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Particle size distribution of soils (0–500 cm) in the Loess Plateau, China

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ABSTRACT

To investigate the spatial variability of soil particle size distribution (PSD) in the Loess Plateau (LP) region of China, 2673 disturbed soil samples were collected in the 243 soil profiles (0–500 cm) across the typical loess zone. The PSD of soil samples were determined using the laser diffraction technique and the regional spatial distribution patterns of PSD were analyzed through classical statistical and geo-statistical methods. The results showed that silt loam was the dominant soil texture (92.6%) at the 0–500 cm soil layer. Sand, silt and clay contents varied slightly with increasing soil depth, suggesting that soil texture was almost homogeneous across the soil profile. Soils were overall sandy in the north and clayey in the south, but soil texture variation uneven with increasing latitude. PSD pattern across the typical LP region depicted latitudinal zonality. Fractal analysis showed a strong relationship between fractal dimension (D) and clay content ($R^2 = 0.98$), demonstrating that D was controlled by the clay content rather than the coarse particles at the regional scale. The limited changes of PSD in the soil profile and the moderate variation of soil texture across the LP will provide a reference to regional scale hydrological, erosion and ecological models in the Loess Plateau of China.

1. Introduction

Soil particle size distribution (PSD) is an important soil physical parameter that affects soil conservation, water and nutrient movement, vegetation productivity and thus ecological restoration (Pan et al., 2010). PSD is widely used in soil classification and in estimating soil hydraulic properties such as soil water retention curve, soil hydraulic conductivity and soil bulk density (Filgueira et al., 2006; Hwang et al., 2011; Hollis et al., 2012; Antinoro et al., 2014). Besides, different PSD-driven sorption properties of soil could affect the mineralization of decoupled carbon and nitrogen and the activity of invertase and xylanase during organic matter decomposition (Stemmer et al., 1999; Bimueller et al., 2014; Zhou et al., 2015). PSD is therefore important for understanding the physical and chemical processes of soil development (e.g., soil water and nutrient cycles) in terrestrial ecosystems.

Fractal geometry is a tool widely used to build insight into complex natural phenomena such as soil/rock mechanics and physics (Millan et al., 2003). Also, fractal dimension (D) is extensively used in explaining the scaling domains of PSD (Tyler and Wheatcraft, 1989, 1992; Filgueira et al., 2006; Zhao et al., 2009). Soil fractal analysis can be used to define PSD which reflects the degree of uniformity of soil texture. For example, Su et al. (2004) noted that D can be used to describe PSD characteristics and its relationship with land desertification. Wang et al. (2008) showed that multi-fractal dimensions reflect soil physical properties as well as soil quality, and also significantly correlated with land use. Zhao et al. (2009) concluded that fractal analysis can be used to evaluate the effect of check-dam on soil texture deposited on farmland soils. The study demonstrated the feasibility of using fractal dimension of PSD in the analysis of soil detachment, soil erosion or even soil desertification.

The Loess Plateau (LP) region of China (with an area of 62×10^4 km^2) has unique landscape over deep loess deposits with intensive soil erosion since ancient times (Chen et al., 2007; Zhao and Xu, 2013). The intensive soil erosion is increasingly limiting the land productivity, inducing environmental degradation and the rise of riverbeds in the lower reaches of the Yellow River (Shi and Shao, 2000). This has increased the need for reliable PSD analysis as a measure to present erosion and/or land degradation in the region.

To control soil erosion and improve land quality, China initiated a state-funded program called “Grain-for-Green” in the LP region in 1999 (Chen et al., 2007). Increasing vegetation cover by planting trees and/or establishing grassland is an effective measure of reducing soil erosion in the region. However, vegetation restoration vis-à-vis soil erosion control drives are limited by water movement and soil water content in both the shallow and deep soil layers (Mengistu, 2009). The need for information on fresh PSD is further evident at regional-scale hydrological modeling of the adaptability and sustainability of vegetation

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restoration drive such as the “Grain-for-Green” project funded by the state. Moreover, the evaluation of soil water availability, water holding capacity, deep soil desiccation and soil bulk density or its pedo-transfer operations requires PSD in diverse soil layers (Sun and Yang, 2013; Wang et al., 2014). Although critical for successful and sustainable restoration of vegetation, fresh regional-scale data on PSD and its fractal features are scarce for the LP region.

Therefore, the objectives of this study were to: 1) collect profile PSD data for the 0–500 cm soil layer in the LP region in China; 2) investigate regional spatial variability of PSD across a typical LP region; and 3) characterize fractal features of PSD for various soil layers in the LP study area.

2. Materials and methods

2.1. Study area

The LP region (34°00′–45°05′N, 101°00′–114°33′E) is the largest loess zone (total area of 62 × 10^4 km^2) in the world and it is located in North Central China (Fig. 1). The LP study area stretches across an altitude range of 200–3000 m, usually over a sediment layer of thickness of 30–80 m (sometimes 150–180 m). While annual mean precipitation (MAP) range from northwest to southeast is 150–800 mm, mean annual temperature (MAT) range from northwest to southeast is 3.6–14.3 °C (Fig. 1). The order of vegetation zones along the southeast-northwest transect of the LP study area is forest, forest-steppe, typical-steppe, desert-steppe and steppe-desert. The order of distribution of dominant soil types from the south to the north of the Loess Plateau is Haplic Luvisols, Terric Anthrosols, Calcic Chernozems, Aridic Leptosols, Calcaric Regosols, Calcic Kastanozems and Aridic Arenosols (FAO/ISRIC/ISSS, 1998). Further details about the study area are document by Shi and Shao (2000) and He et al. (2003).

