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Reclaiming subsided land with Yellow River sediments: Evaluation of soil-sediment columns

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ABSTRACT

A greenhouse experiment was conducted to investigate performance of columns containing varying layers of topsoil and subsoil (silt loam) and Yellow River sediment (sand) as proxies for designing reclamation strategies for subsided land in eastern China. Three control treatments (CK1, CK2, CK3) and 11 experimental treatments were established. CK1 consisted of 30 cm topsoil overlying subsoil and is a proxy for native (undisturbed) soil from the study sites. CK2 consisted of 30 cm of topsoil and 40 cm subsoil overlying sediment and is a proxy for conventional reclaimed soil. CK3 consisted solely of Yellow River sediment. All other treatments consisted of varying combinations of subsoil and sediment overlain by 30 cm of topsoil. These treatments were divided into four groups based on total subsoil thickness as follows: Group 1: 10 cm (T1); Group 2: 20 cm (T2, T3, T4); Group 3: 30 cm (T5, T6, T7) and Group 4: 40 cm (T8, T9, T10, T11). The treatments were used to evaluate morphological characteristics of maize, water and nutrient content of soil and sediment in columns during the experiment. The experimental results indicated a general trend of increase in magnitude of the selected maize characteristics (e.g., dry root biomass) with a corresponding increase in thickness of subsoil within sediment in the multilayered columns. Subsoil location and thickness influenced results as shown by comparison of Group 4 treatments with CK2, which each had the same total subsoil thickness. T8, T10 and T11 had greater dry root biomass at harvest than CK2 and T9. T9 had less % water content at 75 cm than the other treatments, which corresponds to 10 cm less subsoil in T9 in the 40–80 cm zone. Dry shoot biomass at tasseling was larger in T8 and T11 than in T9 and CK2; T10 had similar biomass to CK2 and larger than T9. T8, T10 and T11 had a subsoil layer at 80–90 cm, whereas T9 had a 70–90 cm sediment layer and a significantly smaller water content at 75 cm than T8, T9 and T11. Water content, available and total nitrogen, available and total phosphorous, available and total potassium, organic matter of topsoil and subsoil of all multilayered treatments were the same or larger than CK1 and CK2. This indicates that water and nutrient retention are not adversely impacted by inclusion of Yellow River sediment in the multilayered columns. The results show that strategically designed layered combinations of native subsoil and sediment can be used to construct soils that have favorable hydrological and chemical properties for maize growth. Sandwiching subsoil layers between sediment layers is a promising strategy for enhancing the hydrological capacity of the subsurface (30–120 cm) component of constructed soils. This study provides a guide for field experiments to evaluate optimal technological, agronomic and economic reclamation approaches in the study area and beyond where availability of native soil is insufficient to reclaim subsided land.

1. Introduction

In China, the most important source of energy is coal. Meanwhile, coal mining causes serious ecological and environmental problems, especially in eastern areas where the primary method of coal extraction is underground operations (He and Song, 2012). However, mining inevitably results in a large amount of land subsidence and farmland degradation (Wang et al., 2014). For instance, extraction of 10,000 tons of coal from underground, creates about 0.2 to 0.33 ha subsided land. Moreover, some subsided areas are inundated with water up to depths of 13 m (Hu and Xiao, 2013). Problems due to high water table and flat terrain in eastern areas resulting in a big loss of farmland have forced famers to migrate elsewhere (Wang et al., 2014). Reclamation in these areas focuses on farmland restoration, with a goal of achieving or exceeding pre-disturbance productivity (Hu et al., 2015). For restoring farmland in such areas, the common practice is filling them with available unconsolidated materials (Hu et al., 2015).

To date, the most common materials used to fill subsided areas are

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coal refuse and fly ash (Hu et al., 2003; Hu, 2008), but these materials have some disadvantages, such as potential contamination and insufficient quantity of available material (Hu et al., 2015). Lake sludge has also been used as filling material, but its availability is limited and furthermore it causes poor drainage. A promising alternative is sediment from the Yellow River, which carries the largest sediment concentration of any river on Earth (Milliman and Syvitski, 1992). In this paper, we evaluate a technology which utilizes Yellow River sediment for filling subsided areas (Wang et al., 2014; Hu et al., 2015). However, Yellow River sediment is sandy in texture with limited capacity to retain water and nutrients (Wang et al., 2014; Hu et al., 2015). In order to enhance water and nutrient holding capacity and decrease the cost of reclamation engineering significantly, the optimal thickness of covering soil above the sandy sediment layer needs to be investigated. However, the availability of covering soil is insufficient in some areas. In these cases, we investigate the soil profiles of farmland in the Yellow River flood-plain (Ye, 1985), and propose reconstructing the soil-landscape with alternating soil and sediment layers in subsided areas. It can be expected that different arrangements of soil-sediment layering will have contrasting capacity to retain water and nutrients, which will be reflected by differences of plant growth and yield.

