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Rapid changes in phosphorus species in soils developed on reclaimed tidal flat sediments

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ABSTRACT

Phosphorus (P) plays a key role in the global biogeochemical cycle. The dynamics of P in soils is of considerable importance to the management of soil fertility. However, little is known about P dynamics in reclaimed land at the centennial scale during the initial stage of soil development, when the ambient conditions undergo substantial changes. In this study, conducted in Eastern China, we used a sequential extraction method to analyze the changes in P species in sediments and soils in a coastal reclaimed area representing a sequence of soil ages. Significant accumulation of total P accompanied by organic matter enrichment, desalination, and decalcification were observed in the initial pedogenesis of reclaimed tidal flat sediments. A rapid change in top soil P species within a century of pedogenesis was revealed, which was characterized by a marked decline in P contained within primary minerals (DeP) and an increase in loosely absorbed P, Fe-bound P, authigenic P (CaP), and organic P. DeP decreased from 67.3% to 25.3% of total P, whereas CaP increased from 8.4% to 32.9% along the reclamation gradient. Dissolution of primary minerals and a high rate of fertilization were identified as the major causes of this P trajectory. A key factor controlling the evolution of soil P speciation is the marked change in ambient conditions following land conversion, resulting in a shift in anaerobic conditions, a decrease in pH, accumulation of organic matter, and depletion of carbonates. Under the strong interference of human activities, the P dynamics in soils derived from tidal flat sediments differ from those predicted by the Walker and Syers model. Our results indicate that current nutrient management practices in the studied area can not only avert soil P depletion but also increase P availability.

1. Introduction

Phosphorus (P) is an essential nutrient supporting plant growth and plays a key role in the global biogeochemical cycle (Sanudo-Wilhelmy et al., 2001). Knowing the fate of P in soils is of considerable significance in the management of soil fertility and evaluation of potential environmental pollution (Kumar and Yadav, 2001).

Soil development is difficult to assess experimentally because of the long timescales involved, and soil chronosequences are typically applied as valuable tools for investigating the directions and rates of soil development (Walker and Syers, 1976; Huggett, 1998). On the basis of a review of various long-term soil chronosequences, Walker and Syers (1976) proposed a conceptual model describing P evolution during natural soil development, which demonstrated the loss of P and transformation from primary mineral P to secondary P minerals and organic P. However, whereas the Walker and Syers model and many subsequent studies on P cycling have focused mostly on natural long-term soil chronosequences (Ryan and Zghard, 1980; Crews et al., 1995; Zhou et al., 2013) there has been relatively little research focused on the short-term evolution of P species in response to human activities.

Coastal zones are transitional zones that link terrestrial and marine ecosystems and are hotspots for global biogeochemical cycle studies (Liu et al., 2004). However, coastal areas have been increasingly modified by various human activities for agriculture, construction, and recreation. To alleviate the conflict between growing populations and limited land resources, reclamation of coastal land is an efficient and common measure in such coastal areas (Li et al., 2014). In Jiangsu Province, Eastern China, a total land area of > 260,000 ha was reclaimed between the years 1951 to 2007 (Zhang et al., 2011). According to the land-use plan of Jiangsu Province, over 180,000 ha of tidal flats will need to be reclaimed from 2010 to 2020 (Wang and Zhu, 2009).

Changes in basic soil physical and chemical characteristics after reclamation have been widely studied in recent investigations (Cui

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et al., 2012; Wang et al., 2014; Yin et al., 2016; Zhang et al., 2016). It has been reported that P is the primary factor limiting agricultural production in the reclaimed coastal land in Eastern China (Chen et al., 1993), and that there has been a considerably high P input to these lands through the application of fertilizers (Liu, 2015). Thus, knowledge of P dynamics is essential for agricultural management in these newly reclaimed lands. Recently, long-term P evolution during paddy soil development has been revealed in China's coastal region (Huang et al., 2013; S. Huang et al., 2014; L.M. Huang et al., 2014). However, little is known about the changes in P species at the centennial scale in the years immediately after the occurrence of land conversion. In view of the fact that the response of soil properties to land conversion is more sensitive during the early stage when the ambient conditions undergo substantial changes (Zuo et al., 2012; Li et al., 2015), it is essential to reveal short-term P dynamics in reclaimed coastal land.

Sequential extraction has been shown to be an effective method for revealing the dynamics of P in soils and sediments (Cross and Schlesinger, 1995; Vink et al., 1997; Liu et al., 2004; Zehetner et al., 2008; Boyle et al., 2013; Mishra et al., 2013). A sequential extraction method (SEDEX), developed by Ruttenberg (1992), has been extensively used to study the P cycle in estuaries and marine sediments because this method has provided new insights into the P cycle of coastal calcareous soils by separating authigenic phosphate carbonate minerals from primary apatite minerals (Ruttenberg, 1992; Vink et al., 1997; Monbet et al., 2007; Matijević et al., 2008; Matijević et al., 2009; Jaisi and Blake, 2010; Monbet et al., 2010; Sekula-Wood et al., 2012; Zhuang et al., 2014).

