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Soil development under different cropping systems in a reclaimed coastal soil chronosequence

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ABSTRACT

Dynamics of reclaimed coastal soils under cultivation has not been well understood. In this study, we analyzed major soil chemical properties under two cropping systems (rice–barley vs. cotton–barley cropping systems) along a 60-year soil chronosequence created by intermittent reclamation of coastal salt marshes in Shangyu, Zhejiang Province of China. Soil horizons were identified and selected pedogenic properties such as soil salinity, pH, organic carbon (SOC), nitrogen, phosphorus, potassium, manganese (Mn), zinc (Zn) and copper (Cu) were used to characterize the horizons. Results showed that the soil profiles with 36-year or longer cultivation durations included the soil horizon arrangement of A–B–C, while those with 28-year or shorter cultivation durations had the soil horizon arrangement of A–C. The paddy soil profiles showed the plow pan and redoximorphic features with rice–barley cropping system, but the upland soil profiles did not show redoximorphic features and a distinct plow pan with cotton–barley cropping system. Rice–barley cropping system significantly increased the contents of SOC, nitrogen, diethylenetriamine penta-acetic acid (DTPA)-Mn, DTPA-Zn, and DTPA-Cu in 0–20 cm soil depth, but significantly decreased soil pH, salinity and potassium in 0–20 cm soil depth. The chronosequence of soil development was obvious in terms of increasing the contents of SOC, nitrogen, phosphorus, DTPA-Mn, DTPA-Zn, and DTPA-Cu with cultivation time, and decreasing soil pH, salinity, and the contents of potassium, total Mn, total Zn and total Cu with cultivation time except for no obvious decreases of total Cu in the cotton–barley cropping systems. Thirty-six years of cultivation history seemed to be long enough to differentiate paddy profiles with rice–barley cropping system from upland ones with cotton–barley cropping system in terms of soil pH, salinity, and SOC contents. Therefore, the direction and intensity of soil development undergone by the reclaimed soils depend not only on their natural characteristics but also on the way and time that they are managed after land reclamation. The results of this work could be helpful for management plans in reclaimed coastal areas.

1. Introduction

Natural coastal wetlands (i.e., salt marshes) are an important land resource for agriculture in China, as the coastal area is usually abundant in resources of light and heat. China has been a long history to convert the wetlands into agricultural lands through consecutive land reclamation by protective dikes (An et al., 2007; Cheng et al., 2009; Nambiar et al., 2001; Shi et al., 2002). Parts of the lands were used for paddy fields, other parts for a variety of upland crops (Cui et al., 2012; Fu et al., 2012; Iost et al., 2007; Liu et al., 2013). As a driver of reclamation strategy, detailed knowledge of soil dynamics under influences of various agricultural land uses is crucial, not only from a reclamation perspective, but above all in terms of management rules, which are necessary to ascertain the direct impacts of reclamation on coastal soils (Fernández et al., 2010; Nambiar et al., 2001).

The changes of soil properties in response to different reclamation chronosequences have been documented on the coastal area (Fu et al., 2012; Iost et al., 2007; Liu et al., 2013). Fu et al. (2012) and Liu et al. (2013) concluded that the rice–barley cropping decreased soil salinity after a reclamation time of more than 10 years. Tan and Kang (2009) found both of soil salinity and pH value in 0–40 cm soil layer dropped markedly after reclaiming three years. The series investigations on a cultivation chronosequence revealed clear temporal trends in soil physical, chemical and microbiological properties (Cheng et al., 2009;

Abbreviations: RB16, 16 years of rice–barley cropping history; CB16, 16 years of cotton–barley cropping history; RB28, 28 years of rice–barley cropping history; CB28, 28 years of cotton–barley cropping history; RB36, 36 years of rice–barley cropping history; CB36, 36 years of cotton–barley cropping history; RB60, 60 years of rice–barley cropping history; CB60, 60 years of cotton–barley cropping history; SOC, soil organic carbon; N, nitrogen; P, phosphorus; K, potassium; Mn, manganese; Zn, zinc; Cu, copper; DTPA, diethylenetriamine penta-acetic acid.

