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Dynamic characteristics of soil properties in a *Robinia pseudoacacia* vegetation and coastal eco-restoration

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ABSTRACT

Precipitation is one of the major determinants of soil moisture in plantations growing in the saline-alkali soil in the Yellow River Delta. The present study was conducted on a 28-yr old *Robinia pseudoacacia* plantation, a major vegetation type of the Yellow River Delta, and the results indicated strong seasonal patterns in soil moisture, salt, nutrient and enzyme activities at varying depths with respect to annual precipitation. Soil moisture during the growing season of March to October fluctuated drastically in response to precipitation events and was generally higher than that from November to February. Furthermore, soil water content in the 0–60 cm soil layer was positively correlated with precipitation during the same period but not for the value in the 60–80 cm soil layer. Salt content in different soil layers increased gradually from November to February, decreased from February to September and then increased in October. Precipitation was strongly and negatively correlated with soil salt content in different soil layers (except 20–40 cm). Soil enzymes became less active and soil nutrient contents decreased with soil depth, though different enzymes and nutrients showed seasonal variations. The activity of polyphenol oxidase increased in spring, reached the maximum values in June, and decreased in later months. The activity of alkaline phosphatase, proteinase and urease fluctuated throughout the growing season, with the maximum values in October. Available phosphorous increased in the early months and decreased after August, whereas available potassium, hydrolysable nitrogen and organic substances content in soil gradually increased throughout. Therefore, it is suggested that precipitation is the crucial limiting factor to tree growth through impacts on soil moisture, salt, nutrient and enzyme activities in saline-alkali soils in the Yellow River Delta.

1. Introduction

The Yellow River Delta is one of the most representative estuary wetland ecosystems with active land-ocean interactions in the world. *Robinia pseudoacacia* plantation started in the 1970s and 1980s in the maximum area arbor forest, exerting notably ecological function in this region. However, started from 1990, *R. pseudoacacia* plantation gradually showed the withering tree top and even the sheet death. Many researchers have studied canopy health (Liu et al., 2008), soil water storage ability (Xia et al., 2009) and soil physico-chemical properties (Zhang and Xing, 2009; Sun et al., 2006) on this forest. Precipitation is one of the major determinants of soil moisture in plantations growing in this area. However, it is still unclear the impacts of precipitation on dynamic characteristics of soil properties in the *R. pseudoacacia* plantation.

Soil characteristics have a vital impact on the ecosystem restoration (Toktar et al., 2016). Soil enzymes are the main mediators of soil biological processes because of their intimate relationship to organic matter degradation, mineralization and nutrient cycling (Marx et al., 2001). For example, polyphenol oxidase plays a role in the process of conversion of aromatic organic compounds to humus in soil. Catalase enhances oxidization of compounds using H_2O_2 in soil. Phosphatase hydrolyzes compounds of organic phosphorus

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and transforms them into inorganic forms for plants. Proteases are mainly responsible for hydrolyzing soil proteins into peptides and amion acids. Urease catalyses the hydrolysis of organic nitrogen to inorganic forms, which is from urea-type substrates to ammonia or ammonium ion. Invertase catalyses the hydrolysis of sucrose to glucose and fructose, and is linked to the soil microbial biomass.

Soil enzymes are produced by plants, animals and microorganisms (Zornoza et al., 2006). Their activities have been proposed as appropriate indicators of soil quality due to their high sensitivity to disturbance (Zornoza et al., 2006; García-Ruiz et al., 2008; Hendriksen et al., 2015). Soil moisture is an important determinant factor for soil enzyme activities (Henry, 2013). With the increase of soil moisture, enzyme potential activities increase (Baldrian et al., 2013; ÁBear et al., 2014). Whereas, Acosta-Martinez et al. (2011) reported high enzyme activities in drought soil. This can be explained with the report that under waterlogging condition, enzyme activities were impeded (Kang and Freeman, 1999). Variations on precipitation have been suggested to possess significant effects on enzyme activities (Munson et al., 2010; Ladwig et al., 2015). Salinity also has a powerful influence on soil enzyme activities. The increase of salinity decreases soil enzyme activities (Saviozzi et al., 2011; Pan et al., 2013). On the contrary, Morrissey et al. (2014) found salinity increase enhanced enzyme activity due to the increase of bacterial abundance in tidal wetlands. However, not all enzymes were sensitive to salinity (Saviozzi et al., 2011; Pan et al., 2013). Soil nutrients are positively correlated with enzyme activity (Pan et al., 2013; Burke et al., 2011), such as soil organic matter (García-Ruiz et al., 2008; Hendriksen et al., 2015). However, few studies were carried out to explore the impact of precipitation on soil moisture, salt, nutrient and enzyme in the coastal saline-alkali soil.