The objectives of the present study were (i) to reveal the changes in P species following a century of reclamation from tidal flats by applying the SEDEX scheme; (ii) to examine the relationships between P species and various soil properties; and (iii) to determine the natural and anthropogenic factors influencing P evolution in reclaimed land.

2. Materials and methods

2.1. Site description

The study area (120°30′–120°55′E, 33°00′–33°33′N) is located in Jiangsu Province, China, at the edge of a coastal plain, and has an altitude of several meters above sea level (Fig. 1). It has a warm temperate monsoon climate with distinct seasons and a rainy summer. The annual average temperature is 14 °C, with 209 frost-free days. The annual average rainfall is 1068 mm, with an evaporation potential of 1418 mm. The major soils in this region are Fluvisols (FAO/UNESCO Taxonomy) derived from fluvial-marine deposits.

The Yangtze River is one of the two dominant sources of coastal zone sediments in the studied area. Sediments of Yellow River origin also contributed abundant sediments from the Loess Plateau and other regions in Northern China to this coastal area between 1495 and 1851, until the river channel was diverted northward (Zhang, 1984). Because tidal flats in northern Jiangsu Province have a very high accretion rate due to abundant sediment sources, coastal wetlands have been repeatedly reclaimed in the last century. Dikes were built at different stages of land conversion (Zhang et al., 2013). Thus, the land surrounded by two or more dikes was formed during approximately the same period. Reclaimed lands converted at different historical stages make this region an ideal location to conduct research on initial pedogenesis (Zhang et al., 2016).

The study area, covering an area of approximately 1900 km^2, was divided into five zones in this study based on the time of embankment (Fig. 1). The ages of the reclaimed land were obtained by interpretation of satellite images, and by reviewing local historical literature. Zone A is currently natural tidal flats, normally 2 to 3 km in width. Major species growing here include *Spartina anglica* C.E. Hubb., *Suaeda salsa* (L.) Pall., and *Phragmites australis* (Cav.) Trin. ex Steud., distributed from the shoreline to the present dike (Yao et al., 2009). Zones B, C, D, and E from tidal flat to inland side are reclaimed lands, which underwent conversion 10, 30, 60, and 90 years ago, respectively. The main land-use in Zone B is aquaculture. This zone is dominated by fishing ponds of various sizes. In Zones C, D, and E, reclaimed lands are intensively used for farming. Normally, the salt concentrations in sediments decreased to acceptable levels after several years, and then these zones could be used for crop cultivation. Major crops grown in these zones include rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), maize (*Zea mays* L.), cotton (*Gossypium herbaceum* L.), and rape (*Brassica campestris* L.). Soils with a longer history since

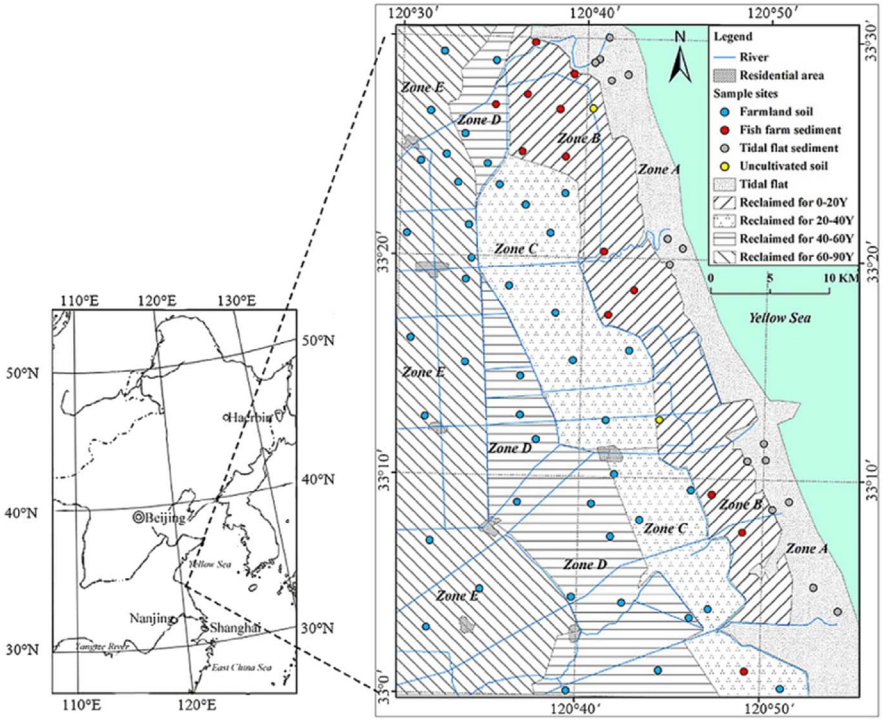

Fig. 1. Location of the study area and sampling sites.