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Soil physicochemical properties associated with quasi-circular vegetation patches in the Yellow River Delta, China

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ABSTRACT

In recent years, decreased runoff and sediment, intensified storm surge and seawater intrusion, urbanization, petroleum exploration, and production, and other factors have gradually deteriorated the unique wetland ecosystem in the Yellow River Delta (YRD). Although previous studies have analyzed the relationships between vegetation and soil properties at different scales, few studies have documented quasi-circular vegetation patches (QVPs) in the YRD, which appear to exhibit faster succession rates that make them ideal for studies on the relationships between vegetation and soil properties. Therefore, this study investigated differences in soil physicochemical properties at 0–20 cm depths between QVPs and inter-QVP bare soil areas, among QVPs, and among plant species communities. Additionally, spatial variations in soil physicochemical properties were explored in south-north and west-east transects across and within QVPs. The results showed that soils beneath QVPs had significant fertility island effects associated with soil organic matter (SOM) and total nitrogen (TN). Furthermore, these areas were richer in clay content, showed slightly higher pH values, and exhibited less available phosphorus (APH), available potassium (APO), total salt content, and silt content than those of bare soil areas. A multiple independent samples nonparametric Kruskal-Wallis H test detected significant differences in SOM, TN, APH, and pH among 18 QVPs, but no significant differences were found in APO, total salt content, sand, silt, and clay contents. Regardless of plant species, different plant species communities had significant effects on soil physicochemical properties. Particularly, soils underneath plant species communities with *Tamarix chinensis* were richer in SOM and TN, and they contained less APH, APO, and total salt content than those without *T. chinensis*. In each QVP, values of SOM and TN in soil samples along the patch perimeter were less than those of samples located midway toward the perimeter, and these values were less than those of samples centered in the patch. However, APO and total salt content values exhibited opposite changes from the perimeter to the center of the patch. The results also indicated significant differences in SOM, TN, APH, APO, and pH between south-north transect A and west-east transect B across QVPs, but no significant differences were found in total salt content, sand, silt, and clay contents. Therefore, the results of this study indicate that QVPs have significant effects on topsoil nutrients and salinity but little effects on soil texture. Furthermore, the occurrence and development of QVPs are associated with suitable soil conditions, including higher clay fractions and lower total salt content values.

1. Introduction

Soils and plants represent two key elements of terrestrial ecosystems (Jiao et al., 2014), and interactions between plants and soils are important for ecosystem functionality (Jiao et al., 2014; Mora and Lazaro, 2013). Vegetation and soils both rely on and resist each other using a feedback mechanism in the plant-soil system (Ehrenfeld et al., 2005; Jiao et al., 2014; Mora and Lazaro, 2013). In general, the feedback mechanism is more obvious in plants that are grown in extreme environments (Ehrenfeld et al., 2005). In arid (including hyper-arid) and semi-arid zones, which cover approximately 36% of the global land area (Yang and Williams, 2015), the markedly patchy structure of vegetation is the result of plant-soil feedback occurring in water-limited areas (Aguiar and Sala, 1999; Bochet et al., 1999; Bordeu et al., 2016;

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Mora and Lazaro, 2013; Saco et al., 2007; Shoshany and Kelman, 2006; Webster and Maestre, 2004). However, soil physicochemical properties exhibit complex spatial and temporal heterogeneity, in large part due to the patchy distribution of vegetation, especially from perennial plants (Bagstad et al., 2006; Butterfield and Briggs, 2009; Liu et al., 2017), where soil nutrients are captured and fertility islands are well-established (Butterfield and Briggs, 2009). The resilience of arid and semi-arid ecosystems depends largely on the standing of fertility islands associated with patchy vegetation, so an understanding of the relationships between soil physicochemical properties and patchy vegetation and an assessment of differences in soil physicochemical properties associated with vegetation patches and bare soil areas are important for the optimal protection and restoration of arid and semi-arid ecosystems.

Banded and spotted vegetation have been reported in Africa, America, Australia, and Asia (Armas et al., 2008; Dunkerley and Brown, 2002; Lejeune et al., 2004; Liu et al., 2013), and these vegetation types do not appear to be specific to particular soils, parent materials, or plant species (Bordeu et al., 2016). Although various hypotheses have been suggested to explain the occurrence and encroachment of patchy vegetation (Aguiar and Sala, 1999; Bochet et al., 1999; Kinast et al., 2014; Sheffer et al., 2011), there is an ongoing controversy regarding the formation mechanisms associated with patchy vegetation patterns. Many researchers have suggested that the disturbance of local vegetation causes the formation of fertility islands, and nutrient effects are most distinct in the top 15 cm of the soil, decreasing quickly with depth (Daryanto et al., 2012). Tree species, tree mortality, and stand landscape features can cause variations in within-stand soil physicochemical properties (Erickson et al., 2005). The invasion and expansion of shrubs increases the spatial heterogeneity of soil physicochemical properties along semi-arid grass slopes in the Loess Plateau, China (Wei et al., 2013). Clustered tamarisk has a larger associated fertility island than that of isolated tamarisk as well as higher available nitrogen and available phosphorous than those of open land. Furthermore, fertility island effects could weaken following vegetation restoration and succession of plant communities in the coastal wetlands of Laizhou, China (Liu et al., 2017). Grasses could increase differences in soil physicochemical properties because of relatively higher quality substrates of soil microflora (Kerns et al., 2003). For instance, perennial alfalfa grasslands and reeds can effectively protect and improve soil nutrients and soil particle fractions in the Yellow River Delta (YRD) (Jiao et al., 2014). In the shortgrass steppe of northern Colorado, enriched nutrient-supply areas under dead patchy plants do not persist beyond several months (Kelly and Burke, 1997). Numerous investigations suggested that soil physicochemical properties are significant factors that control plant growth and plant species distribution, and they are associated with the recovery and maintenance of degraded ecosystems (Abbas et al., 2016; Liu et al., 2018).