This study was conducted in a typical LP region that is about 2/3 (43 × 10^4 km^2) of the Loess Plateau (Fig. 1). Specifically, the typical LP region is the spatial location covering Shanxi, Shaanxi, Gansu, Ningxia, Henan and Inner Mongolia. The distribution of loess is most continuous (in horizontal and vertical space), thickest and has vast loess geomorphic landforms in this region. Land degradation and soil fertility loss are common in most of the LP study area due to severe soil erosion and water scarcity. The main geomorphic landforms are Yuans (large flat surfaces with little or no erosion), ridges, hills and gullies.

2.2. Soil sampling

To accurately determine PSD that is representative of the typical LP region, we devised an intensive soil sampling scheme close to the grid-cell level of the entire study area. For more convenient access to the sampling sites, we chose sampling routes by considering the road transportation systems in the LP study area. The distances between adjacent sites were approximately 40 km. But for better representation of areas with complex landscape and geomorphology, we reduced the sampling distance by half to include at least one additional randomly selected site along the 40 km sampling distance. Each randomly selected sampling point represented the main land use, soil type and topography within the range of sight. To reduce the effect of the roads on the collected data, sampling points were located at least 150 m away from the road. Thus a total 243 sampling sites were selected and correctly located using a GPS receiver (5 m precision). The locations of the 243 sampling sites across the LP study area are plotted in Fig. 1.

For each site, disturbed soil samples were collected using a soil auger (5 cm in diameter) and 11 soil samples collected in different soil layers along the soil transect to the depth of 500 cm. The profile soil samples were collected at the 0–10, 10–20, 20–40, 40–60, 60–80, 80–100, 100–150, 150–200, 200–300, 300–400 and 400–500 cm soil layers. From June to October 2012, we visited 243 sampling sites in the typical LP region and a total of 2673 disturbed soil samples were collected for laboratory analyses.

2.3. Laboratory analyses

The disturbed soil samples were air-dried and passed through a 2-mm mesh for PSD analysis. Hydrogen peroxide was used to remove organic matter and sodium hexametaphosphate used to disperse the samples. After the processing, PSD (volume fraction) of each sample was measured by laser diffraction using the Mastersizer 2000 (Malvern Instruments, Malvern, England) as described by Jia et al. (2013) and Wu and Lu (2012). PSD was classified based on clay (<0.002 mm), silt (0.002–0.05 mm) and sand (0.05–2 mm) contents as in the soil taxonomy developed by U.S. Department of Agriculture (USDA).

2.4. Soil fractal theory

According to Katz and Thompson (1985) and Tyler and Wheatcraft (1989, 1992), when a soil particle size is bigger than R_i (i.e.,

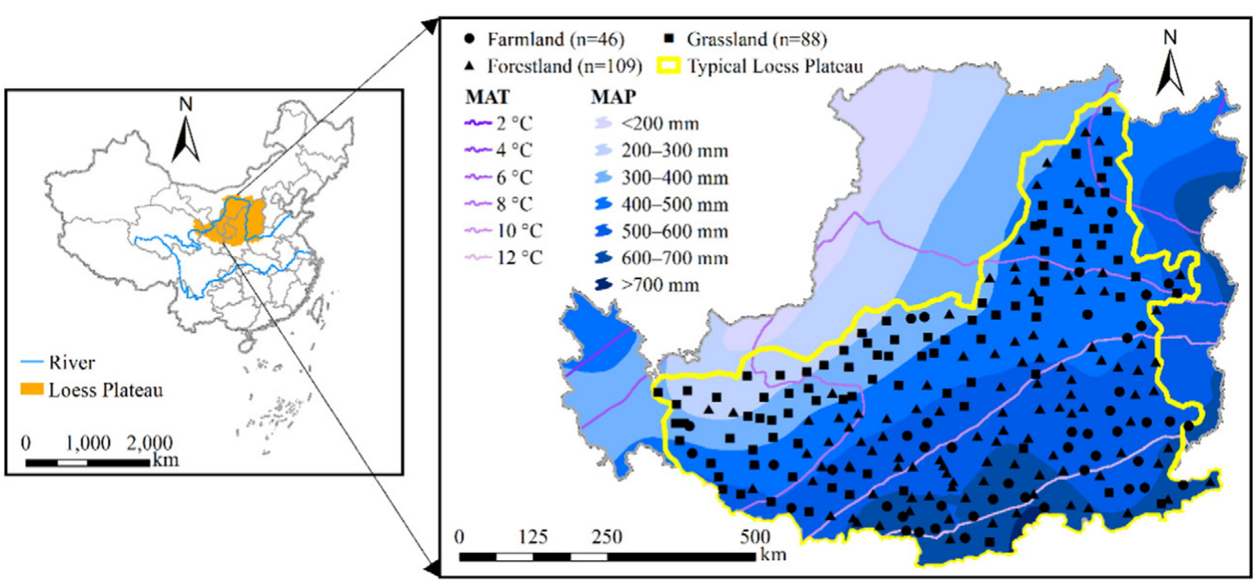

Fig. 1. Map of the 243 sampling locations across the typical Loess Plateau region in central China and the distributions of mean annual temperature (MAT) and mean annual precipitation (MAP) in the region.