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Soil enzymes as indicators of saline soil fertility under various soil amendments

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ABSTRACT

Soil salinity, caused by natural of anthropogenic factors, has been recognized as a challenge to cultivation. Coastal saline soil is widely distributed in China. The relationships between soil properties and enzyme activities under different amendment types were investigated in Yellow River Town, Kenli County, Shandong Province. The aim of our study was to determine the appropriate treatments for alleviating salinity. Hekang (a saline soil modifier), chemical fertilizers, microbial inoculant, and organic fertilizer were applied to coastal saline soil in this study. The results showed that urease and catalase activities were improved under conditions of Hekang, organic fertilizer and microbial inoculant, but not under single chemical fertilizer applications. All the amendment applications improved alkaline phosphatase activity. Urease activity, alkaline phosphatase activity and catalase activity were all significantly positively correlated with soil organic matter (SOM) or soil nitrogen (N), and were negatively correlated with soil salinity or pH. In addition, Catalase activity was significantly negatively correlated with available phosphorus (P); urease activity showed a significantly positive correlation with soil available nitrogen (N) and a negative correlation with available P or available potassium (K).

1. Introduction

Soil salinization, either caused by natural factors or anthropogenic activities, has been recognized as a serious problem worldwide, where there is notably in arid and semi-arid regions (Wichelns and Qadir, 2014; Singh et al., 2013; Wang et al., 2008).

Salt toxicity has negative effects on soil properties, including high pH, high level of sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP), poor soil structure and also low water permeability (Wong et al., 2008; Shukla et al., 2011; Singh et al., 2012a, 2012b). Salt accumulation also has detrimental effects on enzyme activities, microbial and biochemical activities (Rietz and Haynes, 2003; Karlen et al., 2008), limiting agriculture productivity (Rady, 2011). Yuan et al. (2007) conducted a survey in a salt-affected area located in Gansu Province, China to investigate the effects of soil salinity on biomass activity and community structure of soil microorganisms, showing that salinity is a stressful factor which reduces microbial communities and has harmful effects on soil organic matter decomposition and available nutrients uptake. This is similar to the results obtained by Rietz and Haynes (2003).

Soil enzyme activities are closely related to soil properties, soil types and environmental conditions, and are now widely used as important indicators of soil quality and soil biological activities (Rietz and Haynes, 2003; Yuan et al., 2007). Therefore, the study of factors influencing soil enzyme activities is important (Dick and Burns, 2011). Among all the enzymes, urease, alkaline phosphatase and catalase activity are more sensitive to environmental changes. Urease promotes the hydrolyze of nitrogen-containing organic matter specially and is closely related to the formation and availability of N in the soil (Liang et al., 2003). Activity of urease is sensitive to high salinity and sodicity. This suggests that urease activity can be used as an indicator of soil quality (H.S. Zhang et al., 2014). Phosphorus (P) in soil is mainly in the organic form. Alkaline phosphatase is the main enzyme involved in the cycling of P

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because it can transform organic P into inorganic P which is the available nutrient for plants (Dick and Burns, 2011). Alkaline phosphatase reacts to external environments sensitively and is an indicator of the organic P mineralization and biological activity of soils (Krämer and Green 2000; T.B. Zhang et al., 2014; T. Zhang et al., 2014). Catalase can enable the peroxide produced during metabolism to decompose, thus preventing its toxic effects on organisms. These enzyme activities play an important role in the cycling of soil carbon (C), N and P. Also, they participate in a great number of soil biochemical processes and they are directly involved in various biochemical reaction in the soil. However, few studies have compared enzyme activity in coastal saline soils.

Various soil amendments have been documented to improve soil properties. Chemical amendments are a common approach to reclaim saline soils which function to provide a source of Calcium (Ca) to replace the exchangeable sodium (Na) on the exchangeable sites. The replaced Na is then leached from the root zone through irrigation (Qadir and Oster, 2004; Qadir et al., 2006; Sahin et al., 2011). However, chemical amendments have become expensive for farmers with the increasing use by industry.

Microbial application for amelioration of sodic and saline–sodic soils is gaining popularity due to its better amelioration and reduction in economic and environmental costs. A study by Sahin et al. (2011) on irrigated land in the Igdir plain, Northeast Turkey was designed to determine the effects of microbial inoculation (fungi and bacteria) on saturated hydraulic conductivities of four saline-sodic soils ameliorated with gypsum. The results suggested that microbial mixtures played a key role in increasing the saturated hydraulic conductivities under saline soils.

Recently, applications of organic amendments (manure, compost and mulch) have been widely used as a strategy to improve soil quality. Liu et al. (2010) found that the use of organic manure with chemical fertilizers could increase microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) as well as the increase of enzyme activities (dehydrogenase, alkaline phosphatases, β-glucosidase and urease activity). Furthermore, organic amendments may improve nutrient availability and therefore enhance plant growth (Alburquerque et al., 2007). Also, the application of organic matter to saline soils increased soil structural stability and soil bulk density (Tejada and Gonzalez, 2005).