The YRD, one of China's three major river deltas, is one of the fastest growing deltas in the world, and it represents some of the most recently formed land since 1855 (Liu et al., 2013). The unique environmental evolution and ecosystem succession of the YRD have always been the focus of global change research, and these factors have been monitored by the National Aeronautics and Space Administration of USA through the Earth Observatory's Mission (Liu et al., 2014). As a typical fragile ecosystem and a key area of ecological protection, YRD represents aspects of ecological environment protection, development, and utilization as well as vegetation restoration, which greatly concerns numerous scholars (Bi et al., 2011; Cui et al., 2009; Fan et al., 2012; Fang and Xu, 2000; Kuenzer et al., 2014; Ottinger et al., 2013; Qin et al., 2011; Ren et al., 2017; Song et al., 2009; Song et al., 2013; Wang et al., 2012; Xu et al., 2004; Yang et al., 2015; Zhang et al., 2007;). Previous studies investigated the following topics: effects of ecosystem conversion on soil properties (Huang et al., 2012; Wang et al., 2010; Yang et al., 2009); responses of tamarisk to water table depth and soil salinity (Cui et al., 2010); potential plant species distribution under the influence of groundwater level and soli salinity (Fan et al., 2011); spatial variations in winter soil respiration from three different patchy vegetation types (Han et al., 2012); variations in soil nutrients and particle size under natural vegetation and agricultural activities (Jiao et al., 2014); effects of tamarisk on variations in soil nutrients and salinity (Liu et al., 2017); and relationships between vegetation and soil properties at three scales (Liu et al., 2018). However, few studies have documented quasi-circular vegetation patches (QVPs) distributed within a 25-km area from the Bohai Sea in the YRD. Although studies have detected and monitored QVPs and associated pattern dynamics (Liu et al., 2013; Liu et al., 2014; Liu et al., 2015; Liu et al., 2016) and tested hypotheses of QVP occurrence, which is attributed to the seismic exploration of Shengli Oil Field in the YRD (Liu et al., 2012), few studies have considered differences in soil properties associated with QVPs and adjacent bare soil areas. The relationship between soil properties and associated QVPs is largely unknown for the YRD, and these data could greatly inform the management, conservation, and restoration of wetland ecosystems in the YRD.

In this study, we focused on an experimental site in a patchy, vegetated, and abandoned land that was characterized by QVPs with bare soil areas, and we sought to examine the relationships between QVPs and soil physicochemical properties. The objectives were to: (1) examine whether a fertility island exists and determine its spatial characteristics associated with QVPs, (2) examine differences in soil physicochemical properties between QVPs and the bare soil areas between these QVPs, and (3) examine differences in soil physicochemical properties associated with different plant species communities and identify the relationships between QVPs and soil physicochemical properties.

2. Materials and methods

2.1. Site description

The experimental site comprised a section of the Gudong Oil Field located within the YRD in Dongying City, Shandong Province, China. The Gudong Oil Field in a part of the Shengli Oil Field (the second largest oil field in China), and it has been exploited since 1983 (Liu et al., 2015). To reduce petroleum exploration losses resulting from storm surges, a cofferdam was built between May 1985 and February 1986. The experimental site is abandoned land in a low and flat area, and this was an appropriate site for studying the relationship between soil nutrients, soil particle size, and QVPs, because disturbances from human activities and tide water were restricted by the cofferdam. This region has a warm temperate continental monsoon climate with an average annual temperature that varies from 11.7 °C to 12.1 °C, and it has an aridity index of up to 3.56 (Wang et al., 2013). Similar to arid and semi-arid ecosystems around the world, the abandoned land and tidal flat exhibited a mosaic vegetation pattern in two phases (QVPs and bare soil areas) (Fig. 1).

The soil textures of sediments in the YRD vary from sandy loam to silty clay, and the most widely distributed soil types in the YRD are the Fluvisols and Solonchaks (Liu and Drost, 1997). For the experimental site, the main soil type is Gleyic Solonchaks based on the World Reference Base (WRB) soil classification. *Suaeda salsa*, *Tamarix chinensis*, and *Phragmites australis* are the three main types of native vegetation that occur across the YRD, and they are the main plant species associated with QVPs. Because patchy vegetation is often difficult to be detected at the ground level (Lejeune et al., 2004), QVPs were initially identified with the use of high spatial resolution remote sensing imagery in the YRD in 2011 (Liu et al., 2011). The difficulty associated with QVP detection at the ground level due to QVP distributed in remote area or submerged in grassland might be the reason why QVPs in the YRD receive little attention from researchers.