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Cui et al., 2012; Zou et al., 2011). Soil properties including organic carbon, soil reaction (pH), solum thickness and clay content had systematic and time-dependent trends after reclamation of coastal wetlands (Merritts et al., 1991; Muhs, 2001). The paddy soil management and irrigated anaerobic rice cropping were favorable for accumulation of soil organic matter (Zhang and He, 2004). Centuries of cultivation had significantly improved overall soil fertility (Cui et al., 2012). Hubbard et al. (2013) reported that the cover crop cropping systems increased soil carbon and nitrogen due to the input of cover crop biomass, which contributed to improvements in soil structure and fertility. Chen et al. (2011) found that rice cultivation rapidly favored the accumulation of soil organic carbon in the surface horizon and decreasing cocentrations of Ca, Mg, and Na within 50 years, and slowly haddecalcification and migration of clay, P, Mn, and Fe within 700 years. However, soil analytical and mineralogical characterizations had been found to make no notable changes with time due to relatively young soil age after reclamation (Tsai et al., 2007). Many other studies have focused on the soil properties that have developed in reclaimed coastal wetlands under various agricultural activities including: cropping systems (Cui et al., 2012; Yao et al., 2013), paddy fields and uplands (Cheng et al., 2009; Liu et al., 2013), and organic and conventional farming (Fliesbach et al., 2007), but as far as we know few have addressed how soil dynamics would change under different land uses along a reclaimed soil chronosequence (Cui et al., 2012; Fernández et al., 2010).

Cropping systems often affect not only soil properties but also soil development, which makes it difficult to separate the effect of cropping systems on soil dynamics from that of other agricultural activities, such as different reclamation chronosequences. Therefore, to assess the response of soil dynamics to cropping systems, we carried out an experiment with two cropping systems (rice–barley cropping system (RB), a cropping sequence of flooded paddy rice in summer followed by barley in winter, and cotton–barley cropping system (CB), a cropping sequence of cotton in summer followed by barley in winter) in a reclaimed coastal saline soil chronosequence on the eastern coast of Shangyu County, Zhejiang Province of China. The cropping systems represent the major crop rotation patterns and the study area covers typical coastal salt-affected soils in China. The objectives of this study were to compare soil dynamics between the two cropping systems at a field scale experiment along a reclaimed coastal saline soil chronosequence on fairly uniform marine deposits under nearly identical climate and landscape.

2. Materials and methods

2.1. Experimental site

The research area is located in Shangyu County of Zhejiang Province, China. The research area covers about 19,000 ha. The climate is classified as subtropical monsoon with average annual temperatures between 15 °C and 19 °C and annual precipitation of 1300 mm. The potential evapotranspiration is greater than the precipitation amount during the months of July and August (Shi et al., 2002). The test soils were derived from Hangzhou Bay sediments that had been developing under similar ecological conditions, and thus the present soils are in a chronosequence (Fu et al., 2012).

