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Soil hydro-physical characteristics and water retention function of typical shrubbery stands in the Yellow River Delta of China

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ABSTRACT

The shell ridge worldwide that presents a combination of old and new shell ridges is located in the Yellow River Delta of China. The water storage and retention capacities of the shell sand soil are key factors for the growth and development of vegetation and act as important indicators in evaluations of vegetation-related soil and water conservation. We investigated the hydrological and physical characteristics of the soil and the interactions of these characteristics for the following dominant shrubbery stands on the shell ridge: *Tamarix chinensis* Lour, *Periploca sepium* Bunge and *Ziziphus jujuba* var. *Spinosa*. The different shrubbery stands presented significantly different physical shell sand parameters, such as water storage capacity, permeability and water-holding capacity. Compared with the bare soil, the shrubbery-covered shell sand soils showed significantly reduced bulk densities; increased porosities, water storage capacities, infiltration rates and water-holding capacities; and reduced particle sizes. The shrubbery increased the amount of soil water-stable aggregates and reduced the amount of soil air-dried aggregates, and the fractal dimension of the soil water-stable aggregates was significantly higher than that of the air-dried aggregates. *T. chinensis* shrub growth yielded a better soil aggregate structure compared with that of *Z. jujuba*, whereas the *P. sepium* shrub yielded the poorest structure. The soil porosity and the mean weight diameter of the soil aggregates were the major factors that affected the water retention capability of the shell sand. The best water retention capability was observed with the *T. chinensis* shrub stand followed by the *Z. jujuba* and *P. sepium* stands, whereas the bare soil exhibited the poorest results. Our results indicate that *T. chinensis* seedlings are the best choice for planting to improve soil porosity and soil aggregates on the shell ridges of the Yellow River Delta.

1. Introduction

Shell ridges are mainly formed by the shells of shelled organisms that live in the intertidal zone and shell debris that is transported by waves and accumulates near the high-tide line. Shell ridges are distinctive shell sand deposits that lie on the upper surface of tidal flats, where shellfish grow in abundance (Xie et al., 2012). Two shell ridges that are roughly parallel with the coast are located in the Yellow River Delta of China. These are the largest and only ridges with co-occurring old and new shell ridges in the world; thus, they have great scientific value and significance for research on China's marine geology, biodiversity conservation, and ecosystem types. Vegetation on the shell ridges is affected by natural factors, such as droughts and human interference, and often exhibits varying degrees of degradation, which exacerbates soil erosion. Revegetation on shell ridges provides wind-breaking and sand-fixing functions and plays a role in soil and water conservation, and all of these features are important for improving the regional ecological environment and maintaining the local ecosystem stability (Tian et al., 2011; Xia et al., 2013). However, the choice of shrub type based on the objectives of improving the soil physical and hydrological properties and yielding benefits, such as soil and water conservation, remain to be resolved. Several studies conducted on shell ridges (Meldahl, 1995; Saito et al., 2000; Xie et al., 2012) have primarily focused on the coastal geomorphology, sea level and climate changes, coastal ecosystem evaluations, and vegetative distributions (Saito et al., 2000; Xie et al., 2012).

The ability of soil to store and retain moisture has become a topic of great interest in ecological and hydrological studies (Shi et al., 2016; Antinoro et al., 2017). Most current investigations of the water storage capacity of soil under different vegetation covers have been conducted via static comparative analyses of the level of soil moisture (Vogelmann et al., 2013; Zhang et al., 2016). However, studies of the water storage functions of soil are mainly performed by investigating single factors, such as the soil pore characteristics, permeability and aggregates (Xia

Abbreviations: BD, soil bulk density; BD_{LLWR}, BD from the least limiting water range; *D*, soil particle fractal dimension; DC, degree of compactness; MWD, mean weight diameter

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et al., 2012; Vogelmann et al., 2013; Xia et al., 2013; Zhang et al., 2016), and these studies usually focus on hilly areas (Zhang et al., 2006; Liu et al., 2009; Jiang et al., 2013) and rarely consider the soil improvements and soil and water conservation of the coastal shelterbelt (Liu et al., 2015). Because of the lack of data on the physical and hydrological functions of soil under different vegetation covers, the water storage and water retention properties of soil have not been properly characterized and the factors that influence shell sand soil with different vegetation types in muddy coastal zones are poorly understood. To an extent, these limitations have hindered the optimization of configurable vegetation patterns in such regions and prevented the efficient use of the available soil moisture.

Serving as a transition zone between water and land interactions, muddy coastal shell ridges exhibit transitional characteristics in the soil environment formation, water storage, water transport and other ecological processes that are dominated by water. In addition, the special shell sand imparts unusual hydrological and physical properties to the shell ridge that result in different water storage and regulatory functions from those of common terrestrial ecosystems (Tian et al., 2011; Xia et al., 2013). Therefore, to clarify the water-holding capacity of the shell soil and the factors that influence shell ridges with different shrub types, three typical shrubs that grow in the shell ridge of the Yellow River Delta, *Tamarix chinensis* Lour, *Periploca sepium* Bunge and *Ziziphus jujuba* var. *Spinosa*, were used to investigate the bulk density, porosity, particle composition, aggregate size, particle fractal dimension, storage capacity, infiltration characteristics, soil moisture characteristic curves and other parameters of the shell sand soils under different shrubbery stands.