Hekang, saline soil amendment, is a kind of organic high polymer amendment. The principle of Hekang is to improve the solubility of $CaSO_4$ and $CaCO_3$ and to activate the solidified Ca in the soil based on the function of solubilization of anion organic acid complexes. The activated Ca replaces Na adsorbed by soil colloids. The displaced sodium ions and negative valency form water-soluble complexes which are leached from the soil along with chloride and sulphate ions allowing the H+, carbonate and bicarbonate ions to interact producing water and CO2. In China, the area of coastal saline land is $14.0 \times 10^4\,km^2$ along 1.8×10^4 km of coastline adjacent next to the Pacific Ocean. Coastal areas play an important role in the global system. However, these areas are so vulnerable to climatic changes because of poor drainage system and the intrusion of seawater (Datta et al., 2013; Lv et al., 2013). Due to periodic tidal activity, the salinity changes seasonally (Shi et al., 2005; Sun et al., 2012) which makes the soil complicated to manage and unsuitable for sustainable use. High salinity and pH in the coastal saline soils might be the two main limiting factors to enzyme activities. So, it is of great importance to study the effects of amendments on enzyme activities.

In our research, it was hypothesized that the soil amendment treatments Hekang, organic fertilizer and microbial inoculant can promote transformation of organic matter, thus increasing enzyme activity resulting in improved quality of severely salinized soil. The objectives of this study are to 1) find appropriate amendments from Hekang, chemical fertilizer, organic fertilizer and microbial inoculant to ameliorate coastal severe salinized soils based on the indicator—enzyme activity; 2) to reveal the relationship between soil enzyme activities and soil salinity, organic matter or some other soil properties.

2. Materials and methods

The soil for the test was collected from the topsoil (0–20 cm) of the typical zone located in Yellow River Town, Kenli County, Shandong Province (37°45′58. 7″ N, 118°58′40.1″E). This coastal soil is a loamy sand with sever salinity developed in the alluvial fan of Yellow River delta. The soil is with 8.71 of pH and 8.52 g kg^{-1} of salt content, and contained 12.69 g kg^{-1} of soil organic carbon, 0.78 g kg^{-1} of total nitrogen (TN), 42.73 mg kg^{-1} of available nitrogen (N), 16.14 mg kg^{-1} of available P, 178.67 mg kg^{-1} of available K.

2.1. Amendments for the experiment

a Hekang (HK): an organic polymer saline soil amendment (Registration No. 2000 [0277]);
b Chemical fertilizer (CF): urea as N, superphosphate as P, potassium (K) chloride as potash;
c Organic fertilizer (OF): name: Shi Danli; the content of organic matter is 30%, the amount of NPK is 8% and the ratio of N: P: K = 3: 2: 3;
d Microbial inoculant (MI): name: Jinbaobei microbial inoculant; registration No. 2005 [0176] of China; the number of effective viable cells $\geqq 10^{10}\,g^{-1}$.

2.2. Experimental design

There are one control (CK, original soil) and four kind of amendments—HK, CF, OF and MI, with amendment doses: 1, 2, 3 levels, a total of 13 treatments. Each treatment was repeated three times and arranged randomly. Details of the treatments are shown in Table 1.

All treatments received the same chemical fertilizer rate of 75 kg N (urea), 24.6 kg P (P_2O_5) and 46.7 kg K (K_2O) per ha. All fertilizers (half of the Nitrogen) were applied once to the soil before planting, individually. The other half of the Nitrogen was applied as a top dressing during the growing season of *S. salsa*. These doses were established based on the recommendation in the local area.

At June 20, 2014, soil (6 kg) and soil amendments were mixed to bulk density 1.4 g cm^{-3} (the solution of HK was poured into the pot after mixing the soil). The pots with 20 cm in depth, have drainage holes at the bottom and a piece of filter paper was placed on the hole. There is a tray at the bottom of the pot, and if there was some

Table 1
Treatments of the experimental study.

Factor	Fertilizer/kg ha^{-1}		
	Level 1	Level 2	Level 3
CK	–	–	–
HK	15	20	30
CF	N: 75	N: 150	N: 225
	P: 24.6	P: 49.2	P: 73.8
	K: 46.7	K: 93.4	K: 124.5
OF	37.5	75	112.5
MI	7.5	15	30

Note: application of HK, MI and OF with basal fertilizer— N-75 kg ha^{-1}, P-24.6 kg ha^{-1}, K-46.7 kg ha^{-1}. CK: control; HK: Hekang; CF: chemical fertilizer; OF: organic fertilizer; MI: Microbial inoculant.