2.2. Field experiments

Field experiments were conducted with two cropping systems (i.e., rice–barley and cotton–barley cropping systems) and three replications (each one in 22 m × 10 m plot area) at the four experimental sites reclaimed from salt marshes in 1952, 1976, 1984 and 1996 along the coast of Hangzhou Bay and thus cultivated for 60, 36, 28 and 16 years (referred to as cultivation time hereafter), respectively. Table 1 summarizes the description of nine treatments: (i) salt marsh (Marsh), which involved the salt marsh covered by *Phragmites australis* communities in 2012; (ii) 16 years of rice–barley cropping history (RB16), which involved the experimental site reclaimed in 1996 and a 16-year rotation pattern with rice cultivation in summer and barley cultivation in winter; (iii) 16 years of cotton–barley cropping history (CB16), which involved the experimental site reclaimed in 1996 and a 16-year rotation pattern with cotton cultivation in summer and barley cultivation in winter; (iv) 28 years of rice–barley cropping history (RB28), which involved the experimental site reclaimed in 1984 and a 28-year rotation pattern with rice cultivation in summer and barley cultivation in winter; (v) 28 years of cotton–barley cropping history (CB28), which involved the experimental site reclaimed in 1984 and a 28-year rotation pattern with cotton cultivation in summer and barley cultivation in winter; (vi) 36 years of rice–barley cropping history (RB36), which involved the experimental site reclaimed in 1976 and a 36-year rotation pattern with rice cultivation in summer and barley cultivation in winter; (vii) 36 years of cotton–barley cropping history (CB36), which involved the experimental site reclaimed in 1976 and a 36-year rotation pattern with cotton cultivation in summer and barley cultivation in winter; (viii) 60 years of rice–barley cropping history (RB60), which involved the experimental site reclaimed in 1952 and a 60-year rotation pattern with rice cultivation in summer and barley cultivation in winter; and (ix) 60 years of cotton–barley cropping history (CB60), which involved the experimental site reclaimed in 1952 and a 60-year rotation pattern with cotton cultivation in summer and barley cultivation in winter. In this study, the processes of paddy soil formation are triggered by the rice–barley cropping management, and the genesis of upland soils is developed by the cotton–barley cropping management.

Tillage methods were as follows: soil plowing and harrowing under water-saturated soil conditions then surface drainage before planting rice seedlings, dry soil tillage before planting cotton seedlings and sowing barley seeds. The total supplemental irrigation water application was 3500 m^3 ha^{-1} per year, which was applied four times during the rice growth season. Barley and cotton were not irrigated. The planting density of rice was 13.3 seedlings m^{-2} with a spacing of 30 cm × 25 cm. The fertilizer rates in the rice season were 190 kg N ha^{-1}, 84 kg P_2O_5 ha^{-1}, and 75 kg K_2O ha^{-1}. The planting density of cotton was 7.7 seedlings m^{-2} with a spacing of 43 cm × 30 cm. The fertilizer rates in the cotton season were 150 kg N ha^{-1}, 95 kg P_2O_5 ha^{-1}, and 75 kg K_2O ha^{-1}. The seed rate of barley was 75 kg ha^{-1}. The fertilizer rates in the barley season were 150 kg N ha^{-1}, 75 kg P_2O_5 ha^{-1}, and 150 kg K_2O ha^{-1}. Nitrogen fertilizer was applied in the form of urea, phosphorus fertilizer was applied as calcium super phosphate, and potassium fertilizer was applied as potassium sulfate. Stubbles 15–30 cm high were generally left in the fields after rice and barley harvesting, and there was almost no intentional return of cotton residues in the fields after cotton harvesting. Hence about 2.35 Mg ha^{-1} and 4.70 Mg ha^{-1} stubble was annually returned to soil in cotton–barley cropping system and rice–barley cropping system, respectively.

2.3. Soil sampling and analysis

In October 2012, soil samples from each plot and the salt marsh were collected according to five depth units: 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm and 80–100 cm soil layers after the rice or cotton harvesting. Five cores per plot were randomly taken and mixed together, ensuring that the same layers were kept together. Soil samples were air-dried and ground to pass through a 2 mm screen prior to analysis. Soil samples in 0–20 cm depth soil layer were for soil nutrient analysis.

Soil pH was determined by an electrode method with a ratio of soil and distilled water at 1:5 (g:ml) by glass electrode (McLean, 1982). Soil salinity was measured with a platinum electrode on a suspension that was prepared with a ratio of soil and distilled water at 1:5 (g:ml) and soil organic carbon (SOC) was measured by the dichromate oxidation method (Lu, 1999). Alkali nitrogen (N), Olsen phosphorus (P), and available potassium (K) were determined by the diffusion