In greenhouse experiments, McSweeney et al. (1981) evaluated the optimal mixtures (soil and sediment) for reclamation of surface mined land, and compared the growth of soybean among six different combinations of substratum and B horizon materials columns (i.d. 15 cm, h 90 cm); The chemical, physical, and mineralogical properties of these mixtures for plant growth were described by Snarski et al. (1981). The best soybean agronomic performance was found in treatments composed of a 3 m vertical mix of soil and glacial sediment with a cover of native topsoil. Treatments composed of native topsoil and subsoil showed the poorest performance. In similar greenhouse studies, Dancer and Jansen (1981) showed that blending subsoil with calcareous C-horizon-material can help to improve strongly acid subsoil and provide a more desirable texture, and thus resulted in a significant increase in crop production. Subsequently, field experiments were conducted to evaluate the suitability of various soil construction designs which were the same with those used in the greenhouse experiments (McSweeney et al., 1987). Results from the field experiments were similar to those from the greenhouse study.

In this research, our approaches are based on the concepts of radical soil management and soil rejuvenation (McBratney et al., 2016), which outlines various strategies for soil construction and improvement of soil physical and chemical properties. In our case, reclamation of subsided land requires radical intervention because of subsidence as opposed to nutrient depletion and physical constraints. The challenge is to determine the optimum hydro-pedological placement of soil and sediment as measured by plant performance. The objective of this study was to evaluate the effect of various soil-sediment layered sequences on maize growth, and hydrological and chemical characteristics in profile sequences after crop harvest.

2. Material and methods

2.1. Experimental materials

The research was conducted in a greenhouse at the Institute of Land Reclamation and Ecological Restoration, China University of Mining and Technology (Beijing). The topsoil and subsoil used in the experiment was sampled from farmland in Liangshan, Jining City and Shandong Province (Fig. 1). Soils in this area are classified as

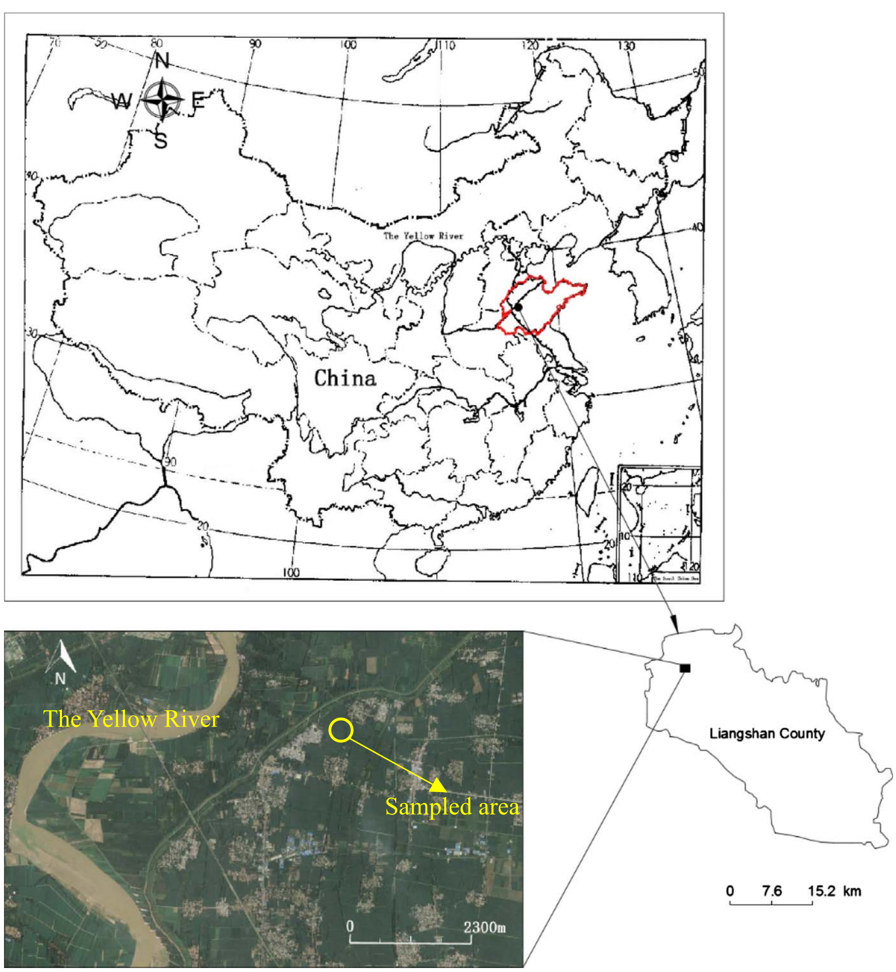

Fig. 1. Sampled area of topsoil and subsoil.