Soil salinity and water are two dominant factors on plant distribution in the Yellow River Delta (Yu et al., 2012). This area suffers greatly from soil secondary salinization and insufficient precipitation, demonstrating a high evaporation-precipitation ratio. Moreover, the decreases of freshwater supply from the yellow river in recent decades and intense human activities have significantly changed the original conditions in this area (Cui et al., 2010). Therefore, the main fresh water source of the coastal saline-alkali soil is from the precipitation and it determines the *R. pseudoacacia* forest survival and growth in this area. As the productivity decline of the *R. pseudoacacia* forest arose in recent decades, its protective functions have dropped significantly. To elucidate the decline mechanism of *R. pseudoacacia* plantation and recover its ecological functions in the Yellow River Delta, the study objectives were designed to explore soil moisture, salt, nutrient and enzyme seasonal change and examine the interactions among them and the impact of rainfall on them.

2. Materials and methods

2.1. Study area

The Yellow River Delta is the youngest land in China, which is located at the entrance of the Yellow River to the Bohai Sea. The secondary salinization is severe because of shallow groundwater, high total dissolved solid and sea water intrusion. The study was conducted at the Production base of Jinan Military Region in the Yellow River Delta (37°49′36.4″N, 118°46′37.1″E). The experimental site has a typical monsoon climate. The annual mean temperature is 12.3 °C, and the minimal and maximum temperature varied from −23.3 °C to 41.9 °C. The frost-free period is 210 days with an effective accumulated temperature of about 4300 °C. The average annual precipitation is 555.9 mm, with nearly 70% of the precipitation falling in summer (June to August). The average annual evaporation is 1962 mm, and 51.7% of annual evaporation occurs in the spring. Saline soil are the dominate soil types in the study area. Soil salt content range is 1.0‰-2.6‰ and pH range is 6.79–8.87. Groundwater level is approximately 1.5 m. The main vegetation in the delta includes *Phragmites australis*, *Suaeda salsa* and *Tamarix chinensis*. The experimental forest is pure *R. pseudoacacia* tree which was established in 1980s by planting nursery-raised one year old seedlings at a spacing of 2.5 m × 3 m. At present, the preservation rate of this plantation is 78%.

2.2. Experimental design

Three plots were established at typical pure *R. pseudoacacia* forest. The size of the sample plots was 30 m × 30 m. Six soil samples were collected randomly from each plot using a soil core cutter (diameter, 7.5 cm) for 0–80 cm soil depth at 20 cm intervals. Soil water content and salt content in different depths were monitored every month from November of 2007 to October of 2008. Furthermore, six soil samples of *R. pseudoacacia* forest in each plot were collected separately using soil core cutter from 0 to 20 cm and 20–40 cm in April, June, August and October of 2008. The soil samples of the same depth were mixed. The soil samples were placed in sealed plastic bags and taken to the laboratory. Some fresh soil samples were preserved at 4 °C for measurement of enzyme activity. Another portion was used for soil parameter analyses.

2.3. Soil moisture, salinity, enzyme and nutrient analysis

Soil moisture was determined gravimetrically by weighing and drying in an oven at 105 °C for 12 h. Some soil samples was air-dried and used for determining soil electrical conductivity (EC). EC was measured using a conducting meter (DDSJ-308, Shanghai, China) in a 1:5 soil-water extract. A portion of soil samples was air-dried and sieved to 0.25 mm to measure available phosphorus, available potassium, hydrolysis nitrogen and organic matter.

Soil enzyme activities were measured as described by Guan. All enzyme activities were determined from wet samples. The polyphenol oxidase activity was measured by gallnut method. The catalase activity was measured by potassium permanganate titration method. The alkaline phosphatase activity was expressed on a soil dry weight by correcting for water content in the soil at the time the sample was removed from the incubation bottle and is given in units of mg *p*-nitrophenol produced g^{-1} soil h^{-1}. The protease activity was measured by the method that gelatin was turned into glycin in phosphate buffer (pH = 7.4). The urease activity was determined by the method that urea was turned into NH_3 in citric acid buffer (pH = 6.7). The invertase activity was measured by the methods for the formation of glucose by sucrose hydrolysis.

Soil organic matter was measured by the $K_2Cr_2O_7$-H_2SO_4 oxidation method of Walkey and Black. Hydrolysis nitrogen was measured by the alkaline diffusion method, and available phosphorus was measured by the Bray method (Institute of Soil Science, Chinese Academy of Sciences, 1978). Available potassium was measured by flame photometry method (Worth, 1985). Precipitation data was provided by Hekou district meteorological station of Shandong Province, China.

2.4. Data analysis

Soil water content, salt content, enzyme activities and nutrient were tested by using a two-way ANOVA. Least-significant difference (LSD) multiple comparisons were conducted. Correlation analyses were used to investigate relationships between precipitation and soil water content and salt content. The statistically