We hypothesized that the water storage and retention capacity of the shell sand would be closely related to the vegetation types and great differences would be observed in the hydrology-physical characteristics of the shell sand under the different shrubbery stands. One goal of this study was to understand the role of the different shrub stands in improving the physical and hydrological structure of the soil and clarify ecological characteristics of soil moisture and the factors influencing the soil moisture parameters on the shell ridges under different shrubbery stands. An additional goal was to comprehensively evaluate the soil water-holding capacity under different shrubbery stands using a principal component analysis (PCA) and the fuzzy membership function method. The results will provide a theoretical basis and technical reference for selecting the optimal shrub type for vegetation recovery of the shell ridges of the Yellow River Delta.

2. Materials and methods

2.1. Study area

The study sites were located in Wangzidao (N38°14′30″, E117°54′38″), which is in the central and eastern coastal lowlands of Wudi County, Binzhou City, Shandong Province, China. The experimental site is located in the buffer zone of the Binzhou National Shell Ridge and Wetland Nature Reserve, the geogaphic location map of the research area is shown in the Fig.1, and it has a coverage area of 80,480 hm^2. This area is in the East Asian monsoon semi-humid continental climate zone in the warm temperate region, and it has an average annual rainfall of 550 mm, an average annual potential evaporation of 2431 mm, an average annual temperature of 12.36 °C, an average annual sunshine duration of 2849 h, and an average annual frost-free period of 205 d. The soil types are mainly shell sand soil and coastal saline soil; the areas on the seaward and landward sides are dominated by coastal salinized soil; and the beach ridge area is dominated by shell sand soil with an average thickness of 1.0–2.5 m (up to 3.0–4.0 m at certain locations). The soil parent material is composed of aeolian sediment and calcareous shell soil. The main shrub species in this area are *T. chinensis*, *P. sepium*, and *Z. jujuba* var. *spinosa*, and the primary herbaceous plants include *Limonium bicolor*, *Setaria viridis*, *Artemisia annua* L., and *Zoysis macrostachya* Merr.

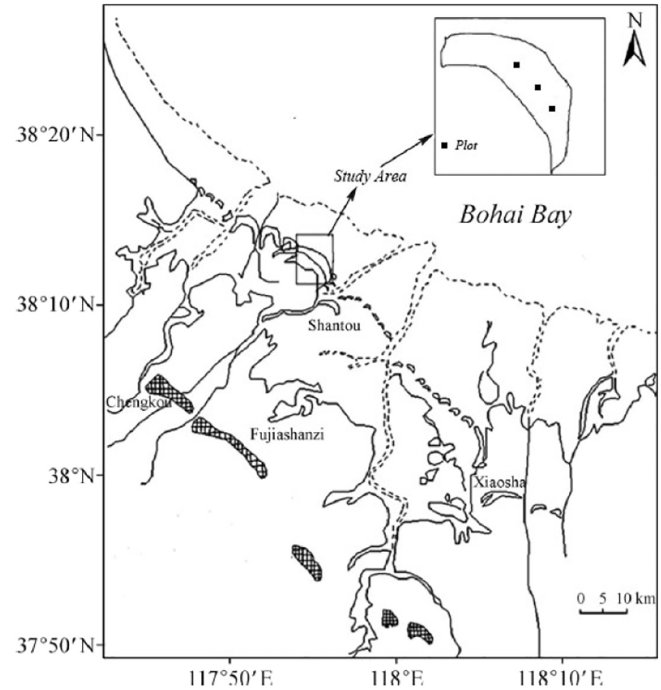

Fig. 1. The geographic location map of the experimental site on the shell ridges in the Yellow River Delta. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Sample site

In July 2015, three monospecific shrubs, *T. chinensis*, *P. sepium* and *Z. jujuba*, growing on similar habitats in shell ridges were selected (Fig. 2). The sampling sites had the following general characteristics: the average age of the dominant shrubs was 8 years; the average heights of the shrubs *T. chinensis*, *P. sepium* and *Z. jujuba* were 1.95 m, 1.58 m and 1.68 m, respectively; and the average ground diameters were 2.36 cm, 1.33 cm and 1.78 cm, respectively. *T. chinensis*, *P. sepium* and *Z. jujuba* had canopy densities of 0.82, 0.75 and 0.78, respectively, and vegetation coverage of 75%, 64% and 70%, respectively. Six experimental observation standard plots for each shrub measuring 10.0 m × 10.0 m were selected, and bare shell sand plots in the same area were used as controls. In each observation plot, five test sites were chosen according to the S-type sampling method, and undisturbed soil sampling and soil parameter measurements were mainly conducted from the 0–20 cm soil layer. Soil aggregates were collected from undisturbed soil samples and then air dried indoors, and the samples were treated with extra caution to minimize the degree of disturbance during their acquisition and transport to avoid damage to the soil aggregates. All the analyses in the present work have been done on undisturbed samples.

2.3. Analysis of soil capacity properties

2.3.1. Determinations of the basic soil physical properties and size of aggregates

Soil moisture was determined using the drying method, and indicators such as the bulk density (BD) and porosity were determined using the soil cutting ring soaking method. The soil capillary water storage, non-capillary water storage and saturated water storage were all determined at a soil depth of 0.2 m (Institute of Soil Science, 1978). The soil water storage capacity formulas used in this study are as follows: