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Effects of Rice-Wheat Rotation and Afforestation on Microbial Biomass Carbon in Coastal Salt-Affected Soils of Eastern China

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ABSTRACT

Rice-wheat rotation and poplar afforestation are two typical land use types in the coastal reclaimed flatlands of eastern China. This study investigated two rice-wheat rotation lands (one reclaimed from 1995 to 2004 and cultivated since 2005, RW1, and the other reclaimed from 1975 to 1995 and cultivated since 1996, RW2) and a poplar woodland (reclaimed from 1995 to 2004 and planted in 2004, PW1) to determine the effects of land use types and years of cultivation on soil microbial biomass and mineralizable carbon (C) in this coastal salt-affected region. The results showed that the soil in PW1 remained highly salinized, whereas desalinization was observed in RW1. The total organic C (TOC) in the top soil of PW1 and RW1 did not show significant differences, whereas at a soil depth of 20–30 cm, the TOC of RW1 was approximately 40%–67% higher than that of PW1. The TOC of 0–30-cm soil in RW2 was approximately 37% higher than that in RW1. Microbial biomass C (MBC) and mineralizable C (MNC) exhibited the trend of RW2 > RW1 > PW1. Sufficient nutrition with more abundant C substrates resulted in higher MBC and MNC, and soil respiration rates were negatively correlated with C/N in RW1 and RW2. Nutrient deficiency and high salinity played key roles in limiting MBC in PW1. These suggested that rice-wheat rotation was more beneficial than poplar afforestation for C accumulation and microbial biomass growth in the coastal salt-affected soils.

Key Words: carbon availability, flatland, land use, mineralizable carbon, nutrition availability, total organic carbon

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INTRODUCTION

Numerous studies have analyzed the adverse effects of increased secondary salinity on crop production, soil organic carbon (SOC), microbial activity, and soil structure (such as aggregate dispersion) (Yan and Marschner, 2012; Kamble *et al.*, 2014). Secondary salinity in soils is mainly caused by agricultural operations, such as artificial irrigation (Al-Ghobari, 2011), the application of chemical and organic fertilizers (Kamble *et al.*, 2014), and monocrop plantation (Clarke *et al.*, 2002). Surface soils with shallow groundwater can also accumulate salt through capillary movement (Rengasamy, 2006). High salt concentrations in soils cause increased osmolarity outside the plant roots and microbial cells (Wong *et al.*, 2010) and increased sodium (Na^+) or chloride (Cl^-) toxicity, which will compete with other cations, interfere with nutrient uptake (Rengasamy, 2006; Grewal, 2010), and eventually reduce crop production and carbon (C) input. Unlike secondarily salinized soils, coastal saline soils originate from marine and fluvial deposits containing high salt concentrations and low organic C levels at the onset of soil formation (Jin *et al.*, 2013). In the context of land resource stress, reclaimed coastal saline mudflats represent important land reserve resources. Indeed, in recent decades, many coastal tidal flatlands have been enclosed for land expansion in the developed coastal areas of China. For example, in the coastal areas of Jiangsu Province, China, 1.8 million ha of coastal mudflats were reclaimed from 1996 to 2008, and an additional 2.7 million ha of mudflats are expected to be reclaimed by 2020. These newly reclaimed flatlands are protected from seawater immersion by seawalls, and over time, the salt concentration declines because of rainfall. Vegetation succession proceeds from bare land to salt-tolerant plants, such as *Suaeda sala*, until *Aeluropus littoralis* flourishes as the dominant species. Farmers then cultivate the *A. littoralis* grassland, planting salt-tolerant crops, such as cotton, wheat, and rice. Poplar woodlands are also common landscapes that are initially used as coastal

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windbreaks. After reclamation and cultivation, the salt content in soil declines in the farmlands on the coastal mudflats, but it continues to be seasonally affected by the intrusion of seawater into the groundwater.

The SOC in coastal saline soil is always low, and C inputs are restricted by the high salt content in the soil. This factor is important for improving soil quality, increasing water-holding capacity (Laird and Chang, 2013), providing nutrients for plants, and helping to stabilize soil aggregates (Six *et al.*, 2000), among other effects. Additionally, SOC accumulation in soil contributes to decreasing atmospheric greenhouse gases (Setia *et al.*, 2011). Land use and plant life exert substantial influences on SOC by altering the decomposition rates and C input. Many reports have demonstrated that intensive cultivation practices (such as tillage, irrigation, and fertilization) directly impact soil structure and microbial community and can substantially reduce SOC and microbial biomass C (MBC) (Bossio *et al.*, 1998). The MBC is an important indicator of soil fertility and can be effectively used as an index to evaluate soil quality (Yadav, 2012). High MBC is always associated with high organic matter (Sabahi *et al.*, 2010). Microbial biomass accumulation also contributes to C sequestration by generating fungal hyphae and organic macromolecules that improve soil aggregation (Liang *et al.*, 2011). The mineralizable C (MNC), which reflects the bioavailability of the SOC, is also determined by the quality of SOC (Jäger *et al.*, 2011). Increased soil salinity has been reported to be associated with decreased microbial biomass and microbial activity (Pankhurst *et al.*, 2001). These factors profoundly impact nutrient cycling, soil fertility, and SOC decomposition .

Rice-wheat rotation and afforested poplar woodlands are two typical land use types in the coastal mudflats of eastern China. In this study, we selected rice-wheat rotation lands reclaimed over two different periods and a poplar woodland reclaimed during the same period as one of the rice-wheat rotation lands to investigate the effects of these two types of land use and the years of cultivation on soil MBC and MNC in the coastal salt-affected region.

MATERIALS AND METHODS

Study area

The mudflats in Dongtai (32°33′–32°57′ N, 120° 07′–120°53′ E) are representative of northern coastal mudflats in China and cover an area of 3 175 ha. The altitude of the flatland ranges from 1.4 to 5.1 m and the temperature from −7.5 to 35.9 °C. The average annual precipitation is 1 100 mm (Wang *et al.*, 2012). The soils in this region were formed from marine and fluvial deposits and always contain high salt concentrations. In the past decades, tidal flatlands were reclaimed in several periods. Rice-wheat rotation and afforested poplar woodlands are two typical land use types in this area. Two rice-wheat rotation lands selected in this study were operated by the same farm, but reclaimed in different periods. One (RW1) was reclaimed from 1995 to 2004, has been cultivated since 2005, and covers 1.83 km^2. The other (RW2) was reclaimed from 1975 to 1995, has been cultivated since 1996, and covers 3.81 km^2. The two rice-wheat rotation lands are separated by a seawall built in 1995. Farming management techniques in RW1 and RW2 were the same. Both were operated using large farming machines, and crop straw was returned to the soil after being shredded by harvesters. The farmlands were irrigated by groundwater, and the nitrogen (N) fertilizer inputs were approximately 600 kg N ha^{-1} year^{-1} in recent years. Because RW1 and RW2 were subjected to the same geographical conditions and agricultural management strategies, the effects of rice-wheat rotation on different time scales on microbial biomass can be studied. One studied poplar woodland (PW1) selected in this study was reclaimed in the same period as RW1. The poplar trees were planted in 2004 with no fertilizer input. Given that PW1 and RW1 share the same reclamation history, the effects of the two land use types on soil microbial biomass can be compared.

Sample collection and laboratory analysis

Soil samples were collected in October 2014 after harvesting the rice but before plowing the soil. In each land use studied, 15 soil samples were collected at each soil depth (0–10, 10–20, 20–30, 30–50, 50–70, and 70–100 cm). After collection, the soils were air dried, ground, and sieved. Soil particle size distribution was determined by the sieve-pipette method (FHZDZTR0007). Soils used for the determinations of electronic conductivity in the 1:5 soil:water extract ($EC_{1:5}$) and pH were sieved using a 0.85-mm sieve and measured with an electrode. The electronic conductivity in the saturated extract (EC_e) was calculated from the $EC_{1:5}$ value (Li *et al.*, 2014). Soil total organic C (TOC), total N (TN), available N (AN), and available phosphorus (AP) were determined according to Bao (2000). Additionally, the soil bulk density (BD) and field water capacity (FWC) were measured using steel cylinders (Zhang *et al.*, 2006).

The labile C pool can exert considerable impacts on ecosystem functioning by influencing the microbial