coastal saline soil. To assess water quality, several chemical compounds were measured, as shown in Table 3. Additionally, for one set of samples, the irrigating water was mixed with bacterial manure in a 1:8 (V/V) manure:water ratio. The major features of the bacterial manure are shown in Table 4.

To simulate natural conditions, spray irrigation was conducted with 800 ml of water added to the top of each column every 7 days after incubation. This interval was chosen as typical for irrigation